C.W.J.M. Klaassen

A Problem-Posing Approach to Teaching the Topic of Radioactivity

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A Problem-Posing Approach to Teaching the Topic of Radioactivity

Een probleemstellende aanpak van onderwijs in radioactiviteit

(met een samenvatting in het Nederlands)

Proefschrift

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR AAN DE UNIVERSITEIT UTRECHT OP GEZAG VAN DE RECTOR MAGNIFICUS, PROF.DR. J.A. VAN GINKEL, INGEVOLGE HET BESLUIT VAN HET COLLEGE VAN DEKANEN IN HET OPENBAAR TE VERDEDIGEN OP WOENSDAG 6 DECEMBER 1995 DES NAMIDDAGS TE 4.15 UUR

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A Problem-Posing Approach to Teaching the Topic of Radioactivity

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1 Introduction

Please allow me to introduce myself...
Jagger and Richards (1968)
Sympathy for the devil
London: ABKCO Music

1.1 How I got involved in educational research

1.1.1 My own education

As far as I can remember, I have never seriously thought about education during my 22-year educational career from kindergarten till graduation in theoretical physics. Thinking back about my secondary school years, the best I can say is that I tried to have as much fun as possible and at the same time to meet the required standards as well as possible. The thoughts I had about education were the usual doubts about why we had to learn a quite extensive German-Dutch translation manual by heart, why some teachers always gave that much homework or why I should pay attention to teachers that were very boring. Furthermore, I found out that I was good at mathematics. I wondered what the purpose of Latin was. I disliked chemistry, though I was good at it. I liked physics and was good at it, but did not really wonder what it was good for. Nice teacher, easy test, good mark, interesting subject, total class disorder; in such terms (and their opposites) my classmates and I talked about the education we enjoyed (and its opposite).

Simply for the reason that I was good at it and liked it, I chose to study physics. I did not want to become a physics teacher. In fact, until the last year of my study of physics I had never thought about a future career whatsoever. If anything, I just wanted to become an Einstein. Though I have failed at the last point, I did find satisfaction in my study. I simply liked most of the subject matter. Again I didn't have any deep thoughts about the education I was exposed to at university. Of course I wondered what was the point of attending lectures when all the lecturers did was read the syllabus, but mostly I faithfully attended just to keep track. I guess I was too busy trying to understand, doing exercises and preparing for examinations to seriously think about education itself.

1.1.2 Teacher training

Now, how could someone whose thoughts about education had never ran any deeper than sketched above get involved in educational research? And some people might even ask: how could someone who graduated in theoretical physics sink that low? The roots of the answers to these questions are to be found in the teacher training I followed during the last year of my study. (Not that I had finally made up my mind and decided to become a teacher. My reasons, if that is the right word, for doing teacher training were rather something like: one never knows, just in case, it will do no harm. Moreover, it was the last chance to get a teacher certificate relatively easy. From the next year on, teacher training would be extended from four months to twelve months.) During teacher training I was forced, for the first time in my life, to think about education itself, or at least about physics education. What is its purpose? What of physics should be taught in secondary school, why and how? These questions were of too general a level, however. I didn't really relate to them. As a student teacher I faced different problems. Apart from the usual order problems, my major initial problem was caused by the fact that I had to teach at a school where the PLON-curriculum was being used. Without going into the details of the PLON-curriculum (for more on PLON, see, e.g., Eijkelhof & Kortland, 1988), I just mention that one of its aims is to relate physics to everyday life contexts. So I had to teach about bridges: what kinds of shape they have, why they are built as they are, why one construction is better than another, etc - and I didn't know anything about that. So instead of teaching about bridges, I felt that I really ought to be learning about them. I hardly understood what I was supposed to teach and was afraid that I would not be able to answer any smart questions. In short, I felt I was a slave rather than a master of the subject matter. The pressure was somewhat released when it turned out that my fellow student teachers had the very same problems and that I could easily bluff my way out of the few smart questions the pupils actually asked. Still it was a kind of shock to me to find out that, no matter how much knowledge of physics I had (or thought I had), I was hardly able to apply that knowledge to relatively simple real life situations. In fact, I realised that never before I had had to apply, or even had felt the need to apply, my knowledge of physics to the ordinary things of everyday life. When I was taught mechanics, of course I had to do numerous exercises about situations involving cars, trains, etc. These situations, however, were not real life situations, but more or less artificial situations that were purposefully designed in such a way that Newton's laws could be straightforwardly applied to them; mention of cars, trains, etc, was rather an ornament than an essential ingredient.

This was the first blow that made me wonder what my knowledge of physics was worth; whether it is of any worth to teach pupils, the vast majority of which will not be physicists, scientific knowledge that is far remote from everyday life; and whether scientific knowledge really contributes to a better understanding of the things pupils encounter in their daily life. These considerations became even more significant when during teacher training I learned, by reading articles and interviewing pupils, that pupils do have their own ideas about the way things are and go; that these ideas are suited to the purposes of everyday life; and that a lot of these ideas, which often seem to be at variance with scientific knowledge, survive education. Quite often, I also found myself attracted to the things that pupils say. My response to the question what makes a car go forward, for example, was the same as what many pupils answer: it is the motor of the car that supplies a forward force.

All these experiences made me interested in physics education. What does an understanding of physics consist in? Is it the ability to manipulate formulas, the ability to relate physical knowledge to the real world, or something else? And how could pupils reach an understanding of physics, whatever it is? As a student teacher, however, I was not able to connect this aroused interest with my teaching. I simply tried to explain the subject matter as clearly as possible and tried to create as pleasant a working climate as possible. And that was hard enough. But when, after graduation, I had the opportunity of becoming an assistant in a research project on physics education, I grabbed it with both hands.

1.2 First steps in educational research

1.2.1 Radiation and risk in physics education

For one and a half years I was an assistant in Harrie Eijkelhof's research project on radiation and risk in physics education (Eijkelhof, 1990). The point of departure for this research project were the results of a pilot study on the PLON-unit Ionizing Radiation (PLON, 1984, 1988). The specific aim of this unit, which is aimed at pupils in the top classes of secondary physics education, is to increase "pupils' ability to assess the risks of ionizing radiation in various fields of application which they might come across, now and in the future" (Eijkelhof, 1990, p.10). The relevant experiences with the unit were that "preconceptions did exist among pupils, both before and after teaching this topic [and that] pupils did not make much progress in reasoning about the risks of radiation" (*ibid*, p.9).

I was involved in studies on pupils' ideas and on teaching and learning problems. I analyzed pupils' answers to a questionnaire about Chernobyl; I participated in exploring pupils' ideas in several context domains of ionizing radiation by means of interviews; and I observed and analyzed a series of lessons in which the PLON-unit Ionizing Radiation was used. Below I describe in general terms some of the things I learned from participating in these studies.

1.2.2 Pupils' ideas

I think that any virgin investigator of pupils' ideas is initially impressed and excited by the fact that pupils say things that a scientist would not say or that even seem to be in flagrant contradiction with what a scientist would say, and from this fact tends to conclude that pupils have ideas of their own that are at variance with scientific ideas. These points can be illustrated by the enormous amount of research into misconceptions, i.e., both by the term *mis*conception and by the enormous amount. As a virgin investigator I would classify as pupils' ideas: "after the Chernobyl accident, the radiation was blown towards the Netherlands and then it came down with the rain;" "after the Chernobyl accident we were not allowed to eat spinach, because the radiation had gone inside;" "it is not safe to eat irradiated food, because a bit of radiation will remain in the food." And after I had seen lots of similar utterances, I would characterize pupils' ideas as showing a lack of distinction between radioactive material and radiation or between irradiation and contamination. After a while, however, I was becoming increasingly dissatisfied with these classifications and characterizations, because they only stated what pupils were *not* saying, namely the scientifically correct thing: pupils did not say that it was in fact radioactive material that was transported; they did not say that radiation doesn't remain in irradiated food; they did not make a distinction between contamination and irradiation, etc. The reason for my dissatisfaction with these negative descriptions was that I failed to see of what use they might possibly be for education. For if we are to give serious application to the idea that any education should start from where pupils are, a description of where they are not is of little help. Somehow a *positive* interpretation of what the pupils are saying should be delivered. This is one line of thought that will be further developed in this thesis.

From the participation in the research on pupils' ideas I also learned that it is all too easy to lose oneself in details. In the questionnaire about Chernobyl, for example, we asked pupils why in some countries iodine tablets had been distributed. Some pupils answered that iodine works against radiation or radioactivity by neutralizing or dissolving it or by converting it into something non-radioactive. Others answered that iodine protects the body just like a lead wall. Still others claimed that iodine increases the body's resistance, for instance by developing anti-bodies. Now one could make something big of all this talk about neutralizing, dissolving, converting, lead walls or developing anti-bodies and classify all the answers as ideas pupils do have, but what would be the point of that? For one thing, no matter how long we make the list, it will never be exhaustive. And secondly, even if the list were exhaustive, it still would not enable us and teachers to positively interpret pupils. A more fruitful proposal, I came to believe, is to try to grasp some general notion on which most pupils seem to agree and to allow them to differ on the details. In the example just discussed this general notion might be the notion of *resistance*: iodine, in one way or another, increases the resistance against radiation or radioactivity. I agreed with what Anderson (1986) had written about research on pupils' ideas: "There is a need to find common elements in the seemingly quite disparate research results, in order that the various findings form a cohesive group, and also to achieve a deeper understanding of the pupils' reasoning." This is a second line of thought that will be further developed in this thesis. It will also be related to the idea of positive interpretation.

1.2.3 Teaching and learning

Like it was in the description of research on misconceptions above, lack of positive interpretation might also be the key phrase to describe the PLON-unit Ionizing Radiation and the way it had been taught in the one class I observed. The way the unit is structured reflects a concern for a clear exhibition of the scientific facts: it starts from first principles (atomic and nuclear models); subsequently it provides descriptions of relevant entities (unstable nuclei, kinds of radiation) and explanations of relevant phenomena (decay, ionization) in terms of these principles; and finally it relates these entities and phenomena to applications (nuclear energy, health care). Furthermore, this exhibition is served piecemeal and each piece is followed by a number of exercises in which the pupils are given the opportunity to digest what they have just taken in.

There seems to be little concern, however, for the way pupils will interpret the texts and exercises, given what they already know and believe. I will now describe one of the many examples of what that may lead to. As noted before, many pupils say that when a person is irradiated some of the radiation remains in the body and that it will cause damage as long as it is inside the body. Most pupils also say that radiation can be stopped, for instance by lead walls. If I attributed these kinds of ideas to one of the pupils (Eric) in the observed class, I could understand why he interpreted the unit's presentation of the properties of the various kinds of radiation as he did. Eric understood why alpha-radiation outside the body won't do any harm. He used the same argument as the unit: alpha-radiation cannot penetrate human skin, so it will never get inside the body. Eric was also able to understand why alpha-radiation, once inside the body, is the most dangerous. Again he used the same argument: once it is inside the body, alpha-radiation cannot get out because it cannot penetrate the skin. The alpha-radiation remains inside the body and will cause severe damage by means of ionization. If, however, beta- or gamma-radiation were inside the body, they would get out again because they can penetrate the skin. This interpretation explains why Eric had misinterpreted the unit's presentation of the properties of the various kinds of radiation, but to make it work I had to attribute some beliefs to Eric: that radiation can be stopped, that it remains in the body, that it causes damage as long as it is inside. And in the process of explaining, I implicitly also delivered an account of how the unit's presentation had modified his beliefs: there are several kinds of radiation; the different kinds of radiation have a different penetrating power; alpha-radiation is already stopped by human skin; not all kinds of radiation remain in the body, only alpha-radiation does; damage is done by means of ionization. According to this interpretation Eric had surely learned something, as is manifested by the modification of his beliefs. It is clear, I hope, that this learning result was not intended by the unit.

I have tried to give an example of how an intervention that doesn't take into account how pupils will interpret it on the basis of what they already know and believe, may lead to pupils' misinterpreting the intervention and to unintended learning results. As I said before, this example does not stand alone. In the lessons I observed I found many similar cases, and from the literature I learned of numerous examples of the survival of pupils' ideas or, as in Eric's case, a slightly modified survival. By attributing a set of beliefs to a pupil in the above example, I also tried to give an explanation of the unintended interpretation of the intervention and of the unintended learning results. I am convinced that a similar kind of explanation will work for most examples of unintended interpretations and learning results.

But of course explanations of negative or unintended results are not interesting in themselves. They are only useful in as far as they can help us in finding a way to construct interventions that will lead to intended results. I think they do suggest such a way. Suppose we know (or have a reasonable picture of) what pupils' beliefs are. Then we can make reasonable assumptions about how they will interpret an intervention and also make reasonable predictions about how their beliefs will be modified in the course of that intervention. The next intervention should then be based on our knowledge (or expectations about) what the modified beliefs are, etc. Although this sketch of a proposal that tries to take into account where pupils are is vague, it does have the consequence that the burden of the construction of interventions is shifted towards the beginning, to the very first intervention(s), to how to begin. It seemed highly unlikely to me that starting with a presentation of first principles (atomic and nuclear models), like in the PLON-unit (and nearly all other textbooks), is the appropriate way to begin the topic of radioactivity. So I began to think about an approach that is not based on micro-level descriptions and explanations. This line of thought, connected with the proposal sketched above, will be further pursued in this thesis.

The way the teacher taught the PLON-unit Ionizing Radiation in the one class I observed only amplified the lack of positive interpretation that is already present in the unit itself. I think the situation can be best described by noting that there was no real interaction or communication between teacher and pupils. The teacher mainly confined himself to explaining the theory and presenting the right answers to the exercises. Of course the pupils did ask questions, but then the teacher normally would not try to find out why a question had been asked but would rather give the right answer straightaway. Furthermore, there was an emphasis on tricks to solve exercises: how to solve for n and X in $^{226}Ra \rightarrow {}^{n}X + {}^{4}He$; how to do calculations with half-life, etc. I do not mean to say, of course, that the teacher was unsympathetic or didn't care for the pupils' well-being. I do realize that teachers in senior high schools have to work under the heavy pressure of examination programmes with prescribed attainment targets and I know that in the exams there is an emphasis on problem-solving. So it is in the interest of pupils, in order that they pass their exams, that they are trained in producing the required answers and in using the appropriate tricks. I can understand why the teacher taught as he did.

On the basis of my experiences as a pupil, student and research assistant, I gradually came to take the position that this kind of education contributes to verbalism and formalism and not really to insight. But what is more important, I started to believe that education would be much more exciting, challenging and interesting, both for pupils and teachers, if they really did interact and communicate and if the exams didn't dangle so frightfully above their heads as a sword of Damocles all the time.

1.3 My PhD-study

1.3.1 Aim

As may be clear from what I have written above, I was full of ideas at the end of my appointment as a research assistant, and my interest in educational research had only increased. So I applied to become a PhD-student, the application was honoured and I could start as a PhD-student in July 1988. As then formulated, the aim of the study was:

> to develop a constructivist theory for contextual physics education for middle ability pupils about radioactivity and atomic models.

The main reason why the topic 'radioactivity and atomic models' had been chosen was rather pragmatic. As a research assistant I had been working on the same topic and I had already developed some ideas about it. So I could make some sort of a flying start and that might considerably enhance my chances of reaching the finish. A secondary reason for the topic, and a reason for the target group of middle ability pupils, was that around that time a new examination programme for the middle ability stream, which included 'radioactivity and atomic models' as a new topic, was to be implemented.

Another feature of the new examination programme was the shift towards contextual physics it aims at. Physics should more than before be related to everyday life contexts and to applications. This is one of the reasons for the appearance of the word 'contextual' in the above formulation. Another reason is that the group I was working in had a long-standing tradition of promoting, developing and implementing contextual physics education: the PLON-curriculum is the group's brainchild.

Constructivism, finally, was certainly *en vogue* at the time (and still is), as might be illustrated by the extensive body of literature on it. It would have been a sign of ignorance if 'constructivism' was not somehow mentioned in the aim of the study. On the issue of what kind of education constructivism stands for, however, there seemed to be nearly as many views as there were researchers. One common element that is apparent in the literature is that it refers to an attitude to seriously take into account what pupils know -an attitude to be exhibited by teachers in their practice, by curriculum devisers in writing materials, and by researches in their evaluation of educational practice. I think there is more widespread agreement on what constructivism is not: it does not stand for education that treats pupils as black boxes (as in behaviouristic approaches) or as empty boxes (as in extreme forms of didactic teaching).

At the time, I could find myself in the above formulation of the aim of my PhD-study. It would enable me to elaborate and interrelate the kind of ideas I developed when I was a research assistant: positive interpretation, establishing real interaction and communication, not starting from first principles, etc. The latter point seemed to be very urgent, because it is well-known that many pupils have severe difficulties with particle ideas and with relating those to macroscopic phenomena (e.g., Lijnse *et al*, 1990). Furthermore, if we really wanted to make a case of seriously taking into account where pupils are, we would certainly have to pay attention to the everyday life contexts and applications that pupils are familiar with. My only concern was that the examination programme was going to be too heavy a burden. Somehow I had to find a way to meet its requirements, while leaving enough room for experimentation.

1.3.2 Design

My PhD-study can roughly be divided in four periods: an orientation; a first round of writing, trying and evaluating materials; a second round of writing, trying and evaluating materials; writing this thesis. In the first period, which took about a year, I oriented myself towards middle ability pupils and their ideas about radioactivity and particles. I also familiarized myself with current teaching practice at the bottom classes of secondary schools for the middle ability streams. I observed a series of lessons in which a unit on the topic of radioactivity was used that is specifically aimed at middle ability pupils. I devised some 'constructivist interventions' that were tried out by a teacher. This first period can best be described as a floundering and pottering period.

The second and third period, each of which took about a year, had the familiar pattern of developmental research (see, e.g., Gravemeijer, 1994): writing materials, writing down expectations, observing lessons with the materials, evaluating the materials in the light of the expectations, rewriting the materials in the light of the evaluation, etc. In the second period, the one teacher who was going to participate in this action research and I also spent a considerable amount of time on getting acquainted with each other and with each other's work.

1.4 Outline of this thesis

Chapters 2 and 3 are a direct continuation of lines mentioned above. Chapter 2 is about positively interpreting what pupils say, in particular about situations having to do with radioactivity. In chapter 3 I bring forward, and argue against, the common tendency to base a treatment of the topic of radioactivity upon micro-level explanations.

Chapter 4 and appendix 1 are of a general, philosophical and methodological nature. In here I present a theory of interpretation that is based on the work of the philosopher Davidson, and that has served as a general background and source of inspiration for my thinking about matters relating to science education.

In chapter 5 I continue the 'teaching and learning'-line mentioned above, by exploring the possibilities for improving science educational practice at a content-specific level. I will argue that these possibilities are to be sought in appropriately taking into account the content-directed evaluative attitudes (desires, aims, interests, etc). That is, as far as the cognitive attitudes are concerned it will be argued that pupils' science learning should be thought of as a process in which they, by drawing on their existing conceptual resources, experiential base and belief system, come to add to those. What I think needs to be added to this is that, if the process is to make sense to them, pupils must also be made to *want* to add to those, in a way that leads to a proper understanding of science. An approach to science education that explicitly aims at this I call problem-posing.

I also suggest that this programmatic view of the possibilities for improving science educational practice at a content-specific level is to be further explored and empirically realized by science educational research. The results of this research will consist of empirically based didactical structures, roughly: examples of good science education.

In the remaining chapters I take a few steps in this direction. In chapter 6 I present some ideas that are based on the work of van Hiele and ten Voorde, and of which it will be argued that they are of heuristic value in outlining a didactical structure at a global level. In chapter 7 I discuss some aspects of the process of constructing and reconstructing a didactical structure. In chapters 8 and 9 (which are companion chapters) I present and evaluate a concrete didactical structure, namely of the topic of radioactivity. In chapter 11 I make some suggestions for the construction of other didactical structures.

Chapter 10 concerns the teacher, both the teacher with whom I have cooperated quite intensively and, more generally, the role of the teacher in a problem-posing approach.

Another way to outline this thesis is by means of the following four main themes. Firstly, there is a general, philosophical and methodological theme, which is to be found in chapter 4 and appendix 1. Secondly, there is a didactical theme concerning science education in general, which is addressed in section 2.2, and chapters 5, 6, 7 and 11. Thirdly, there is a more specific didactical theme that concerns the learning and teaching of the topic of radioactivity, which is treated in sections 2.3 to 2.5, and chapters 3, 8 and 9. The final theme concerns the role of the teacher, which is the subject of chapter 10.

2 Orientation towards pupils' beliefs about radioactivity

The identification of misconceptions or 'alternative' ideas usually points at a misinterpretation.

2.1 Introduction

In chapter 1, I have committed myself to an attitude to seriously take into account where pupils are in the construction of classroom interventions. I have also noted that in the construction of especially the early interventions in a unit on some topic, we should somehow take into account what pupils' beliefs about that particular topic are before it is formally taught. Since I was going to devise a unit on radioactivity for middle ability pupils, I did some research on those pupils' beliefs about radioactivity before formal education on the topic. This chapter reports on that research.[1)]

In section 2.3, I review previous research on pupils' ideas about radioactivity and especially the findings of Harrie Eijkelhof (1990). As far as his research on pupils' ideas is concerned, Eijkelhof has confined himself to senior high school pupils. I have done the same kind of interviews with middle ability pupils as Eijkelhof and his assistants (of whom I was one) have done with senior high school pupils. In section 2.4 the design of the interviews is described, and what the middle ability pupils said is reported and compared to what Eijkelhof had found.

For me, reporting what pupils have truly uttered is not the same as reporting what they believe. Going from the former to the latter is an important step in what I call interpretation -a step, moreover, in which we unavoidably face the problem that is described, along with some principles to solve it, in section 2.2. In section 2.5 I try to apply the lesson of section 2.2 to what is reported in section 2.4 in order to give an interpretation of what the middle ability pupils said.

2.2 The problem of interpretation

2.2.1 The interdependence of belief and meaning

As is usual in interview studies that try to probe pupils' understandings, "the interviewer has the task of trying to extract information from the student, follow up certain comments he makes, reduce the embarrassment of extended periods of silence, and

1. Some preliminary ideas about the subject of this chapter can be found in Klaassen *et al* (1990) and Millar *et al* (1990).

clarify a student's thinking. However, all this must be done without putting words into the student's mouth, providing cues and information which will bias a student's subsequent answer" (Osborne & Gilbert, 1980). So the interviewer usually emphasizes that the interviewees can say whatever they think is true, that they are not going to be judged, that the interview is not an oral examination, etc. In short, the interviewer tries to create such an atmosphere *that* the interviewees can be taken to hold true what they say. This does not yet settle the matter of *what* they have asserted, however: we still have to interpret that. We have only tried to secure that we can interpret them on the basis that they do hold true what they have uttered. And if we want to interpret them positively, this raises a problem.

> A central source of trouble is the way beliefs and meanings conspire to account for utterances. A speaker who holds a sentence to be true on an occasion does so in part because of what he means, or would mean, by an utterance of that sentence, and in part because of what he believes. (Davidson, 1984a, p.142)

> [T]he sentences that correspond to beliefs are (1) sentences held true by someone, and (2) sentences that have an interpretation. Someone else can know what I believe if he knows what sentences I hold true, and what those sentences mean. (Davidson, 1986a)

> [I]f we merely know that someone holds a certain sentence to be true, we know neither what he means by the sentence nor what belief his holding it true represents. His holding the sentence true is thus the vector of two forces: the problem of interpretation is to abstract from the evidence [what sentences he holds true] a workable theory of meaning and an acceptable theory of belief. (Davidson, 1984a, p.196)

This problem of interpretation arises if we do not take identity of meaning for granted, if we do not assume that a speaker uses his words as we do, if we do not want our interpretation to simply consist in the statement that a student says something a scientist would not say. In short, this problem of interpretation necessarily and unavoidably emerges in the context of positive interpretation. So the problem is not only relevant to philosophers, like Davidson, but also to science educators. For what are pupils trying to say when in their talk they use words like 'force,' 'energy' and the like? It is clear from the literature (e.g., Driver, Guesne & Tiberghien, 1985) that they use these words in another sense than scientists. But what are they trying to say when they use these words in their talk about fired cannonballs, dropped basketballs or tossed coins. And how are we to determine that from their utterances?

2.2.2 Solving the problem of interpretation

In some cases, the problem of interpretation is solved relatively easy.

> Let someone say … 'There's a hippopotamus in the refrigerator'; am I necessarily right in reporting him as having said that there is a hippopotamus in the refrigerator? Perhaps; but under questioning he goes on, 'It's roundish, has a wrinkled skin, does not mind being touched. It has a pleasant taste, at least the juice, and it costs a dime. I squeeze two or three for breakfast.' After some finite amount of such talk we slip over the line where it is plausible or even possible to say correctly that he has said there was a hippopotamus in the refrigerator, for it becomes clear he means something else by at least some of his words than I do. The simplest hypothesis so far is that my word 'hippopotamus' no longer translates his word 'hippopotamus'; my word 'orange' might do better. (Davidson, 1984a, p.100-101)

Of course there are also cases that are more disturbing, for example:

> how clear are we that the ancients -some ancients- believed that the earth was flat? *This* earth? Well, this earth of ours is part of the solar system, a system partly identified by the fact that it is a gaggle of large, cool, solid bodies circling around a very large, hot star. If someone believes *none* of this about the earth, is it certain that it is the earth that he is thinking about? An answer is not called for. The point is made if this kind of consideration of related beliefs can shake one's confidence that the ancients believed the earth was flat. It isn't that any one false belief necessarily destroys our ability to identify further beliefs, but that the intelligibility of such identifications must depend on a background of largely unmentioned and unquestioned true beliefs. To put it another way: the more things a believer is right about, the sharper his errors are. Too much mistake simply blurs the focus., (*ibid*, p.168)

The point is that we can only intelligibly attribute a particular belief to someone (whether or not we also hold that particular belief) against the background of related beliefs we share with that person. "If we are going to understand the speech or actions of another person, we must suppose that their beliefs are incorporated in a pattern that is in essential respects like the pattern of our own beliefs" (Davidson, 1980b). Positive interpretation thus amounts to describing utterances in such a way that we can read a reasonable pattern of beliefs in them. ('Describing utterances' could also be called 'translating' or 'redescribing.' In the first example, the utterance 'There's a hippopotamus in the refrigerator' is tentatively redescribed into 'There's an orange in the refrigerator' in order to make it cohere with 'It's roundish, has a wrinkled....')

2.2.3 It matters that the problem of interpretation is recognized and properly solved

Interpretation becomes a matter of great moment when educational strategies are based on the interpretations that are given to pupils' speech and actions. The conceptual change model of learning is a case in point: first the alternative ideas, conceptions or frameworks that pupils have before education are studied and then, on the basis of the results of those studies, classroom interventions are devised to encourage pupils to change their pre-educational ideas. Pupils' beliefs about some topic or phenomenon are studied by using such techniques as: word association, free association, concept mapping, interview-about-instances, interview-about-phenomena, naturalistic studies, written tasks, rule assessment, observational methods (Driver & Erickson, 1983). All of these methods somehow rely on the use of language. Of course this is the right thing to do. If we are to understand what pupils are thinking and doing we should use all resources available, and language is certainly one of the most important ones. At the same time, however, if we are going to understand them, we unavoidably face the problem of interpretation: we hear their utterances and see their movements, and we want to know what they are trying to say and achieve. In this section I discuss some prototypical examples of studies on pupils' ideas and ask whether in those studies the problem of interpretation has been recognized and properly solved.

Force and motion

The first example concerns the many studies on children's ideas about motion, or intuitive theories of motion (e.g.: Clement, 1982; McCloskey, 1983; Halloun & Hestenes, 1985; Gunstone & Watts, 1985). Let me begin with a brief overview of some results of those studies. The following are often reported as basic intuitive rules that children (or, more generally, lay people) seem to operate by.

> Motion requires a force.
> Motion implies a force.
> Force and motion are proportional to one another.

In somewhat more detail, the intuitive theory is reported to be something like this.

> Motion requires a force not only in the sense that a force is needed in order to set an object in motion, but also in the sense that sustained motion needs a continuous force. The required forces are usually exerted by external agents. There is a proportionality between force and motion in the sense that more force has to be exerted in order to set an object in a faster motion or to sustain a faster motion. Motion implies a force in the sense that if an object is in motion, then there is a force in the direction of its motion. This is a force that the moving object has, though not permanently. It must have got this force in the first place, and there are two ways in which it can have got its force. First, from an agent that has exerted a force on it; second, from another moving object that has carried over some of *its* force. That is, forces are imparted by agents and transferred from one object to another. If an object is given some force (in one of these two ways), it is set in motion or, in case it was already in motion, it is set in a faster motion. There is thus also a proportionality between force and motion in the sense that an object moves faster if it has more force. If there is no continuous supply of force, the motion of an object cannot be sustained and thus becomes slower. So if there is no continuous supply of force, the force of an object wears out. That is, apart from being exerted, possessed and transferred, forces can also be dissipated.

Perhaps it is also worthwhile to give a few examples of what children or lay people actually say, in order to see in what sense they say can be said to hold the above intuitive theory. Here is what some children in the age group 11-14 say (I have taken the quotes from the paper by Gunstone & Watts).

> "If he wanted to keep moving along … he would have to keep pushing, otherwise he'll run out of force and just stop."
> "To keep going steadily you need a steady push. If you don't force something to move it's not going to go along is it?"
> "Why do they [things rolling along the floor] stop? It's just they always stop. After you push it they go as far as the push … how hard it was, and after that wears off it just goes back like it used to be."

A first thing to note is that those children do not always frame their ideas in the exact words of the above intuitive theory. However, the step from "If he wanted to keep moving along he would have to keep pushing" or "To keep going steadily you need a steady push" to 'Sustained motion needs a continuous force' is a very small one. It is therefore reasonable to assume that they might have expressed their idea by an utterance of the latter sentence as well, or at least have assented to an utterance of it. Similarly, they might as well have said 'There is a proportionality between force and motion' instead of, or as a generalization of, "After you push it they go as far as the push … how

hard it was." There are also cases in which their wording (e.g., "he'll run out of force" or "[the push] wears off") is already pretty close to the above intuitive theory ('the force of an object wears out'). Another familiar such case (see, e.g., Clement, 1982) is that students, when asked to draw the forces that are present when a tossed coin is in its upward motion, draw an upward force which they call, e.g., "the force I'm giving it" or "the force of throwing the coin up." This comes pretty close to 'if an object is in motion, then there is a force in the direction of its motion' and 'forces [can be] imparted by agents.'
Children or lay people can thus be said to hold the above intuitive theory in the sense that they either do express their ideas in pretty much the wording of the intuitive theory or, else, might at least have done so.

On the basis of the above remarks I from now on assume that children and lay people hold true the intuitive theory as it is formulated above. What does follow from this? According to many researchers it follows that their intuitive theory is "at variance with the principles of Newtonian mechanics" (McCloskey, 1983), that "students come to the classroom with naive conceptions or preconceptions …, and these preconceptions are usually incorrect from the scientific point of view; thus they are referred to as *misconceptions*" (Chi, 1992).

I agree that a statement like 'Sustained motion needs a continuous force' seems to be in flat contradiction with Newton's first law, and that in Newtonian mechanics an expression like 'to have a force' is meaningless. But from this it does not follow that the intuitive theory contradicts Newtonian mechanics. This conclusion only holds good, if we assume that children and lay people use and understand the word 'force' in the way that we, as physicists, use and understand it, i.e., if we assume identity of meaning. I think it is more natural to assume, however, that children and lay people do *not* use the word 'force' as physicists do, just as it is more natural to assume that someone who holds true an utterance of "There's a hippopotamus in the refrigerator" does not quite use some of his words as we do than that he actually believes that there is a hippopotamus in the refrigerator. So the mere finding that children and lay people hold true the intuitive theory as it is formulated above does not yet throw any light on what they actually believe. It still needs to be found out which beliefs are represented by their holding it true. Thus, by reporting the above as children's or lay people's intuitive theory, the problem of interpretation is not yet solved. At best the report can be read as a statement of the problem, in that it brings out that children's and lay people's uses of the word 'force,' though quite common, are not in accordance with how the word is used in Newtonian mechanics and so cannot be interpreted in accordance with this scientific usage. The problem therefore is how we are to interpret their uses of the word 'force.'

The way to solve this problem, according to section 2.2.2, is to redescribe the intuitive theory that children and lay people hold true in such a way that we can read a pattern of beliefs in it that they share with us. In order to choose a plausible such pattern, it is of course essential to take into account what their intuitive theory is about, i.e., what sorts of situations they were talking about when they uttered, nearly enough, (fragments of) that intuitive theory. In general, these were familiar situations in which some object was in motion, usually after it had been kicked, pushed, thrown, etc by some agent. An appropriate pattern of beliefs that applies to such situations, is something like the following.

- agents can make an effort to cause something to happen, for instance set things in motion (throw a ball, ride a bike);
- the more effort you make, the more effect you beget (throw the ball further away, ride the bike faster);
- to keep things in motion you have to keep making an effort (keep pedalling, keep pushing), otherwise they will, eventually, come to a stop (if I stop pedalling me and my bike will come to a stop);

- the motion of an object can also cause something to happen (the motion of a ball can cause the breakage of a window, or the motion of another ball);
- a faster motion of an object can cause an increased effect (a very fast motion of the ball may cause the breakage of several windows, or a faster motion of the other ball).

Note, first of all, that this pattern of beliefs is correct and, in particular, not in contradiction with Newtonian mechanics. A physicist does agree, e.g., that when riding my bike on a flat road I need to keep pedalling in order to keep going steadily, because otherwise I would come to a stop. I do not see, therefore, in what sense Newton's laws would "strike at the roots of commonsense reasoning" (Ogborn, 1993). Or, to put it the other way around: if it was possible to derive something from the principles of Newtonian mechanics that contradicted the above pattern, I would say something is wrong with those principles because I do not see what is wrong with the pattern. Note, furthermore, that the basic notions in the above pattern are those of agency and causation. This suggests that it is in terms of these notions that children's and lay people's uses of the word 'force' should be analyzed.

I will now try to show that the above pattern of beliefs is indeed appropriate to interpret children's and lay people's uses of the word 'force.' That is, it is possible to so redescribe their uses of the word 'force' that, thus redescribed, the above intuitive theory translates into the above pattern of beliefs. First of all, I detect three main uses of the word 'force' in the intuitive theory: as part of (a) the expression 'to exert a force on,' (b) the expression 'to have a force,' and (c) the expression 'to get a force from.'

Let me begin with the expression 'to exert a force on.' The basic use of this expression is in a sentence of the form '*A* exerted a force on *O*,' where *A* is an agent and *O* an object. I interpret this sentence as follows. Children and lay people hold it true just in case (1) there was an action of which *A* was the agent, and (2) something happened to *O*, and (3) *A*'s action caused what happened to *O*.[2)] So the point of the expression 'to exert a force on' is to have available a general way of saying that an agent did

2. This analysis is inspired by Davidson's analysis of sentences with event- or action-verbs (1980a, pp.105-203; 1985e).

something that caused something to happen to an object, e.g. when there is no need to specify what it is that the agent did (kick, push, throw, swing a bat, or whatever) and what it is that happened to the object (set in motion, kept in motion, deformed, broken, or whatever).

In line with the above interpretation, children and lay people generally do not use the expression 'to exert a force' when there are no agents involved. It makes no sense for them to say, e.g., "The ball exerted a force on the window," simply because a ball cannot be the agent of an action. It cannot do something in the way that we can, and so condition (1) for the application of the expression 'to exert a force on' is not satisfied. Nevertheless its motion can, just like our actions, cause something to happen to other objects. To be able to express the latter is, I think, the point of the expression 'to have a force' in relation to moving objects. So I take children's and lay people's holding true the sentence 'If an object is in motion, then there is a force in the direction of its motion' as an expression of the belief that the motion of an object can cause something to happen to other objects that are located in the direction of its motion.

The basic use of the expression 'to get a force from' is in a sentence of the form '*O* has got a force from *A*,' where *A* is an agent and *O* an object. Its point derives, I think, from situations in which children and lay people not only want to say that an agent did something (e.g., that he swung a bat) and that there was an immediate effect of his action (e.g., that a ball was set in motion), but also that the causal chain was longer (e.g., that the motion of the ball caused the breakage of the window) and that his action caused the more remote effects in the causal chain as well (that he broke the window). I therefore interpret the sentence '*O* has got a force from *A*' as follows. Children and lay people hold it true just in case (1) there has been an action of which *A* was the agent, and (2) there is a motion of *O*, and (3) *A*'s action caused the motion of *O*. There is also a derivative use of the expression 'to get a force from,' namely in a sentence of the form 'O_1 has got a force from O_2,' where both O_1 and O_2 are objects. On my interpretation children and lay people hold this sentence true just in case there is a motion of O_1 that has been caused by a motion of O_2. The point of this derivative use is, again, to be able to express that "an agent causes what his actions cause" (Davidson, 1980a, p.53), namely in cases where the causation proceeds via several links in a causal chain that involves several other objects. E.g., in case an agent sets one ball in motion, whose motion causes the motion of a second ball, whose motion …, whose motion causes the breakage of the window, this last ball has got its force from the second last ball, which has got …, which has got its force from the agent.

Let me take stock. I have tried to solve the problem of interpretation, i.e., I have tried to find out which beliefs are represented by children's and lay people's holding true the above intuitive theory. In order to do so I have not assumed identity of meaning but, conversely, have tried to find out how they use and understand expressions like 'to exert a force on' and 'to get a force from,' namely by redescribing those expressions in such a way that what they say comes out as largely correct. More concrete, by redescribing those expressions as indicated above, it can be seen that the intuitive theory translates into the above pattern of beliefs. By interpreting them in this way, I have in effect attributed a pattern of beliefs to them that, as noted above, is correct and, in particular, not in contradiction with Newtonian mechanics. Thus it is by assuming identity of pattern of belief that I have come to attribute a meaning to their expressions 'to exert a force on' and 'to get a force from.'

Let me also go briefly into the implications for education. I agree with Gunstone & Watts (1985) when they write:

> The issue of language is difficult and complex. Students use language which is meaningful to students; teachers use language which is meaningful to teachers. There are a range of important teaching implications to be derived from an understanding of language and its role in learning.

But, as I understand it, I disagree with how they go on:

> We merely wish to draw attention to one of these implications which arises from considering the intuitive rules used by students. Language which is meaningful to teachers may, because of students' views of the world, have a quite different (even conflicting) meaning for students. If we are not sensitive to this, we can unwittingly reinforce the very views we want to change.

Language which is meaningful to teachers may indeed have a different meaning for students. In fact, I have just argued that this is indeed the case with respect to expressions in which the word 'force' occurs. However, this is *not* because they have alternative beliefs about the world, i.e., beliefs we would want to change (I interpret what Gunstone & Watts call 'views of the world' as 'beliefs about the world'). There simply is no identity of meaning concerning some terms because scientists have come to assign a rather special meaning to some of them (e.g., 'to exert a force on'), while to others they may not even attach a meaning at all (e.g., 'to get a force from'). So I would rather say that if we are not sensitive to this, we can unwittingly create a lot of talk at cross purposes between teachers and students. Furthermore, I see no need to change students' intuitive theory, simply because, if appropriately interpreted, there is nothing wrong with it. I do see a need, of course, to make them (want to) add substantially to what they already believe in order that they come to understand Newtonian mechanics.[3)]

Chi (1992) mentions another implication for education. She concludes, on the basis of "an extensive survey of the science education literature," that "the fundamental conception that underlies most of the students' conception of physical science concepts is to treat them as a kind of substance." With regards to education she accordingly

3. It is well-known that many courses in Newtonian mechanics do not lead to such an addition. Students who have had high school physics, or even college physics, very often have not added substantially to the above intuitive theory or, perhaps worse, have arrived at some uncomfortable cross between the intuitive theory and Newtonian mechanics. Again, I think it is wrong to diagnose this situation as showing that their intuitive theory "is highly resistant to change" (Clement, 1982), because of the implicit suggestion that the intuitive theory ought to be changed. My diagnosis not only is that there is a lot of bad education, but also that it is a non-trivial and challenging task to make pupils (want to) add substantially to what they already believe in a way that leads to their understanding of Newtonian mechanics.

suggests that "in order for students to really understand what forces, light, heat, and current are, they need to change their conception that these entities are substances, and conceive of them as a kind of constraint-based event (including fields), thereby requiring a change in ontology."

I do not subscribe to Chi's conclusion that students use the word 'force' as if it refers to a material object (which is how I interpret her statement that 'the fundamental conception that underlies most of the students' conception of physical science concepts is to treat them as a kind of substance'). I rather think that in much of the research on which Chi has based her conclusion researchers have (wrongly) interpreted students as if they use the word 'force' to refer to a material object, probably because the word 'force' grammatically functions as a noun and students use the word in such expressions as 'to have a force' and 'to get a force from.' On my interpretation students do not assign a meaning to the word 'force' in isolation at all and, in particular, do not use it to refer to any entity whatsoever. And the fact that students may hold true a sentence like '*O* has got a force from *A*' does not, on my interpretation, reflect that they conceive of a force as some*thing* that, literally, can be handed over from an agent to an object. If they hold the sentence true, they thereby simply claim the occurrence of two events (an action of which *A* was the agent, a motion of *O*) that are causally related. My interpretation requires no other ontology than the familiar one of common objects and events.

Accordingly, I also do not subscribe to Chi's suggestion with regards to education, namely that a change in ontology is required in the sense that for pupils to really understand what forces are, they need to change their conception that these entities are substances and conceive of them as a kind of constraint-based event. First, I do not believe that pupils conceive of forces as some kind of entity (of the material object kind). Secondly, in teaching Newtonian mechanics I would not aim at making them conceive of forces as any entity whatsoever. For I note that in Newtonian mechanics too the word 'force' does not have a meaning in isolation, but only as it is part of smallest meaningful expressions such as 'to exert a force on.' Furthermore, in Newtonian mechanics too an understanding of such expressions requires no other ontology than that of objects and events. What I think is important to realize with regard to education, is that in Newtonian mechanics an expression like 'to exert a force on' is not used in the sense in which students use it, and that students use expressions containing the word 'force' that are not used in Newtonian mechanics (e.g., 'to have a force'). One of the central tasks of education thus becomes to create a space in pupils' conceptual apparatus for e.g. the term 'to exert a force on,' in its scientific sense, to occupy. The process of creating this space is not one in which "students must induce or be told that physics entities belong to a different ontological category" (Chi, *ibid*), but one of making them see the point of having available such a term in its scientific sense. Furthermore, just as in the above it was a shared view of the world (a shared pattern of beliefs) that enabled me to interpret what students mean by their uses of the word 'force,' so I suggest that in the process of creating appropriate spaces in their conceptual apparatus we should somehow productively make use of, build on, and extend this shared view. Finally, the aim of teaching Newtonian mechanics is not to make students really understand what kind of entities forces are, but to enable them to explain and predict the occurrence of events by means of laws in which the notions of agency and causation play no role.

Molecules
Let me give one more example. It concerns the numerous studies that have been conducted on the way pupils relate microscopic particles to macroscopic phenomena. In fact, in October 1989 an international seminar was held, in which this theme was considered 'a central problem in secondary science education' (Lijnse, Licht, de Vos & Waarlo, 1990). I suppose the results of such studies are by now familiar: it is reported that pupils *believe* that the molecules of a fluid expand when the fluid is heated, that the hard molecules of ice melt when ice melts, that the molecules of sulphur are yellow, that the molecules of glue are sticky on the outside, etc. It is then often noted that pupils mean something else by the word 'molecule' than scientists do. But if that is so, then the statement, e.g., that they believe that molecules of sulphur are yellow is non-informative. For if pupils mean something else by the word 'molecule' than we do, what is it then that they believe when they hold true an utterance of "Molecules of sulphur are yellow?"

In order to solve this problem of interpretation, the best we can do is attribute to them the (correct) belief that a substance can be divided in little bits that, apart from their size, are just like larger amounts of the substance (have the same properties, are subject to the same regularities, etc), and accordingly interpret their expression 'molecule of ...' as 'tiny bit of ....' For if we do so, we are, in most cases, in perfect agreement with them: like us they suspect that every droplet of the fluid expands when heated; like us they know that small bits of ice are hard and can melt; like us they see that tiny grains of sulphur are yellow; like us they feel that small amounts of glue are sticky; etc.

So one should be careful with the conclusion that it is "common for students to attribute macroscopic properties (such as melting or expanding) to particles" (Johnston, 1990). If we read this as 'pupils attribute macroscopic properties to *their* molecules,' there will be no problem. But this conclusion is obvious: their 'molecule of ...' *is* essentially macroscopic (though the 'tiny bit of ...' may be so small that it cannot be perceived). If, on the other hand, we read it as 'pupils attribute macroscopic properties to *our* molecules,' we will be misinterpreting them: they are *not* talking about our molecules. Furthermore, if we are to teach pupils about the particulate/kinetic theory of matter, there is no need "to address directly some of [their alternative ideas about the nature and behaviour of matter] and to encourage students to reject them" (*ibid*). Since in the above we have made maximum sense of their words by optimizing agreement on beliefs, *perforce* their ideas are not 'alternative' at all but rather in optimal agreement with our own ideas. So we will have no reason to encourage them to reject those ideas.

In teaching about the particulate/kinetic theory of matter, we rather face the educational task "in what sense macroscopic phenomena have to become problematic to the pupils" (ten Voorde, 1990) in order that they come to feel a need for our particles and the specific way we use our particles in accounts of macroscopic phenomena. The central problem, as I see it, is how we can meaningfully make pupils partners in an enterprise that aims to explain, under the assumption that an object is a certain collection of particles, all macroscopic changes of that object solely in terms of changes of position and velocity of those particles due to their mutual interactions.[4)]

Subtractions and their role in science education
In the above I have indicated that in the process of learning Newtonian mechanics or the particulate/kinetic theory of matter, pupils need not (be challenged to) abandon their intuitive theory of motion or their ideas about their particles. I have not meant to suggest that pupils will *never* have to subtract *anything* or that the cases in which subtractions are needed may not play an *important* role in their process of learning science. The importance of such cases may, e.g., be that they create a place in pupils' conceptual apparatus for a term subsequently to be introduced to occupy, or that they make pupils want to add to what they already believe. The subtractions that are needed and that may play this important role, however, will I think mainly concern pupils' expectations of what will happen in a situation that they never before have witnessed or paid attention to, namely when *they themselves* recognize that what they expected was going to happen does not in fact happen. In such cases pupils may e.g. come to realize that their expectation was implicitly based on some generalization, and that this generalization is indeed valid in most situations they have come across but not in this new situation. Let me give an example.

When pupils are asked what will happen to the reading of a thermometer that is placed in a pan of boiling water when the pan remains on the hot plate or the hot plate is turned to a higher setting (something they have never witnessed before), many of them will say that they expect the thermometer to rise. When they then find that the reading of the thermometer remains the same (100°C), they themselves will of course admit that their expectation has not come out. In this sense one may say that the experiment poses a conflict, and that as a result of it pupils will have to withdraw their expectation. But, of course, this withdrawal in itself cannot be the point of the experiment. Part of its point rather is that pupils will find the outcome of the experiment surprising. For as they now come to think of it, they cannot think of any other situation in which an object was near some heat source and did not get warmer. In fact, it is the point of a hot plate (or of turning it up to a higher setting) to make things warmer. They may thus come to realize that in their expectation they implicitly made use of a generalization that was based on situations they have come across, something like: as long as an object is near a heat

4. It is well-known that many courses in the particulate/kinetic theory of matter fail to achieve this. It is easy to see that this will be the case for courses in which molecules are defined as the smallest parts of a substance that still have all the properties of that substance and are introduced as the product of a process of division. For this definition and this introduction cohere nicely with an interpretation of 'molecule of ...' as 'tiny bit of ....' In section 5.3.2 I will argue that a well-known constructivist approach to teaching the particulate theory of matter, in which the main educational task is considered to be that pupils remove their supposedly alternative ideas in favour of appropriate scientific ones, also fails to meet the task of meaningfully introducing pupils to what scientific particle models are all about. We need to think of other ways to meet the latter, non-trivial, task.

source, it gets warmer.[5] So apart from their expectation, pupils will not have to withdraw very much. In many situations it still is the case that an object does get warmer as long as it is near a heat source. What they now come to add to this is that there are also situations in which this is not so.

Whether there is any use of the experiment in an educational process depends of course on whether it is possible to so embed it in a series of activities that it can be given a *further point*. It is perhaps possible to let the experiment precede by such a series of activities that, on the basis of those activities, the element of surprise that the experiment induces in pupils is very likely to prompt their formation of a particular kind of intention, e.g.: to find out whether there are also other liquids that have an invariant boiling point, or whether freezing too occurs at a fixed temperature. The further point of the experiment then is that pupils are provided with reasons to extend what they already know in certain directions. And an even further point may be that this extension contributes to creating a place in pupils' conceptual apparatus for a concept subsequently to be introduced to occupy (e.g.: the concept of a pure chemical substance).

2.2.4 Some general notes on methodology

The strategy that I have applied above (and that in chapter 4 I argue to be unavoidable for correct interpretation) is one of matching patterns of belief. It will be clear that this strategy is frustrated by assuming identity of meaning all too lightly (especially concerning terms to which scientists in the course of the development of science have come to assign a specific meaning), and by distributing isolated utterances too quickly into separate categories (instead of trying to read, in the totality of utterances held true, a coherent pattern of beliefs that corresponds close enough to a pattern of our own). It are precisely these two, what I consider to be, methodological errors that are often made in the many studies on 'alternative' frameworks/conceptions that have appeared in the science education literature. I suggest that it would be interesting to apply an analysis like the ones I have given above with respect to studies on pupils' 'alternative' ideas about motion and molecules to other such studies as well. This would come down to redescribing those studies' accounts of what pupils believe in such a way that they turn out to do and say things that, according to us, are the reasonable things to do and say under the circumstances. I conjecture that the result of such an analysis will be that those studies' identifications of misconceptions or 'alternative' ideas generally come down to misinterpretations.

Note that the task of matching patterns of belief will be greatly facilitated if the interview-situation involved events that occurred during the interview or objects for

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5. Or, as some authors (e.g.: Anderson, 1986; diSessa, 1988; cf section 2.5) suggest, perhaps the generalization that was implicitly used was even more general and based on even more situations they have come across, e.g. something like: if one thing has a certain effect on other things, those other things will be more affected the longer they are near the one thing. The generalization mentioned above is then a special case of this more general generalization, with the 'one thing' specialized to 'a heat source' and the effect it has on other things to 'making them warmer.'

pupils to handle with, and if the interview-situation furthermore was rather simple and surveyable, both for the pupils and for us who want to understand what they see in the situation, what they think about it, what they mean by what they say, what they want to achieve, why they do as they do, etc. For the objects that are present and the events that are occurring in the interview-situation can then be taken to have caused pupils' coming to hold some sentence true, their coming to believe that they have accomplished (or not yet accomplished) what they thought they were asked to do, etc. The task then roughly comes down to keying their sentences in such a way to sentences of our own that their holding a sentence true is often enough caused by the same events and objects as our holding our matching sentence true. We thus make our interpretation depend on the events and objects that we take their sentences as being about, in the sense of making them right (according to us) in what they say about those events and objects.

The interviews on radioactivity that are reported in the remainder of this chapter are not of this kind, in that the interview-situation does not (or hardly) involve events that occur during the interview or objects for pupils to handle with, but mainly verbal talk about situations having to do with radioactivity (the Chernobyl accident, X-ray photography, etc). Of course it has been tried to secure as well as possible that the interviewer and the pupils were talking about the same situations by choosing well-known or familiar situations, by providing suitable information (e.g., photographs), by letting the pupils describe the situations, etc. But since there are no observable events and objects in the interview-situation that could serve to relatively easily work one's way into pupils' belief system, another strategy has to be taken to match patterns of beliefs. In section 2.5, this will be done by placing pupils' talk in a familiar pattern of general commonsense knowledge. In chapter 1, in connection with the question why in some countries iodine tablets were distributed after the Chernobyl accident, I have already hinted at this procedure. I have tried to explain (understand) pupils' answers to that question by placing their talk in a familiar pattern associated with the general notion of resistance: if something has an effect on something else, the effect can be decreased by adding a resistance. I do not mean to suggest that this strategy to match patterns of belief on a fairly general level is the best or the only one, but rather that for the case at hand it seems to be the most appropriate and perhaps the only one available.

2.3 Review of previous research on pupils' ideas about radioactivity

2.3.1 Eijkelhof's findings

In his thesis (1990), Eijkelhof gives a survey of the few studies on pupils' ideas about radioactivity that had been carried out before he tackled the issue. Eijkelhof notes that these studies had had a more limited scope than his. Furthermore, in the cases where there is overlap the results of these studies are compatible with his findings, or at least understandable given his findings. Below some of his findings are presented.

> As regards the meaning of 'radiation', we found many associations with other kinds of radiation, especially with light, but also with heat, radio waves and sound waves. Invisibility is a property which is acknowledged by almost all pupils. Some pupils seem to reify radiation by calling it a kind of gas ("radon"). A large proportion of pupils make distinctions between natural radiation, X rays and "radioactive radiation". They draw these distinctions partly from their ideas about differences in effects, partly from differences in function, of these kinds of radiation.
>
> According to many pupils the propagation of 'radiation' is influenced by ventilation: this is seen as a means of preventing further accumulation of radiation in rooms where X rays are used, in factories where food is irradiated and in houses which are well insulated. Related to this view is the idea that radiation could be carried away by the wind (in the Chernobyl context). From a scientific point of view one might conclude that 'radiation' is then being used for 'radioactive substances'.
>
> Many pupils lack the scientific idea of absorption of radiation. They seem to have 'conservation' ideas about radiation, which could be summarized as:
>
> > when an object (such as food or a wall) receives radiation, the radiation will accumulate in the object; when the amount of radiation is large enough, the object will itself start emitting radiation.
>
> So 'absorption' is confused with 'accumulation of radiation'. The same idea applies to people who receive radiation, a difference being that people are seen as living beings with some resistance: the body has some defence system which breaks down radiation as long as there is not too much.
>
> In the light of this, it is to be expected that indiscriminate use of the terms 'contamination' and 'irradiation' will be very common. Many pupils speak of 'contamination' when someone or something has received a certain amount of 'radiation', sometimes specified as "a surplus" of it or "more than normal". (Eijkelhof, 1990, p.96)
>
> The term 'radioactivity' is often used in implicit and explicit ways to mean 'radiation'. So pupils spoke about "radiating", "releasing" or "emitting radioactivity" and defined 'radioactivity' as "radiation" or "an accumulation of radiation". We also found meanings which could be labelled as 'the source of radiation'. Here we refer to pupils' descriptions of "radiation emitting substances"; "particles"; "an atom of radioactivity", "having", "handing over" or "containing radioactivity". Very often effects of radiation were included in the definition of the term 'radioactivity': the pupils spoke of "dangerous" and noxious", (*ibid*, p.97).

Eijkelhof also gives some examples of how pupils talk about the danger of (applications of) radiation: "X rays must be dangerous as my mother and the nurse had to stand behind a special window;" "if irradiation of food happens in a room like that [with thick walls], it cannot be said that it is not dangerous;" "[irradiation of food is not dangerous], otherwise they wouldn't do it." More generally, he identifies two views about the danger of radiation, which he labels 'radiation is dangerous' and 'the dangers of radiation are limited'. According to both views radiation is potentially dangerous, but they differ with respect to the extent in which the danger can be controlled: "on the first view hardly any control exists; the second puts more trust in experts and the safety measures taken" (*ibid*, p.99). On page 98 of his thesis, Eijkelhof compares the two views as follows.

Radiation is dangerous	*The dangers of radioactivity are limited*
radiation / radioactivity / radioactive matter is permanent: it never falls to zero and can accumulate in the body; in the event of contamination nothing can be done	radiation / radioactivity / radioactive matter decreases in the long run; in the event of contamination, some measures can be taken
the effects of radiation / radioactivity / radioactive matter are always dangerous, leading to cancer and other serious consequences	a small dose of radiation will be broken down by the defence system of the human body
all radiation is dangerous, including X rays	X rays are very different from (radioactive) radiation and are less dangerous
safety measures indicate how dangerous the applications are	safety measures are effective in reducing the risks of radiation
radiation standards have a very limited value as any quantity of radiation has a hazardous effect	radiation standards indicate a safety level: below them it is safe
radiation is dangerous as it passes through anything	radiation can be stopped by lead sheets and concrete walls
radiation / radioactivity is dangerous as it cannot be observed by the human senses	radiation / radioactivity / radioactive matter can be measured
the detrimental consequences in the long run are uncertain	a lot is known about the effects of radiation

Finally, on page 100 Eijkelhof presents a list of missing scientific distinctions in pupils' beliefs.

Between 'radiation', 'radioactivity' and 'radioactive substances'.
Between 'irradiation' and 'contamination'.
Between 'absorption', 'accumulation' and 'stopping' of radiation.
Between 'activity' and 'dose', and their units.
Between the effects of 'high' and 'low' doses of radiation.

2.3.2 Reflection on Eijkelhof's findings

As may be clear from the above presentation, Eijkelhof has given some characteristics of pupils' talk about "radioactivity, ionizing radiation and risk in the contexts of Chernobyl, medical use of radiation, radioactive waste disposal, food irradiation and background radiation" (*ibid*, p.95-96). He has noted some usages of terms that are characteristic in the sense that they are quite common in the 'mean' senior high school pupil's talk about a wide range of context domains of radioactivity and radiation. An example is the seemingly undifferentiated use of the words 'radiation,' 'radioactivity' and 'radioactive matter.' Another example is the use of words like 'having,' 'containing,' 'handing over' and 'accumulating' in connection with radiation and radioactivity. Or the regular use of words like 'dangerous' in connection with (applications of) radiation.

Furthermore, Eijkelhof has generalized over pupils and context domains and has thus arrived at some typical classes of common utterances in a variety of context domains. Examples of such classes are:

a. the propagation of radiation is influenced by air currents (wind, ventilation);
b. when an object receives radiation, the radiation will accumulate in the object.

But has Eijkelhof recognized the problem of interpretation that I have described in section 2.2? In an evaluation of his findings he does mention 'problems of interpretation':

> The results suggest that an approach in which pupils' ideas are studied from the specific perspective of physics, as in the study by Riesch and Westphal (1975) on the radiation transportation process, will face difficulties as pupils attribute alternative (different or undifferentiated) meanings to scientific terms and use context-dependent ideas. The pupils are unlikely to use a coherent theory about the world … and appear unaware of any need for consistency across situations … One might therefore expect serious problems of interpretation. (*ibid*, p.100-101).

I think that Eijkelhof's 'serious problems of interpretation' are not related to the problem of interpretation as I see it. The reason is that Eijkelhof seems to have solved his 'serious problems of interpretation' by appealing to incoherence and inconsistency. This is certainly not the way to solve the problem of interpretation as I see it. Of course I do not assume that pupils have a perfectly 'coherent theory of the world' -neither have I. All I want is to understand what makes pupils say the things they are saying. And my claim is that we do not reach such an understanding by appealing all too lightly to incoherence and inconsistency. On the contrary, in doing so we simply undermine our ability to understand what it is they are so incoherent or inconsistent about. If we cannot see much reason, coherence and consistency in the utterances of the pupils, we will not be able to solve the problem of interpretation as I see it. Let me try to make this point clear by giving two examples.

Apart from some context-dependent differences of usage, Eijkelhof has noted an undifferentiated use of the words 'radiation,' 'radioactivity' and 'radioactive matter.' I agree with Eijkelhof that this common usage suggests that for pupils all three words are true of the same sort of entity, which he denotes as 'radiation/radioactivity/radioactive matter' or, briefly, 'it.' I would like to understand, however, pupils' undifferentiated use of those three words: why are they doing so? If I could understand that, I would find no trouble in translating their words 'radiation,' 'radioactivity' and 'radioactive matter' into one and the same word 'it.' And an utterance falling in class a above would then express the belief that *it*'s propagation is influenced by air currents.

Eijkelhof (*ibid*, p.96) comments on class a: "From a scientific point of view one might conclude that 'radiation' is then being used for 'radioactive substances'." Now suppose that that was the case: that for pupils the word 'radiation' is actually true of radioactive substances. In that case it would be incorrect to attribute to a pupil, on the basis of an utterance falling in class a, the belief that the propagation of radiation is influenced by air currents: that is just something she says. And when she says it, it really expresses for her the following belief:

a' the propagation of radioactive substances is influenced by air currents.

Now, between which of the two options are we to choose: one sort of entity, it, which can be transported by air currents, or two separate sorts of entity, radiation and radioactive substance, of which the latter can be transported by air currents? And on what grounds are we going to choose?

The second example concerns Eijkelhof's observation that pupils "seem to have 'conservation' ideas about radiation." I agree with Eijkelhof that utterances falling in class b, pupils' use of words like 'having,' 'containing,' 'handing over' and 'accumulating' in connection with radiation and radioactivity, and the indiscriminate use of words like 'contaminated,' 'irradiated' and 'containing radiation,' all point in that direction. But again, I would like to have more evidence to support the plausibility of attributing to pupils the belief that radiation is conserved.

Eijkelhof's conclusion that "'absorption' is confused with 'accumulation of radiation'" does not help me any further. On the contrary, what if pupils do indeed confuse absorption and accumulation in the sense that they really mean 'absorption' whenever they say 'accumulation?' If that were the case, an utterance of b would express the following belief:

b' when an object receives radiation, the radiation will be absorbed in the object.

And then there would be no reason to attribute to pupils the belief that radiation is conserved.

Again the question arises: which option are we to choose and on what grounds? And by combining both examples even more questions do arise. How are we to interpret the word 'radiation' in b (or b'): will it be 'it,' 'radioactive matter,' or even something else? Does it make sense to interpret b' as expressing the belief

b" when an object receives a radioactive substance, the radioactive substance will be absorbed in the object?

These two examples not only illustrate the interdependence of meaning and belief, but also that without any further constraints we can always change the meanings we give to some of the words a person uses by making compensatory adjustments in the beliefs we attribute to that person. They thus illustrate the problem of interpretation as I see it, and also that Eijkelhof has not recognized it. In order to solve it, somehow we have to impose constraints. I have already indicated that the constraints come down to finding common ground: we must suppose that the other's beliefs are incorporated in a pattern that is nearly enough like the pattern of our own beliefs. On the basis of this supposition we can accordingly determine the meanings we give to her words and thus solve the problem. In the case at hand, we should not consider classes a or b (or any other class) in isolation, but try to interpret the 'mean' pupil's words in such a way that we recognise a familiar and reasonable belief structure in the totality of classes, i.e. in the totality of typical utterances of the 'mean' pupil.

It is this last, but important, step that Eijkelhof has not taken, although all the necessary material is in his thesis. Furthermore, this last step would not have complicated the presentation of his findings, but would rather have simplified it by bringing to the fore some underlying belief structure to which pupils' utterances fit. I will try to take this last step in section 2.5, not on the basis of Eijkelhof's material but on the basis of comparable material that I have gathered by interviewing middle ability pupils. Since this material, which will be presented in section 2.4, turns out to be rather similar to Eijkelhof's material, my analysis will indirectly also be applicable to the latter.

2.4 Interviewing middle ability pupils about radioactivity

2.4.1 Aim and procedure

Aim

The aim of my interview study among middle ability pupils has been threefold. Firstly, to collect material consisting of assertions of middle ability pupils about (a range of context domains of) radioactivity. Secondly, to roughly compare those utterances with those of senior high school pupils (in the expectation that there would be no significant differences). Finally, to positively interpret those utterances. This section will be devoted to the first two aims, the next to the third.

Procedure

In December 1988 I conducted four interviews with groups consisting of two middle ability pupils of about 15 years old. Each interview took about half an hour. Two of the groups consisted of girls, two of boys. The interviews were held with two pupils, partly to set them at ease, partly to stimulate additional comments on each other's answers. Each interview began with an introduction. The pupils and I introduced ourselves. I told something about the aim and the procedure of the interview and asked permission to audiotape the interview.

I tried to create an atmosphere in which the pupils felt free to express their own thoughts. I emphasized that I was not going to judge them, that it was no problem if they did not know an answer, that the interview was not going to be an oral examination, that if they had any questions I was happy to answer them after the interview, etc. During the interview I would try to refrain from giving comments and would not push any further when pupils indicated they did not know what more to say. As an aid to myself, I had written down the main questions I was going to ask. Depending on the answer of a pupil I would sometimes search for further clarification, usually by repeating the last words of the answer or by asking the other pupil to comment on it. All these measures were taken to secure as well as possible that the pupils could be taken to hold true what they say. Of course this does not mean that the interviews were deadly serious and that there was no time or opportunity for an occasional joke.

In the first question I asked for examples of where one has to do with radioactivity and radioactive radiation[6]. About some of the cases they mentioned I would then try to let

6. 'Radioactive radiation' is a literal translation of the Dutch words 'radioactieve straling,' which are commonly

them tell some more. For that purpose, I would usually ask some questions about:

- the properties of radiation: why is it used in that situation?; how do you conceive of radiation?; what can it be compared to?
- the origin of the radiation: why is it present in that situation?; where did it come from?
- what happens with the radiation: how long will it be present?; where will it go to?
- danger and protection: is there any danger in that situation?; for whom or what?; what might be the effects?; are there effective safety measures?

Depending on what situations the pupils themselves brought up and how much they had to say about them, in some interviews I also brought up one or two of the following situations involving radioactivity: medical applications (X-rays, irradiation of cancer); nuclear bombs; irradiation of food; radioactive waste; background radiation. To introduce a new topic of conversation, especially when an unfamiliar application like irradiation of food was going to be talked about, some illustrations (e.g. a sketch of a food irradiation factory) were shown.

Each interview ended with questions on the detectability of radiation and on background radiation. How can one tell whether radioactive radiation is present or not? Can it be seen, felt, measured? And after having introduced a Geiger counter as an instrument to measure radioactive radiation, I asked for the origin of, possible consequences of and possible protection measures against background radiation.

2.4.2 Description of results

After the interviews the tapes were transcribed into protocols of about 12 pages each. After leaving out my questions and introductions of particular situations involving radioactivity, passages in which I really put the words into the pupils' mouths, passages in which the pupils or I wandered too far from the main road set out by the questions given above, repetitions in pupils' answers, etc, each protocol reduced to a collection of pupils' utterances of about two pages. It is essentially this resulting total collection of utterances that is presented below. The utterances are grouped according to the particular situation in the talk about which they were uttered and repetition of similar utterances coming from different interviews is avoided. Since Eijkelhof's results point at much communality among senior high school pupils and the general public, it is reasonable to assume that the communality extends to middle ability pupils too. Furthermore, the interviews themselves have given no clues for abandoning that assumption: each interviewed couple agreed on most of the issues. In fact, in section 2.5 I will make maximum use of the assumption by trying to deliver a positive interpretation based on the totality of utterances of all the eight interviewed pupils. This corresponds to my aim to reach an interpretation (understanding) of the 'mean' middle ability pupil's thoughts about radioactivity. Or to put it in a more modest and feasible manner: to reach an understanding of the thoughts of the 'average' of the eight interviewed pupils.

The utterances below are presented to give the reader a fair idea of what my interpretation in the next section is based upon. Of course it should be remembered that

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used as 'radiation having to do with radioactivity.'

the utterances were originally in Dutch. They are translated in such a way that the versions in English remain as closely as possible to the original wordings in Dutch. No real attempt is made to translate spoken Dutch into spoken English. This is why native English speakers probably will not recognize the utterances below as representing the idiom of 15-year-old, native English speaking kids. So be it.

Where one has to do with radioactivity and radioactive radiation

One important feature to notice right at the start is that the pupils talked easily and at length about the subject. It was relatively easy for me to conduct the interviews.

Concerning the question where one has got to do with radioactivity and radioactive radiation, one group mentioned: hospitals (X-ray machines); nuclear power stations and accidents with them, in particular Chernobyl; "an X-ray machine they had found somewhere in Africa on a rubbish dump, some people died of it" [probably the pupils intend to refer to the radiation therapy device that was taken apart by some junk collectors in Goiania, Brazil, in 1987]. Another group mentioned that "everywhere around, really" one has got to do with radioactivity and radioactive radiation: "on the moors, in the woods, agriculture." The group also mentioned nuclear power stations, and in particular Chernobyl: "People who work in nuclear power stations have got to do with it, they have to leave after a couple of years, I believe, otherwise they would get too much radiation;" "It will give trouble to the people who live a stone's throw from a nuclear power station. If the station breaks down, the radiation will come out and cover the people." Finally, the group mentioned "experiments with big explosions" and nuclear bombs. The third group mentioned "something with the ozone layer;" X-rays; irradiation of cancer ("because you hear about things that happen afterwards, after such an irradiation"); irradiation of kidneys, perhaps ("if they use it for cancer, then it seems to me they might also use it for kidney stones"). The group also thought that maybe ultraviolet lamps and sun lamps have got to do with it: "Something ultraviolet, you know. Well, if you stay under it too long, you will get sunburnt. You're only allowed to stay under it for such-and-such a time. And you're more likely to get cancer." The fourth and least talkative group, finally, mentioned nuclear arms, nuclear power stations and also that "it's in the air." When later in the interview I asked them whether in hospitals one also has got to do with it, they mentioned X-rays and irradiation.

When asked how they know all these things, most pupils mentioned sources like television, radio, newspapers, "I hear it from my mother and brother," "just through the grapevine."

Chernobyl

All groups implicitly or explicitly referred to Chernobyl. And also in their talk about other situations (see below) they regularly made comparisons with Chernobyl. I now give the utterances that apply specifically to Chernobyl.

> "A nuclear power station was somewhat overheated, or so, I'm not sure, but at any rate there had been a fire and so all that radiation was released in the air."
> "In the environment everything died, people died of cancer."
> "Just a little bit of it immediately kills you."

> "[Cancer] is the main disease caused by the radiation. I believe you can get cancer from it and quite a lot of diseases."
> "In Norway it also was very bad. In the end, all the animals had to be shot."
> "The honey was contaminated with radiation."
> "From the grass and several cows we discovered that there was also more radiation on the things here [in The Netherlands]. It all came from Chernobyl. It was carried by the wind and drifted towards us."
> "[It can be carried by the wind] because it is very light. I don't know, a kind of gas, or so, gaseous. It's neither fluid nor solid."
> "I think it simply mingles with the air and when it rains -it also mingles with the rain- it comes down and ends up in the ground."
> "Even here there were vegetables we were not supposed to... It goes all over the world. It spreads out over all countries and it ends up in the ground. It gets into the ground."
> "It decreases more and more. In the end it will run out, I think."

X-rays

According to all groups in which medical applications were discussed, X-rays have got something to do with radioactivity and radioactive radiation[7)]. According to pupils, X-rays are taken for the following reasons and purposes.

> "X-rays are more efficient than... I don't know how they would have to do it otherwise, but it seems to me it's more efficient."
> "I think otherwise you should have to feel whether it is indeed broken. And there might be a crack in your bone, or so, and that you can see on an X-ray."
> "It is shined through the patient to see what kind of diseases he has."
> "They can look behind your molars to find out, perhaps, whether the roots are all right. With X rays they can see all that, but not by just looking into your mouth."
> "Maybe at my birth [I had an X-ray], I don't know, or when I was still in my mother's belly. Maybe they take X-rays [of pregnant women] to see how the child is doing, I'm not sure, or to see whether it will be twins or a boy or a girl. I think they could use X rays for that purpose."

About the properties of X rays and what they can be compared to, the pupils noted the following.

> "You don't see it."
> "In some cases you don't see it, but in the X-ray machine [in Goiania] it had a colour. That's why the people rubbed it on their skins. I think that that colour is the radioactivity-radiation."
> "I think it would be possible to see them [X rays], otherwise you wouldn't be blinkered. Because of the X rays you have to be blinkered, just as in welding because of the ultraviolet radiation. Otherwise you'll burn your eyes or get welding-eyes [actinic conjunctivitis]. So I think it would be possible to see them, but you're simply not supposed to look at them. The same applies to the people that go to stand behind a screen. They're also not allowed in front there. So it not just applies to the people of whom an X-ray is taken, doctors and so on are also not supposed to look at them."

7. The Dutch word for 'X rays' is 'röntgenstraling,' which would literally translate into 'roentgen radiation.'

"I think X rays have something to do with ultraviolet, because ultraviolet also goes right through your body."
"X rays are so intense that… it seems to me that if a nuclear bomb, or something like that, is dropped, that then too it will be so much that you could simply see your bones. That's what I compare X rays to: to light, very intense light."
"[X rays can be compared to] a laser beam. Laser beams are not really radiation, but just bound light. But I think it can be compared to X rays, because you can make it shine right through a person and you can also do that with radioactive radiation."
"[X rays can be compared to] a gas. You don't see them and they're dangerous, aren't they, if you get too much on you; and a gas is the same, really: you don't see it and it's also dangerous."

About the origin of the roentgen radiation (X rays), the pupils had the following to say.
"[It came] from such a thing, a very large…"
"[The radiation] comes from such a machine."
"It is in X-ray machines, I don't know exactly what."
"Sooner or later it will be used up or worn off and then you can use it no more. But I'm not sure where it comes from."
"[In an X-ray machine] are those radioactive-radiation-fluid. I believe it is a bit luminous. Those people [in Goiania] had rubbed it on their skins, because they thought it was very pretty."

About what happens with the radiation after an X-ray is taken, pupils told the following.
"[When an X-ray is taken,] part of the radiation falls into your skin, otherwise those diseases couldn't come up. If it didn't get into your skin, I think you wouldn't get diseases from it."
"Of course a little bit remains in your body, but that is rather minimal. I think it will have been completely worn off after a couple of minutes. It's just inside your body, isn't it. I think it just mingles with your blood or something else, I'm not sure how. At any rate you shouldn't take X-rays too often, because then you can get cancer."
"[When an X-ray is taken] small particles of the radiation get into your body and later it wears off a bit. Just like a kind of gas that wears off after a couple of years."
"It simply wears off. I think you might compare it to a battery, or so. A battery also wears off."
"Maybe it's broken down. That it simply has some sort of force inside, which decreases sooner or later."
"It also depends on how much there is. It is also in nuclear bombs and there it also has a lasting effect. But there you've got quite a lot and does it take a million years before it has worn off."

Concerning the possible effects the pupils noted the following.
"You're not allowed to make that much use of an X-ray machine, because it radiates right through your body."
"[That one is advised not to take too many X-rays] proves that it is not really healthy, otherwise they wouldn't recommend that. If it was healthy, they could easily take X-rays because nothing would happen."
"With such an X-ray machine you've only got a bit, but at the time of Chernobyl, that was quite a lot. There the people in the neighbourhood simply died after a couple of minutes. I think much more radiation was released there. It got into almost everything in large amounts."

> "The more you get, the worse the disease will be."

From their own experience, most pupils knew that when making an X-ray the nurse stands behind a screen. About the purpose and function of this screen the pupils remarked the following.

> "[The nurse stands behind a screen] because she's not supposed to see them [the X rays]. I think they are harmful for your eyes. If you were to look at them, I think your eyes would burn away."
>
> "[The nurse stands behind a screen] because if she got a bit too much radiation, that would not be good, I believe."
>
> "[The nurse stands behind a screen] because if she has to do that [making X-rays] every day, then of course she would get… and since some radiation is released or is brought into contact with her, then of course she would get quite a lot inside."
>
> "[The radiation] glances off the screen into the room, I think."
>
> "I think a screen stops the X rays, so that they won't enter your body. I think they will linger somewhere in the air and spread out, or so."

Irradiation of cancer

According to all groups in which medical applications were discussed, irradiation of cancer has got something to do with radioactivity and radioactive radiation. About the purposes of irradiation the pupils made the following remarks and comments.

> "People don't know exactly how to treat cancer. It [irradiation] is not so expensive as operating and irradiation is much easier. I think the chances of survival are better than with an operation."
>
> "That's the opposite [of getting cancer from radiation]. I don't know how that works. It is of course a remarkable fact."

About what happens with the radiation after irradiation, the pupils said the following.

> "[After being irradiated,] some part of the radiation will be in the body and some part in the air. It enters your body, doesn't it, and destroys the tumours, or the kidney stones if that's the problem. I think the radiation remains inside the body. I don't know for how long, I don't have experience with it."
>
> "Maybe the radiation is caught by some other apparatus or the patient will simply have it inside and maybe a little bit remains in the walls."
>
> "In some people it lingers and… if one person is irradiated he will get nothing while some other will get, let's say, a headache… I'm not sure, but maybe it lingers in some people and doesn't in others."
>
> "It just remains in the body and after a while it wears off or breaks down."
>
> "I think it just remains inside [your body] and that the radiation just kills some cells, or so, inside your body. I think that in due course it will ever more get out of the cells, leave the body and come into the air."
>
> "I think it will also be broken down by some substance, because some people don't get complaints while others do. So maybe in some people it isn't broken down because they haven't got enough substances of some sort."

Concerning the possible effects and safety measures (the nurse has to stand behind a wall), the pupils noted the following.

> "I think it is [harmful]. Otherwise you wouldn't hear those stories about people getting headaches and things like that after being irradiated. Perhaps it's carcinogenic."
>
> "[The nurse stands behind a wall, because she] may have to do this every day. So she's

> more likely to get those harmful substances than that patient, who is there for just once or twice in his life."
> "The wall does help. In there it's not that much, of course. At the time of Chernobyl, it went right through the walls. But of course that was much more. Here the wall will stop it, I think."
> "I think it the whole wall will eventually dissolve."

Nuclear bombs

In two groups the topic of nuclear bombs was discussed. Both groups agreed that nuclear bombs have got to do with radioactivity and radioactive radiation. About the radiation, one pupil noted:

> "It is transparent. You don't see it at all."

About what happens with the radiation after the bomb is dropped, the pupils said the following.

> "The radiation goes into the air."
> "It just weakens in the end. Every year such-and-such weaker. I don't know exactly… it just gets weaker. It drifts to other countries and things like that. It mingles with the air. It decreases."
> "It lingers in the air, the radiation. It does decrease, I believe, but I think there's still some radiation there [in Japan] now."
> "The radiation [of the bombs on Japan] by now is so weak that… by now it doesn't any longer trouble us, though it does to the people there."
> "There always remains a little bit and then it won't be excessively… but it does remain harmful."

About the effects, the pupils said the following.

> "You just see that explosion and then… well, all those people just dropped dead or some people vanished completely. That's what you saw in that film [The Day After]."
> "It results in death and diseases."
> "There's lots of damage and many people get killed. Even after quite some time people are dying from it."
> "The people, the animals nearby… well, everything really [will have to deal with it]. People will be contaminated with it and if you stand by too close, you will be completely… well, swept away really. And yes, after quite some years it will still give trouble to the animals and people. They will all fall ill, develop cancer or whatever, who knows also skin diseases, pregnant women will give birth to deformed children. They all will fall ill and… well, will not live much longer."

One pupil noted about possible protection measures:

> "[You might be able to protect yourself] if you had a room with very thick lead walls, that would help. But if you were to go out afterwards, it wouldn't help no more because that radiation will still be there. It would be weaker after a couple of years, but still rather high."

Irradiation of food

With one group I talked about irradiation of food. My first question was whether they had ever heard about irradiation of food. The pupils reacted immediately:

> "Yes. Spinach, and things like that. A couple of years ago we weren't allowed to eat spinach, because it was contaminated by irradiation [the other pupil adds: Chernobyl].

> [That means that] there is radiation… well, that was… some very dangerous substances were inside, so that was harmful for your body. The radiation was simply in the ground, I think, or had gone into the ground with the water and had thus come into the vegetables. I believe [those substances are the radiation], yes."

I continued by noting that I did not mean to talk about Chernobyl but rather about a factory where food is irradiated, one of the pupils again reacted immediately:

> "I know that. I believe with oranges, or something like that, to keep them for a longer time."

After I had shown a picture of a food irradiating room, in which carts containing potatoes rotated around a radioactive source, one of the pupils asked whether the potatoes that are at the bottom of the cart are also being irradiated. The other pupil answered:

> "Well, the radiation goes right through."

About what happens with the radiation after irradiation, the pupils told the following.

> "[When the food is irradiated,] the radiation will remain inside, maybe for some years. But it decreases. I do think the radiation simply gets weaker."

When asked whether they would eat irradiated food, the pupils said the following.

> "If the radiation gets too strong… too much radiation, perhaps in the potatoes or in the other food, I don't think that's a very nice idea, because too much radiation is not good for your body. If you eat it [irradiated food], it [the radiation] will simply end up… well, I don't know exactly where it will end up inside your body, but it will simply end up inside your body. And you're only supposed to get such-and-such a permillage or so inside your body. Well anyhow, you'd better not have too much, of course. I mean, I would eat as few irradiated food as possible actually."
>
> "Eating irradiated food doesn't sound like a good idea to me. Maybe an accident has happened in that factory. Certain harmful substances might be in the food and then you will get… well, infections or whatever, all kinds of lumps on your skin. It doesn't sound like a good idea at all."

Radioactive waste

In two groups the topic of radioactive waste was discussed. Both groups agreed that it has got to do with radioactivity and radioactive radiation.

> "[Radioactive waste] comes from nuclear power stations."
>
> "[Radioactive waste has got to do with radioactive radiation,] because of those factories. They illegally dump that waste somewhere. The poison gets into the ground, spreads and then you automatically have it in some residential district. You are irradiated and get diseases."

The pupils made some remarks on the sources and properties of radiation, for instance when asked what would be seen if a vessel of radioactive waste were to be opened.

> "[If you opened a radioactive waste vessel,] you would perhaps see some luminous stuff. That was recently on television. A father had brought his daughter some luminous stuff, which later turned out to be radioactive. I think something like that would also be in those vessels."
>
> "If you were to open a vessel of radioactive waste,] I don't think that there would be that much to see, really. I wouldn't know what it looks like. Oil, I think, or something

like that, something oily. I think that that will be the radioactive. Not just radiation, it seems to me that it would be hard to put that inside such a vessel. I think the radiation is in that waste, in that oil."

"Sometimes you hear that an accident has happened with some ship, that something radioactive is leaking. So that would be fluid."

"There is fluid and there is gaseous… perhaps that the vapours also come off. I think the radiation is a kind of vapour that comes off. It soaks in your body, which slowly dies off, and kills cells."

"[Whether poison and radiation are the same thing or different] depends on how you look at it. It can be in powder form, it can also be fluid, but I think it can also be radiation. I think radiation is rather some sort of gaseous… I don't know how to explain. At any rate, you can't see it and well… look, otherwise you could have seen the radioactive radiation in the air, but as far as I know you can't see it."

The pupils noted the following ways of dealing with radioactive waste and possible consequences thereof.

"They dump it in sea, burn it or store it underground."

"I've heard that they dump it in sea, in iron vessels."

"It mostly happens when a new residential district is built where they used to dump it. The poison comes up and the radiation gets out. That it is released when it rots away."

"In the Rhine, which is that much polluted, you see the fishes floating up to the surface. And that is all because of those radioactive vessels containing radioactive waste."

"[It has to be stored,] because they can't leave it anywhere else. It's much too much. How else are they to do it? [If they didn't store it] it would get into the air and that results in pollution and acid rain. I think all that has got to do with radioactive radiation."

"It will have to be stored for some hundred years, or so. Otherwise they wouldn't have to build those storage spaces: they could simply dump it in sea. After a couple of hundred years, the radiation will be completely gone. As far as I know it's the same as with those nuclear arms. I mean… well, after a couple of hundred years the radiation will have gone, disappeared. I think it is dissolved, or something like that, by… [other pupil: some other cells, or so] Well, I don't know, that it is processed. Just like the trees breathe in foul and breathe out pure oxygen."

"When it is burnt, the radiation just remains in the air. I think that the fluid or solid part is burnt, that its radiation goes into the air and that the solid part then becomes a poison. The radiation spreads and perhaps affects the ozone layer. I think only radiation can do that."

Asked whether it would be wise to come near a vessel of radioactive waste, the pupils replied the following.

"If you're standing near such a vessel, you will be more susceptible to radiation than if you are further away."

"I believe you could come near [a radioactive waste vessel], but it isn't really healthy because of all those things inside."

"I think it doesn't make a difference whether you're nearby or far away. I think they are sealed in such a way that nothing can come out, none of the radiation gets through. Otherwise they might as well store it in open containers or bottles."

Background radiation

In all groups I asked how people can tell whether radioactive radiation is present or not.

> "I believe they can measure it with something, I don't know what."
>
> "There's a certain radiation meter for that purpose, which… with the naked eye you can't… but you can measure it."
>
> "Measure it with a… well, some small device that indicates whenever there is radiation. That device is so sensitive to certain… well, pressure or waves in the air that we cannot see, that it is able to measure it."
>
> "Those scientists investigate that with some device. They've got a small device that indicates whenever there is radiation. It peeps or ticks, or something like that. Geiger ticker or whatever it is called."

When asked whether radioactive radiation can be seen, heard, felt, etc, the pupils said the following.

> "[Radiation] cannot [be seen, heard or felt]."
>
> "In Brazil it was a kind of fluid, so there it could be seen."
>
> "You can't see it, but you can feel it by pain, I think."
>
> "You can't see it, I believe. I think it's just like the air. I believe you can feel it. Well, not really feel it, but you can't stand it. Not really feel it, but notice it because it will cause complaints after a while."
>
> "I think you can perhaps tell from the environment, all the things it does, and so on. Plants, maybe you yourself will get ill, and so on."

After having introduced a Geiger counter as an instrument to measure radioactive radiation, just one of the pupils claimed to be surprised that the counter measured radiation inside the interview room. The others were not surprised. About why radiation is measured, where and when it can be measured and in what amounts, the pupils had quite a lot to say.

> "There's always radiation present. For you've also got that acid rain and things like that, so there's always radiation around you."
>
> "I think it's everywhere, in every house."
>
> "I think there is always a bit in the air, a bit radioactive. You hardly notice it."
>
> "I believe it also came from somewhere else, from the ground. That it was simply in the ground."
>
> "It will probably have been blown with the air from somewhere, from some power station or so, that something had been released and has thus been blown with the air. Maybe it also comes from… well nothing, really, that it's just around you. I don't know where it comes from, it's simply there. It's everywhere, really, but near nuclear power stations there is some more. And in some countries, perhaps also in some cities, it is also somewhat stronger."
>
> "[Wherever you hold the counter, it will measure radiation,] because simply everywhere in the air there is a little bit of radiation. Whether you measure here, in America or on the North Pole, everywhere there is a little bit. Of course at some places it will be stronger than at others. If you were to measure near a factory, it would measure more than here in this room."
>
> "I think that near a nuclear power station it will measure quite a lot. People who work there are well-paid, but they are not allowed to work there for long periods. Otherwise they would get cancer and other diseases. You have to wear those special suits in there because of the radiation. I think it is like at the dentist. That it are lead suits, which stop it, so that the radiation won't enter your body. They are to protect you."
>
> "There's got to be a little bit of radiation. I think it's simply in the air already, just a

> tiny bit, you know. I think that if there hadn't been any people, that then it would have measured even less than it did in this room, just an occasional peep."
> "It has always been in the air. It just gets more and more because of all those companies that use it and simply dump it, and so on, nuclear accidents add some more. It just becomes more and more, but there has always been a bit in the air."
> "I think there will be more of it outside than inside. The wind carries it along. It comes from those nuclear power stations."
> "It comes from the air. The air is polluted. Or from Chernobyl, it all comes to here and so at first it also has to be in the air."
> "Maybe the accident in Chernobyl has got something to do with it. It might be that there is still a little bit in the air. Maybe the bricks of the school are affected by the rain. Maybe there is still a little bit on them."
> "It's just radiation that is released by some things: experiments or something like that, who knows, with big explosions; nuclear bombs."
> "It probably comes from nuclear power stations. That's where they make all those things, those nuclear…"
> "I've never heard that it comes from the ground. Wouldn't they have put it in there themselves?"
> "[If there hadn't been any people,] I don't think [you could have measured radiation. It's man-made.]"

One group discussed whether airing the room would make any difference.

> "Airing the room won't have any effect, because the radiation usually stays behind. If you were to open the window, it wouldn't decrease that much, I think. The radiation goes through everything, through glass, through everything. So it doesn't really matter whether the window is opened or closed."
> "It goes a bit faster if you air the room, because then it is aided. The wind blows through the room and takes along the radioactivity."
> "A bit might be taken along, but not everything. Only in due course it completely runs out, so I don't think that everything will go away at once."

About the possible consequences of background radiation, finally, the pupils said the following.

> "If there's too much of it, [it could do harm. But like it is here in this room,] I think it doesn't."
> "In this room it is so little, that it hardly does any harm."
> "There is always a bit in the air. If it's not too much, it won't be harmful for the environment, I think. Maybe that's natural, that it has also been around in earlier times."
> "This isn't something to really get… so little radiation. Some of the substances inside your body still will be able to handle it and break it down."

2.4.3 Comparison to Eijkelhof's findings

By reading pages 74 to 84 of Eijkelhof's thesis (1990), one might most easily convince oneself of the similarity between the utterances of middle ability pupils that are presented above and the utterances of the senior high school pupils that were interviewed in his interview study. Below, I limit myself to a rough comparison.

The middle ability pupils also associate radioactive radiation with light (very intense light, laser beams), gas or poison. In all sorts of situations they also talk about radiation/radioactivity/substances being carried along by the wind; lingering in the air; getting into the ground, food, animals, people, etc; remaining for a while in all sorts of objects; wearing off in the long run; being broken down by (some substances in) the human body; being able to pass through anything; being stopped by screens, lead walls or special suits; having severe and long-term effects (death, cancer, deformed children, etc).

There are also some differences between the middle ability pupils' and the senior high school pupils' utterances. As might be expected, the senior high school pupils tended to more frequently use scientific words ('atom,' 'molecule,' 'DNA,' 'wavelength'). Secondly, the middle ability pupils more frequently tended to associate radioactive radiation with things like acid rain, the ozone layer, and pollution of the air and rivers.

2.5 Interpreting pupils' utterances

2.5.1 Task and method

The task I now face is to solve the problem of interpretation that has been mentioned in section 2.2: we know what sentences the 'mean' middle ability pupil holds true (the utterances that are presented in section 2.4), and we want to know what (s)he means and believes. To solve the problem of interpretation we need a method for separating the contributions of meaning and belief to the utterances held true.

> What matters is this: if all we know is what sentences a speaker holds true, and we cannot assume that his language is our own [that he uses his words as we do, KK], then we cannot take even a first step toward interpretation without knowing or assuming a great deal about the speaker's beliefs. Since knowledge of beliefs comes only with the ability to interpret words, the only possibility at the start is to assume general agreement on beliefs. ... The guiding policy is to do this as far as possible, subject to considerations of simplicity, hunches about the effects of social conditioning, and of course our common-sense, or scientific, knowledge of explicable error.
>
> The method is not designed to eliminate disagreement, nor can it; its purpose is to make meaningful disagreement possible, and this depends entirely on a foundation - *some* foundation- in agreement. (Davidson, 1984a, p.196-197)

Towards the end of section 2.2.3 I already noted that in the case at hand pupils' utterances are such that one cannot relatively easily work one's way into their belief system by recourse to events that occurred or objects that pupils handled with during the interviews, because the interviews mainly involved verbal talk about situations having to do with radioactivity (the Chernobyl accident, X-ray photography, etc). I then also suggested another strategy to match patterns of beliefs, namely on a fairly general level. In order to secure agreement on general matters as well as possible, I think it is appropriate to identify pupils' beliefs within a familiar pattern of general commonsense knowledge concerning the way that something may affect (harm) something else. Below I first argue why such a pattern forms an appropriate background to interpret pupils' utterances. Against this background I subsequently try to intelligibly attribute particular beliefs about radioactivity to pupils and to explain erroneous beliefs.

2.5.2 Interpreting pupils' utterances against an appropriate background of general commonsense knowledge

What is best known about 'things having to do with radioactivity,' and what generally makes them controversial subjects of public debate, are the harmful effects that they may have, in particular to people. As is clear from section 2.4, pupils too are quite aware of, emphasize, and even exaggerate to some extent, the severe and/or long-term effects: death, cancer, all sorts of diseases, deformed children, acid rain, etc. I think this effect-oriented emphasis in their utterances justifies an attempt to interpret their utterances within a general pattern that serves to explain how things are affected and how it can (to some extent) be prevented that things get affected. The basic notions in this general pattern, which Anderson (1986) has called the experiential gestalt of causation and diSessa (1988) a commonsense version of Ohm's Law, are those of an *affector*, an *instrument* and a *resistance*. The basic ways in which these notions are related are the following:

- an affector harms an object by means of an instrument;
- if the affector is counteracted by a resistance, the object will be less affected.

Furthermore, there are also some obvious semi-quantitative relations involving these notions:

- the stronger the affector is, the more the object is affected;
- the longer the affector harms an object, the more the object is affected;
- the more affectors harm an object, the more the object is affected;
- the nearer the agent is to an object, the more the object is affected;
- the greater the resistance is, the less the object is affected.

In order to make an attempt to relate pupils' utterances to this pattern, a good place to start is with what they have to say about factors influencing the effects. Here are some examples.

> "With such an X-ray machine you've only got a bit, but at the time of Chernobyl, that was quite a lot. There the people in the neighbourhood simply died after a couple of minutes. I think much more radiation was released there. It got into almost everything in large amounts."
> "If you're standing near such a vessel, you will be more susceptible to radiation than if you are further away."
> "I think it doesn't make a difference whether you're nearby or far away. I think they [radioactive waste vessels] are sealed in such a way that nothing can come out, none of the radiation gets through."
> "The wall [behind which the nurse stands] does help. In there it's not that much, of course. At the time of Chernobyl, it went right through the walls. But of course that was much more. Here the wall will stop it, I think."
> "[The nurse stands behind a screen] because if she has to do that [making X-rays] every day, then of course she would get... and since some radiation is released or is brought into contact with her, then of course she would get quite a lot inside."
> "You shouldn't take X-rays too often, because then you can get cancer."
> "The more you get, the worse the disease will be."
> "People who work there [in nuclear power stations] are well-paid, but they are not

> allowed to work there for long periods. Otherwise they would get cancer and other diseases. You have to wear those special suits in there because of the radiation. I think it is like at the dentist. That it are lead suits, which stop it, so that the radiation won't enter your body. They are to protect you."

I suggest to think of X-ray machines, radiation therapy devices, nuclear power stations, radioactive waste vessels and Chernobyl as affectors. Somehow they are affecting people, especially the people in the neighbourhood. The reason that they affect people seems to be that something (in the quotes above it is called 'radiation' or 'it') enters them, gets inside. I suggest to think of this *something harmful that gets inside the object* as the instrument. The more of the instrument you get inside, the worse the disease will be. Chernobyl is a stronger affector than an X-ray machine, because it has released more radiation, which has gone into almost everything in large amounts. So it seems likely to think of an affector as something that releases the instrument. Being near an affector for too long periods (working in a nuclear power station) and having to do many times with an affector (taking or making many X-rays) increase the chances of getting cancer and other diseases. But there are also means to reduce the effects, even if you are very near to the affector: sealing the affector in such a way that the instrument cannot escape (and so cannot enter your body), or preventing the instrument to get into your body by wearing special suits or standing behind a wall or a screen. I suggest to think of something that prevents the instrument of entering the object as a resistance. If the affector is very strong (as in the case of Chernobyl), the resistance will hardly give any protection. I think that the notion of resistance also applies to the following utterances:

> "I think [that after irradiation the radiation] will also be broken down by some substance, because some people don't get complaints while others do. So maybe in some people it isn't broken down because they haven't got enough substances of some sort."
>
> "This isn't something to really get… so little radiation. Some of the substances inside your body still will be able to handle it and break it down."

Here the effects are reduced, not by preventing the instrument to enter the body, but by breaking down the instrument when it is already inside the body (and thus already affecting the body). So I suggest to broaden the above description of a resistance a bit, and to think of it as *something that counteracts the instrument*, either by preventing it to enter the object or by counteracting it when it is already inside the object.

I think it is also appropriate to use, instead of the above notion of an affector, the somewhat broader notion of a *potential affector*. I suggest to think of the latter notion as applying to *something because of which the instrument might get into the object*. (Clearly an affector, in the above sense of 'something that releases the instrument,' is a potential affector.) The reason for introducing the notion of a potential affector is that it enables me to understand some of pupils' utterances about irradiated food on the same par as those about Chernobyl, X-ray machines, etc.

> "[When the food is irradiated,] the radiation will remain inside, maybe for some years."
>
> "Too much radiation, perhaps in the potatoes or in the other food, I don't think that's a very nice idea, because too much radiation is not good for your body. If you eat it [irradiated food], it [the radiation] will simply end up… well, I don't know exactly where it will end up inside your body, but it will simply end up inside your body. And you're only supposed to get such-and-such a permillage or so inside your body. Well

> anyhow, you'd better not have too much, of course. I mean, I would eat as few irradiated food as possible actually."
> "Eating irradiated food doesn't sound like a good idea to me. Maybe an accident has happened in that factory. Certain harmful substances might be in the food and then you will get… well, infections or whatever, all kinds of lumps on your skin. It doesn't sound like a good idea at all."

The irradiated food contains the instrument ('radiation,' 'it,' 'harmful substances'), and by eating the food we get the instrument inside. And the more affectors harm an object (the more irradiated food a person eats), the more the object is affected. According to the above description, irradiated food is a potential affector just like, e.g., Chernobyl, an X-ray machine or radioactive waste.

> "A nuclear power station was somewhat overheated, or so, I'm not sure, but at any rate there had been a fire and so all that radiation was released into the air."
> "It is in X-ray machines, I don't know exactly what."
> "It seems to me that it would be hard to put that [radiation] inside such a vessel. I think the radiation is in that waste, in that oil."

Given the new formulation of potential affector, it is clear that pupils' descriptions of how an affector harms an object are stories that describe how the instrument got from the affector into the object.

> "From the grass and several cows we discovered that there was also more radiation on the things here [in The Netherlands]. It all came from Chernobyl. It was carried by the wind and drifted towards us."
> "I think it simply mingles with the air and when it rains -it also mingles with the rain- it comes down and ends up in the ground."
> "Even here there were vegetables we were not supposed to… It goes all over the world. It spreads out over all countries and it ends up in the ground. It gets into the ground."
> "A couple of years ago we weren't allowed to eat spinach, because it was contaminated by irradiation. [That means that] there is radiation… well, that was… some very dangerous substances were inside, so that was harmful for your body. The radiation was simply in the ground, I think, or had gone into the ground with the water and had thus come into the vegetables. I believe [those substances are the radiation], yes."

Above I have written about an object being affected, because of something (the instrument) being inside it. The following utterances amplify this point.

> "I think the radiation is a kind of vapour that comes off. It soaks in your body, which slowly dies off, and kills cells."
> "I think [that after irradiation the radiation] just remains inside [your body,] and that the radiation just kills some cells, or so, inside your body."
> "[When an X-ray is taken,] part of the radiation falls into your skin, otherwise those diseases couldn't come up. If it didn't get into your skin, I think you wouldn't get diseases from it."
> "In some people it lingers and… if one person is irradiated he will get nothing while some other will get, let's say, a headache… I'm not sure, but maybe it lingers in some people and doesn't in others."

This suggests the belief that *the object is affected as long as the instrument is present in the object*. This is not only a plausible belief, it is also consistent with the idea that after irradiation some people get complaints because they have not got substances that break down the instrument. And given that effects may show up after some time (in some cases even after several years), it is plausible to assume that the instrument lingers for some time.

As regards the instrument itself, the pupils are less clear. It is referred to in several ways: '(radioactive) radiation,' 'X rays,' 'it,' 'radioactivity,' 'small particles of the radiation,' 'harmful/dangerous substances.' Below are some of the more recurrent things that pupils say about the instrument. (Context-dependent properties such as 'making visible cracks in bones,' 'destroying tumours,' 'keeping oranges for a longer time' or 'something luminous people rubbed on their skins' are omitted.)

> "Just a little bit of it immediately kills you."
>
> "[Cancer] is the main disease caused by the radiation. I believe you can get cancer from it and quite a lot of diseases."
>
> "I think you can perhaps tell from the environment, all the things it does, and so on. Plants, maybe you yourself will get ill, and so on."
>
> "The radiation spreads and perhaps affects the ozone layer. I think only radiation can do that."
>
> "You can't see it, I believe. I think it's just like the air. I believe you can feel it. Well, not really feel it, but you can't stand it. Not really feel it, but notice it because it will cause complaints after a while."
>
> "[X rays can be compared to] a gas. You don't see them and they're dangerous, aren't they, if you get too much on you; and a gas is the same, really: you don't see it and it's also dangerous."
>
> "It [poison] can be in powder form, it can also be fluid, but I think it can also be radiation. I think radiation is rather some sort of gaseous… I don't know how to explain. At any rate, you can't see it and well… look, otherwise you could have seen the radioactive radiation in the air, but as far as I know you can't see it."
>
> "It is very light. I don't know, a kind of gas, or so, gaseous. It's neither fluid nor solid."
>
> "It is transparent. You don't see it at all."
>
> "I think it would be possible to see them [X rays], but you're simply not supposed to look at them."
>
> "I think X rays have something to do with ultraviolet, because ultraviolet also goes right through your body."
>
> "I think they [laser beams] can be compared to X rays, because you can make it shine right through a person and you can also do that with radioactive radiation."
>
> "The radiation goes through everything, through glass, through everything."

So apart from being an instrument, something harmful that gets inside the object, some other attributed properties seem to be invisibility (or at least: not to be looked at), transportability and power of penetration. Furthermore, most pupils know that it can be measured with some suitable device. In the sequel I will denote the instrument that is involved in situations having to do with radioactivity by 'radiation*.' (This notation is chosen, because most often the pupils use the word 'radiation' to refer to the instrument that is involved in situations having to do with radioactivity. The asterisk is attached to indicate that radiation experts refer to something different when they use the word 'radiation.') Because of properties like invisibility it is understandable that the pupils have no clear picture of radiation* and often compare it to other mysterious things like gas or a laser beam.

2.5.3 Reflection on the interpretation

I think to have covered most of pupils' utterances in section 2.4 by viewing those as instances of a familiar pattern of general commonsense knowledge concerning the way that something may affect (harm) something else. To summarize:

- an affector harms an object by means of an instrument;
- the instrument (radiation*) is something harmful that gets inside the object;
- radiation* is invisible, transportable and penetrating;
- the object is affected as long as radiation* is present in the object;
- a potential affector is something because of which radiation* might get into the object (e.g. Chernobyl, an X-ray machine, radioactive waste, irradiated food, etc);
- the effects may be reduced by a resistance: something that counteracts the radiation*, either by preventing it to enter the object (e.g. lead, walls, special suits) or by counteracting it when it is already inside the object (e.g. substances in the body that break it down).

Furthermore, some general semi-quantitative relations apply: the stronger the affector is, the more the object is affected; the longer the affector harms the object, the more the object is affected; the more affectors harm an object, the more the object is affected; the nearer the affector is to the object, the more the object is affected; the greater the resistance, the less the object is affected.

I think that two often recurring types of utterances are not yet covered. They correspond to beliefs that are not incorporated in the above pattern of beliefs, but which can easily be added to it. One is the belief that the *radiation* itself gets weaker in the course of time*, which can be supported by the following utterances.

> "[When an X-ray is taken] small particles of the radiation get into your body and later it wears off a bit. Just like a kind of gas that wears off after a couple of years."
> "It simply wears off. I think you might compare it to a battery, or so. A battery also wears off."
> "It simply has some sort of force inside, which decreases sooner or later."
> "It just weakens in the end. Every year such-and-such weaker. I don't know exactly... it just gets weaker."
> "[You might be able to protect yourself] if you had a room with very thick lead walls, that would help. But if you were to go out afterwards, it wouldn't help no more because that radiation will still be there. It would be weaker after a couple of years, but still rather high."
> "[When the food is irradiated,] the radiation will remain inside, maybe for some years. But it decreases. I do think the radiation simply gets weaker."
> "[When airing a room,] a bit might be taken along, but not everything. Only in due course it completely runs out, so I don't think that everything will go away at once."

The idea that radiation* gets weaker in the course of time, seems to be a particular case of what diSessa (1988) has generally called 'dying away' -the idea that "sounds, motion, and so on, all *die away* of their own accord" and of which he mentions the sound of a struck bell as a prototypical circumstance.

The other type of utterances that is not yet covered corresponds to the belief that some radiation* does not come from one affector or another: *natural radiation**. It might be supported by the following utterances.

> "It will probably have been blown with the air from somewhere, from some power station or so, that something had been released and has thus been blown with the air. Maybe it also comes from… well nothing, really, that it's just around you. I don't know where it comes from, it's simply there."
>
> "There's got to be a little bit of radiation. I think it's simply in the air already, just a tiny bit, you know. I think that if there hadn't been any people, that then it would have measured even less than it did in this room, just an occasional peep."
>
> "There is always a bit in the air. If it's not too much, it won't be harmful for the environment, I think. Maybe that's natural, that it has also been around in earlier times."

I propose that the above may serve as a general belief structure that accounts for the 'mean' pupil's utterances about situations having to do with radioactivity. I think some closing remarks are appropriate. First, the above is just a general belief structure and there may be differences between pupils as far as the details are concerned. There may for instance be differences as to how a wall acts as a resistance: the radiation* glances off the wall, the radiation* remains in the wall, etc. I think these kinds of idiosyncratic differences are not very essential for an understanding of the 'mean' pupil. At any rate, these differences are now understandable against a common background.

Secondly, the general belief structure is to be understood in relation to pragmatic everyday life purposes and values. It reflects and guides people's thoughts and actions in reaching a sufficient feeling of safety and maintaining good health. One might even say that it leads to over-cautious behaviour, for instance by preferring not to eat irradiated food because of the radiation* inside (because it is a potential affector). But not eating irradiated food will not do any harm (as long as other food is available), like over-cautious behaviour generally will not do much harm. Of course there are exceptions. In The Netherlands, for example, there is the extreme case of a girl that covered herself in plastic after the accident in Chernobyl, did not leave her room and only ate tinned food. Eijkelhof (1990, p.63) also gives some less extreme case-descriptions that had been reported by radiation experts, for example:

> "some workers who look after animals which are irradiated by X rays in experimental settings had a feeling of being neglected: they had not been issued dosemeters and did not get regular blood tests in contrast to personnel who irradiate the animals, although the latter personnel had less contact with the animals;"
>
> "the social isolation of an industrial worker who received an extra radiation dose by accident: he was considered by his colleagues and neighbours to be suffering from 'radioactive contamination'."

Thirdly, the above interpretation solves the problems I have reported in section 2.3 when discussing Eijkelhof's findings. I can now understand pupils' use of words like 'having,' 'containing,' 'handing over' and 'accumulating' in connection with radiation and radioactivity. These words naturally figure in stories that describe how the instrument (radiation*) got from the potential affector into the object. Pupils' indiscriminate use of words like 'contaminated,' 'irradiated' and 'containing radiation' is understandable by interpreting these words as referring to the condition that the instrument (radiation*) is inside the object. Eijkelhof's tentative conclusion that pupils "seem to have 'conservation' ideas about radiation" can be justified by referring to the belief that the object is affected as long as the radiation* is present in the object, which has a natural place in the pattern of beliefs. I now do not have any trouble in interpreting words like 'radiation,' 'it,' 'radioactivity,' 'small particles of the radiation,' 'harmful/dangerous substances,' of which Eijkelhof notes that they seem to be used in an undifferentiated manner, as referring to one and the same thing: radiation*, i.e. the one and only instrument that is involved in situations having to do with radioactivity.

Finally one might ask whether the above is a correct (or even the unique) interpretation of pupils' utterances. To ask for uniqueness would be to ask for too much. There will remain some trade-offs between the beliefs we attribute to pupils and the meanings we give to their words. However, by trying to interpret the pupils against the background of a coherent pattern of beliefs, I hope to have limited down the resulting indeterminacy, at least on major points, to a degree sufficient for establishing successful communication and for initiating successful learning. And I want nothing more than just that. Since the above interpretation is used in the construction of classroom interventions (see chapters 6 and 8), the adequacy of my interpretation will indirectly be tested in the evaluation of those interventions (see chapters 7 and 9).

3 Orientation towards traditional treatments of the topic of radioactivity

We might ask ourselves whether [the] idea
of a particle as a physical reality is
self-evidently the starting point to learners.
Ten Voorde (1990)

3.1 Introduction

In chapter 1 I have noted that if one wants to link up with pupils' pre-instructional beliefs, it seems inappropriate to begin a treatment of the topic of radioactivity with a presentation of atomic and nuclear models. This point may be amplified by the findings presented in chapter 2, from which it is clear that knowledge at the particle level (if present at all) hardly plays any role in pupils' reasoning about situations having to do with radioactivity. In chapter 1 I have also noted that already at the beginning of my PhD-study I had set the aim of devising a unit about radioactivity that does not start with micro-level explanations. My reasons for setting this aim and believing in its viability were inspired by the work of ten Voorde (e.g., 1990), who developed a chemistry course in which pupils eventually come to describe chemical reactions in terms of rearrangements of chemical elements, but in which micro-level explanations play no role.

Before I started working on this aim I had also studied current units on the topic of radioactivity. In this chapter I will report some of the findings. In section 3.2 I point out that there seems to be some sort of consensus as to how to teach the topic of radioactivity. Current units on the topic of radioactivity all more or less have the same general structure, and descriptions and explanations in submicroscopic (nuclear) terms are predominant in all of them, from the beginning to the end. As I will also try to make plausible, this consensus seems to be there because it is considered to be self-evident that if one wants to teach about radioactivity, one should introduce as quickly as possible some kind of particle model in terms of which radioactive processes are subsequently to be introduced. That is, it is not really considered whether perhaps it could be done differently. This finding strengthened my above mentioned aim of trying to do it differently.

The aim was also strengthened as a result of studying whether and how, in a unit about the topic of radioactivity that is based upon micro-level descriptions and explanations, the latter actually contribute to an understanding of radioactive phenomena. These contributions are not impressive, as I will try to illustrate in section 3.3, both by anecdotically describing some class observations and by reflecting on the use of micro-level knowledge about radioactive processes to an understanding of, for instance, the difference in danger between a situation in which something is contaminated and a situation in which something is irradiated.

I conclude with briefly mentioning some possibilities for designing a unit on the topic of radioactivity that does not start with micro-level explanations but rather ends with them.[1)]

3.2 The tendency to self-evidently base a treatment of the topic of radioactivity upon micro-level explanations

I do not know of any Dutch unit on the topic of radioactivity that is not structured essentially as sketched below. From colleagues abroad I have heard that the situation is pretty much the same in other countries. So I assume that anybody who knows the secondary school curriculum of physics will immediately recognize the following structure.

1. A nuclear model is presented as an extension of molecular and atomic models:
   - introduction of the basic submicroscopic entities and some of their properties: nucleus, electron, proton, neutron, atomic number, mass number, isotope.
2. The process of radioactivity and the properties of radioactive matter and the radiation it emits are described in terms of these submicroscopic entities:
   - radioactive process: unstable nucleus → new nucleus + radiation;
   - nature and properties of radioactive matter: it consists of unstable nuclei; activity is the number of decaying nuclei per second; half-life is the time after which half of the unstable nuclei have decayed;
   - nature and properties of the different kinds of radiation: alpha-radiation consists of helium nuclei (2p/2n); beta-radiation consists of electrons; gamma-radiation is a form of electromagnetic radiation.
3. A treatment of the effects of radiation (also in microscopic terms):
   - ionization, radical formation, damage to cells.
4. A treatment of relevant everyday life situations involving radioactivity: background radiation, nuclear energy, radiation in medicine, nuclear arms, use of radiation in industry and agriculture.

This general structure has not been altered by the recent shift towards 'contextual physics' or 'physics in contexts' (cf Yager, 1992, on the status of this shift). It e.g. also applies to the way the topic of radioactivity is treated in the PLON-curriculum, which aims to promote a broad scientific literacy amongst pupils and in which the topic is included because it is a subject of public debate (important applications concern health, energy supply and defence) and is surrounded by controversy (associations with danger). The main difference between the PLON-unit *Ionizing Radiation* (PLON, 1984, 1988) and more traditional units is that the effects and applications (3 and 4 in the above structure) are given much more attention (cf Eijkelhof, 1990, pp.24-27). The general structure was also not altered when in 1987 in my country the topic of radioactivity was included in the syllabus for the middle ability streams. This may be illustrated by figure 3.1. It shows the table of contents of an exemplar-unit on the topic of radioactivity that was then specially devised for middle ability pupils: *Radiation, you cannot avoid it...* (Knoester & Lancel, 1988).

1. See Klaassen *et al* (1990) and Millar *et al* (1990) for some preliminary ideas about the subject of this chapter.

1 Why radiation and radioactivity? (1)
1.1 Working with this unit
2 On atoms (2)
2.1 What is an atom?
2.2 What does an atom 'look' like?
2.3 Different atoms
2.4 What does the nucleus look like?
2.5 How 'empty' is an atom?
2.6 Summary
2.7 Exercises
3 Sources of radiation (2)
3.1 One kind of atom with different nuclei
3.2 Nuclei can change
3.3 The amount of radiation from a substance
3.4 How fast does the activity decrease?
3.5 Summary
3.6 Exercises
4 Nuclear radiation (1)
4.1 Different kinds of radiation
4.2 Properties of nuclear radiation
4.3 Where does the radiation go?
4.4 Making visible nuclear radiation
4.5 Summary
4.6 Exercises
5 Receiving radiation: dangerous or not? (2)
5.1 Damage to cells
5.2 Internal irradiation
5.3 How much radiation can a man stand?
5.4 How much radiation does a man get?
5.5 Protection against radiation
5.6 Summary
5.7 Exercises
6 Use of radiation (2)
6.1 Radiation is everywhere in nature
6.2 Radiation in health care
6.3 Industrial use of radiation
6.4 Radiation after a nuclear explosion
6.5 Nuclear waste
6.6 Irradiation of food

Figure 3.1 Table of contents of the unit *Radiation, you cannot avoid it....* (The numbers between parentheses represent the number of 50 minute periods that are devoted to a chapter.)

I conclude that there is a wide-spread tradition of teaching the topic of radioactivity as applied basic nuclear physics. I even think that, perhaps as a result of this tradition, there is a tendency to self-evidently associate the topic of radioactivity with nuclear models. The following example is meant to illustrate this tendency. Let me begin with some background information. In 1988 the then Minister of Education and Science of the Netherlands installed thirteen committees, which were to devise a national curriculum for the first three years of secondary education ('basisvorming:' basic education). The committees, one for every subject in 'basic education,' were given the task of proposing attainment targets on two levels: a general level and a higher level. The idea behind the two levels was that the number of subjects a pupil did on the higher level would determine which stream (lower, middle, higher, pre-university) the pupil would flow into after 'basic education.' In formulating the attainment targets for physics/chemistry, one of the subjects in 'basic education,' the committee for physics/chemistry was also instructed to pay special attention to the relations between physics, chemistry and everyday life contexts and applications. To that end the committee proposed ten so-called context-domains, in each of which attainment targets (on two levels) were formulated (Eindtermencommissie natuur- en scheikunde, 1989). Examples of proposed context-domains are: use of water; substances and materials at home; electrical energy at home; forces and safety; radiation and protection against radiation. The attainments targets within the latter context-domain are given in figure 3.2.

General level	Higher level	Concepts
Ionizing radiation		
1 different sources of radiation	*the annual radiation dose (in mSv) from the different sources*	radioactivity cosmic radiation; radioactive substances in the soil, building materials, food, water, air; X-ray machines
2 four kinds of radiation with different penetrating power	*nature of the four kinds of radiation: He-nucleus, electron, electromagnetic radiation*	α, ß, γ and X rays
3	*description of radioactive decay in terms of changing unstable nuclei* *activity and its unit becquerel (Bq); activity-time-diagrams* *determination of the half-life of a radioactive substance from an activity-time-diagram*	
4 possible effects of radiation on organisms: damage, induction of cancer, death	*relation between dose (in Sv) and consequences for the human body*	radiation effects, radiation sickness
Use of radiation		
5 difference between irradiation and contamination		examples of open and closed sources
6 purposes and methods of use of sources of radiation in health care		X-rays, tracers, internal and external sources of radiation
7 examples of protective measures against radiation and the intake of radioactive substances	*relation between the properties of a source of radiation and protective measures*	absorption and penetrating power concrete, lead apron, effect of distance, remote handling, gas masks, intake of iodine
8	*effects of radioactive substances and radiation for people and the environment*	*mean life; waste from nuclear power stations, hospitals and laboratories*
9 measures that can be taken to reduce the effects of radioactive waste and radiation for people and the environment		limited production and use; guarded disposal in for instance salt domes

Figure 3.2 Attainment targets in the context-domain 'radiation and protection against radiation' (Eindtermencommissie natuur- en scheikunde, 1989). The italicized attainment targets apply only to the higher level.

The committee's proposal was distributed across the whole educational field (teachers, inspectors, etc.) with the request to comment on it. To cut a long story short, and to illustrate the above mentioned tendency, the curriculum for physics/chemistry was judged too full (as usual) and something had to be deleted: the context-domain 'radiation and protection against radiation.' One of the decisive reasons for the deletion of precisely that context-domain were the many protests of teachers who argued that the topic is far too abstract for especially the 'weaker' pupils, because it involves rather theoretical notions like nuclear models, etc. As the reader will probably already have noticed, the attainment targets of the general level, which would apply to the 'weaker' pupils, do not mention abstract and theoretical notions like nuclear models at all.[2)] The only thing I can conclude is that for the protesting teachers the topic of 'radiation' was so self-evidently associated with 'abstract' and 'theoretical' that they did not bother to read the attainment targets for the general level, or, if they did read them, did not notice that those attainment targets do not mention atoms, nuclei, etc., or, if they did notice that, could not think of any other way to attain those targets than by teaching about atoms, nuclei, etc. So if I succeeded in showing that it is possible to meaningfully teach about radioactivity without having to teach about atoms, nuclei, etc first, I would at least have brought such largely unquestioned associations up for discussion.

3.3 Does a treatment based upon micro-level explanations contribute to an understanding of radioactive phenomena?

3.3.1 Some class observations

My aim of devising a unit on the topic of radioactivity that is not based upon micro-level explanations was further strengthened when I had observed, towards the beginning of my PhD-study, two series of lessons in middle ability classes that used the unit *Radiation, you cannot avoid it...* (Knoester & Lancel, 1988). Below, I rather anecdotically describe some findings of the observations.

As already noted, the unit has the familiar structure described in section 3.2. It begins with an introductory chapter, in which the importance of knowing something about radioactivity to understand e.g. the Chernobyl accident is emphasized. It is followed by a chapter called 'On atoms,' which contains a direct presentation of the hierarchical structure of matter along the lines of figure 3.3 (which is taken from the unit).

It turns out that after two to three 50 minute periods with lots of exercises the pupils succeeded in remembering micro-facts like the following: the constituent parts of an atom are a nucleus and electrons, the constituent parts of a nucleus are protons and neutrons, the atomic number equals the number of protons and the number of electrons, isotopes differ in the number of neutrons, etc. Furthermore, they were generally able to solve problems like the one in figure 3.4.

2. The committee had taken over the advice of Harrie Eijkelhof and myself to not include nuclear models in the attainment targets of the general level. So the fact that those attainment targets do not mention nuclear models does not contradict the tendency that I try to illustrate here.

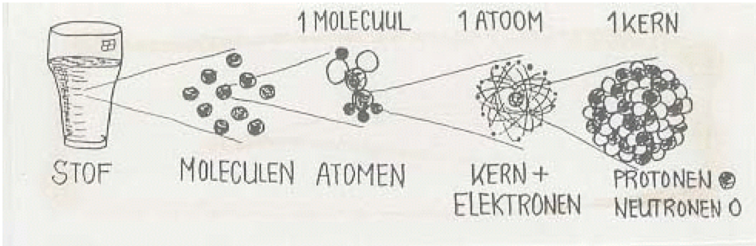

Figure 3.3 From substance ("stof") to protons, neutrons and electrons.

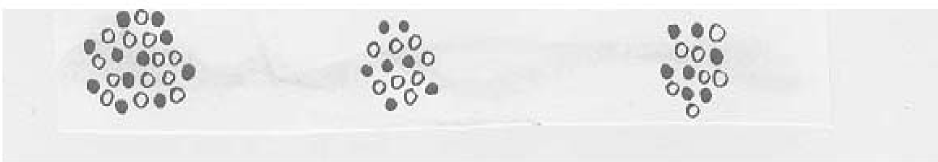

Figure 3.4 Exercise: What is the atomic number and the number of neutrons of the above nuclei?

An obvious consequence of a direct presentation along the above lines is that it makes pupils dependent on the way that things are presented, both verbally and pictorially. E.g., when at the end of the chapter 'On atoms' the teacher in one of the classes noted that protons, electrons, etc cannot be seen, pupils were very surprised to hear that and began asking questions such as: "If they can't be seen, can we then feel them somehow instead?;" "How do we know they exist?;" "How do we know that they look the way they are pictured?" Some pupils commented "So it's all fantasy," or even "So it's all bullshit," and one or two pupils showed that they got some imagination themselves and produced their own 'model:' "Why say that electrons move around the nucleus? They might as well be moving inside the nucleus."

This problem is, of course, well-known and well-documented (see, e.g., de Vos, 1985; Nussbaum, 1985). Given that the (sub)microscopic models are not introduced as specific explanatory systems for macroscopic phenomena, pupils are not made partners in why the models are as they are. They simply are not provided with any other means to reason about the correctness of a model than in terms of whether things really look like they are depicted. Accordingly, they will understand a direct presentation of the hierarchical structure of matter as a story about how things look on an ever smaller scale. The introduced (sub)microscopic entities, moreover, are then often understood by them as small-scale macroscopic objects (cf section 2.2.3).

Now, one may simply accept that pupils are indeed not made partners in why the models are as they are, but nevertheless hold that a direct presentation of those models provides a useful preparation to understanding radioactive phenomena. I think there are also good reasons to doubt the latter. For one thing, when radioactive processes are introduced in micro-terms, pupils' understanding of those processes still very much depends on how things are depicted. This may be illustrated by their reactions to the figures 3.5 and 3.6.

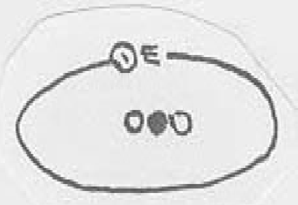

Figure 3.5

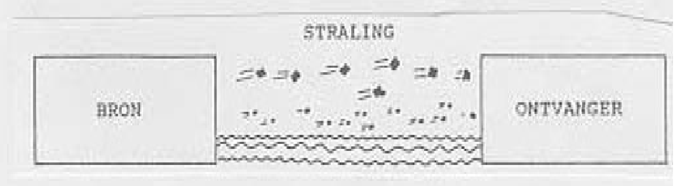

Figure 3.6

Figure 3.5 shows that electrons move in a shell around the nucleus. When later in the unit the pupils were told that some nuclei are unstable and emit radiation, some of them wondered why this radiation is not stopped by the shell around the nucleus (i.e. the solid line around the nucleus). And after having seen figure 3.6, some pupils asked whether radiation is not absorbed by water and what those things flying through the air are. The teacher explained that the waves at the bottom do not represent water but, just like the things above it, a kind of radiation, and added that, of course, the radiation cannot be seen. Some pupils then wondered how one can tell that the kinds of radiation look as depicted.

Some of the introduced (sub)microscopic entities, moreover, seemed to be understood as small-scale macroscopic objects. Some pupils, for instance, said that each individual nucleus gradually loses all its radiation, that half-life is the time in which a nucleus loses half of its radiation, or that unstable nuclei emit radiation as long as they are unstable. This talk makes sense if we understand it as being about small pieces of radioactive material.

I think it also speaks against a direct presentation of (sub)microscopic models as providing a useful preparation to understanding radioactive phenomena that pupils do not experience it as such. During the elaborate treatment of the chapter 'On atoms,' for instance, pupils wondered what molecules, atoms, protons, etc have got to do with what the unit was supposed to be about: radiation (given that the title of the unit is 'Radiation, you cannot avoid it...'). They regularly asked when they would at last start talking about that, and from time to time there even arose quite some friction between teacher and pupils over this. The pupils probably experienced the treatment of the chapter 'On atoms' as an unnecessary postponement of addressing the topic of radiation, which most of them claimed to be interested in. The teacher could only justify the elaborate treatment by saying that 'later on' they would understand what it was for: "It is like learning the rules of a game, which are very dull in themselves, but once you know them and start to play the game it may be great fun."

'Later on' there were indeed some instances where knowledge of micro-facts seemed to be useful to pupils in understanding radioactive phenomena. Given that some unstable nuclei change by emitting a helium nucleus, for instance, a pupil was able to deduce that this gives rise to a new substance "because it hasn't got the same number of plus-things [protons] any longer." But there were also instances in which micro-level descriptions and explanations rather seemed counter-productive. The very same statement, for instance, that some unstable nuclei change by emitting a helium nucleus, for many pupils blurred the distinction between radioactive material as a source of radiation and the radiation itself, because both consist of nuclei. In fact, many pupils interpreted 'nuclear radiation' (as the radiation is called in the unit) as 'radiation that consists of nuclei' rather than as 'radiation that is emitted by nuclei.'

3.3.2 Some reflections on the use of micro-level knowledge about radioactive processes

In this section I argue that, even if pupils understand a direct presentation of micro-level knowledge as intended, this knowledge in itself is of little practical use. For example, in terms of a micro-level description of the radioactive process (e.g., unstable nucleus → new nucleus + electron), one may introduce the notion of radioactive matter as something that contains unstable nuclei. But thus introduced, this notion is no help in establishing whether or not some given object is radioactive. For there are no direct ways to check whether an object contains unstable nuclei, but only indirect ones such as measuring with a Geiger counter.

Furthermore, in terms of the micro-level description 'unstable nucleus → new nucleus + electron,' one may introduce one kind of radiation, beta-radiation, as something that consists of electrons that are emitted in this process. One can then also distinguish between irradiated and contaminated objects: an irradiated object has only received radiation (electrons) while a contaminated object has received radioactive matter (unstable nuclei) as well. Thus introduced, it is clear that a contaminated object, just like radioactive material, emits electrons that may do damage to its surroundings. That is, a contaminated object presents a radiation danger to its surroundings. It is not as straightforward, however, to understand that an irradiated object does not present a radiation danger to its surroundings. For one may argue as follows: an irradiated object has received electrons and those could do damage, e.g. when the object is eaten.[3)] It is of course possible to block this argument by extending the

3. Note that this reasoning is not far-fetched. If we replace 'electrons' by 'radiation*' it is in accordance with pupils' pre-instructional beliefs concerning irradiated food (cf section 2.5).

micro-level description to what happens with the emitted electrons when they get into an object, e.g. along the following lines. Beta-radiation consists of emitted electrons, but emitted electrons as such are not beta-radiation. They are only beta-radiation, and are only able to do damage, as long as they are moving. Some (simplified) mechanism can also be provided: electrons collide with the particles of the object; it are those collisions that cause damage to the object; because of the collisions the electrons lose speed; in the end they come to a stop and will no longer do damage. So if an object is irradiated with beta-radiation there may indeed remain some electrons in the object, but they are standing still and will no longer do any harm -even if the object is, for instance, eaten.

Let me now also call into question the usefulness of this micro-level account of absorption processes for practical purposes. First of all, even though the account is a simplification of the actual absorption processes that take place, it is already rather involved. So I doubt whether it will serve to get across the point of distinguishing between contamination and irradiation. Secondly, the absorption processes occur in just a fraction of a second. And I think that this does not call for an even more involved explanation in terms of particles, but simply for an empirical establishment: once it is emitted, radiation will under normal (non-vacuum) conditions have 'disappeared' almost immediately, in the sense that no radiation will be measured any longer.

3.3.3 Conclusion

I hope to have provided sufficient reasons for not basing a unit about radioactivity upon micro-level descriptions and explanations. I have not yet presented an alternative approach. It is natural, however, that such an alternative approach should aim at an empirical development of a coherent macroscopic description of radioactive phenomena in such terms as 'radioactive matter,' 'radiation,' 'contamination' and 'irradiation.' The approach should somehow include the introduction of empirical criteria for checking the presence of radioactive matter and the establishment of empirical facts like the 'disappearance' of radiation and the relatively localized spreading of radiation.

Furthermore, such an approach might prepare the ground for (or need for) subsequent micro-level explanations for the empirical facts that are already expressed in macroscopic terms. The fact that radiation, once emitted, almost immediately 'disappears,' for instance, might eventually be explained in terms of collisions as has been done above. In chapter 8 the details of an alternative approach will be worked out.

4 Understanding understanding

[T]here could not be thoughts in one mind
if there were no other thoughtful creatures
with which the first mind shared a natural world.
Davidson (1989b)
When thought takes thought as subject matter,
the observer can only identify what he is studying
by finding it rational -that is, in accordance with
his own standards of rationality.
Davidson (1990b)

4.1 Introduction

Understanding, as a human activity we are all engaged in, is in a sense rather unproblematic. We all know that people "think and reason; they consider, test, reject and accept hypotheses; they act on reasons, sometimes after deliberating, imagining consequences and weighing probabilities; they have desires, hopes and hates, often for good reasons. They also make errors in calculation, act against their own best judgement, or accept doctrines on inadequate evidence" (Davidson, 1985c). It are these kinds of accomplishments, activities and errors that set us apart from other animals, and that make us the rational animals we are. Furthermore, "[t]here is no secret about the nature of the evidence we use to decide what other people think: we observe their acts, read their letters, study their expressions, listen to their words, learn their histories, and note their relations to society. How we are able to assemble such material into a convincing picture of a mind is another matter" (Davidson, 1987a).

It is this 'other matter' that is the major subject of this chapter. It is, of course, a matter that has been treated in various ways in various disciplines (philosophy, psychology, neurobiology, etc). I myself am very much attracted to Donald Davidson's approach to the subject, because it answers to my basic intuitions and is rather comprehensive in scope.[1)] Davidson's leading question is: what makes it possible that people come to understand one another? His approach to this question, and the answers he comes up with, have served as a general background and source of inspiration for my thinking about matters relating to science education (as may already have become clear from section 2.2).

Davidson's approach, and the answers he comes up with, depend on his analysis of the

1. This chapter may therefore be read as my understanding of Davidson's philosophy of mind. I do not want to claim that I fully understand Davidson's philosophy as he intends it to be understood, nor that there are no internal tensions in it that will have to be remedied. My aim here is not to try to improve on Davidson's approach but to expose the leading ideas behind it. I am aware, and Davidson would be the first to admit, that many of the basic ideas are not new and can be found in the writings of various people. What is new is the way in which they are explicitly combined into a coherent whole. It is only because Davidson presents the ideas in the light of his coherent whole that in the following I mainly quote Davidson (unless indicated otherwise). I have also profited from lectures that Davidson has delivered in Utrecht and Leuven in the fall of 1994.

special kind of understanding that is involved when two people understand one another. And indeed this kind of understanding is special: for what we are after when we want to understand others, is that we are able to view them as having thoughts about and talking about a world they share with us, as having needs, values, hopes and fears, as acting intentionally to promote their values and as subject to moral evaluation. We want to understand them, and to be understood by them, as endowed with thought and reason, as rational agents, and as intending to be understood as such. So we know beforehand that the question what it is that makes mutual understanding possible *has* an answer, because the nature of thought, speech and intentional action is such as to be made interpretable (understandable). Of course this does not answer the question, but rather asks for a further illumination of the nature of thought, speech and intentional action.

From the fact that the phenomena to be illuminated are social phenomena, it follows that such an illumination must show how it is possible for one person to fathom the thoughts, meanings and actions of another, on the basis of publicly observable behaviour (roughly: on the basis of the other's motions, made noises, and place in the world). This does not entail that thought, meaning and action "can be *defined* in terms of observable behaviour, or that [they are] 'nothing but' observable behaviour; but it does imply that [they are] entirely determined by observable behaviour, even readily observable behaviour" (1990c). That simply is all an interpreter has to go on.

In sections 4.2 and 4.3 I draw attention to some basic ideas about what is involved in, and makes possible, mutual understanding, by discussing some rather simple examples of how we actually do come to understand one another. In section 4.4 I will somewhat further elaborate these ideas and discuss their consequences concerning such issues as the relations between the subjective, the objective and the intersubjective, and between the social and the physical sciences. In appendix 1, finally, I give an indication of how the rather informal account of sections 4.2 and 4.3 can be turned into a serious theory of interpretation. In my opinion this theory, if further developed, will be of important methodological relevance to science educational research, and the social sciences in general.

4.2 Understanding human thought and action

4.2.1 The ineluctability of a sharing of standards of rationality

What is intentional meets minimal standards of rationality

In trying to understand others as rational agents, I want to render them intelligible to me in much the same way as I want to be intelligible to them. I want to understand others as much like myself, as sharing my basic thoughts and values and as answering to basic, and shared, norms of rationality. That I cannot do without norms and even have no choice but to assume that others share my basic norms of rationality, should not be thought of as my lack of imagination or as some authoritarian trait of mine. It simply is an unavoidable consequence of the special kind of understanding that I am trying to reach, namely understanding within the realm of the intentional. In fact, already simply to say of someone that she performed an intentional action is at the same time to declare that she shares minimal norms of rationality with me. For an intentional action is an action done with some intention, and for me to understand it as such there is the minimal requirement that I recognize some value she wants to realize, and a belief that by acting as she does she has some chance of realizing the value. If I say of her, for instance, that she raises her arm with the intention of catching her teacher's attention, she must have wanted to make it the case that she has caught her teacher's attention (no doubt for further reasons), and she must believe that by raising her arm she has some chance of achieving her end. Still, her having this desire and this belief is not enough. She must have gone one step further -in fact so simple a step, that we are apt to miss its subtlety. She must have concluded -from her finding something desirable in it being the case that she has caught her teacher's attention, and her belief that by raising her arm she has some chance of catching her teacher's attention- that there is something desirable about raising her arm. That is, "a belief and a desire explain an action only if the contents of the belief and desire entail that there is something desirable about the action, given the description under which the action is being explained. This entailment marks a normative element, a primitive aspect of rationality" (1987b). So it is rather a matter of definition that what is intentional meets minimal standards of rationality.

Norms and the holistic nature of thought and action

It will be clear that there is more to rationality than just this simple entailment, and I will now discuss some more aspects. The following is not meant, however, as *the* exhaustive and definite list of basic norms of rationality. I just want to give some idea of the kinds of norm that seem to play a role in mutual understanding. What the norms of rationality do is regulate the relations between beliefs, desires, intentional actions, etc; they tell when a collection of beliefs, desires, intentions, etc, are related in such a way that they form a rational set.

An obvious set of regulative principles is given by the *principles of logic*. If I have the belief that it is raining and storming, I also have both the belief that it is raining and the belief that it is storming. If I have the belief that now it is not raining here, I do not have the belief that it is raining here and now. If I believe both that all whales are mammals and that Moby Dick is a whale, I also believe that Moby Dick is a mammal. Or, to put things the other way round: if we understand someone as believing that all whales are mammals, as believing that Moby Dick is a whale, but also as believing that Moby Dick is not a mammal, we somewhere must have misunderstood that person because the set of those three beliefs does not form a rational set. *We* must try again and revise our understanding of that person.

Another principle regulates our choices between courses of action when we see various options. In the case mentioned above, we considered a pupil who raised her arm because she found something desirable in catching her teacher's attention and believed that raising her arm would promote that value. This case illustrates a simple form of reasoning: to conclude from the perceived value of the end to the perceived value of the means. But usually our reasoning is more complicated. We do not normally "perform every action that we believe would promote some good or satisfy some obligation. We don't, if for no other reason that we can't, since acting to promote one good will often prevent our acting to promote some other good. And of course many actions that we know would promote some good we also know would produce much greater evils" (1987b). Let me again take a simple example: buying new clothes. I think we all know the sort of thing that happens: we end up with various pieces of clothing and will have to make a choice. We will take into consideration how well the various pieces fit us, try some combinations, think about whether they combine with clothes we already have, judge their quality, compare their prizes, see how well, young or fashionable we look in them, think about what 'the others' will think of them, ask for a second or third opinion, etc. Usually an endless number of things can be said, and will be said, both for and against each particular piece (or combination of several pieces). But after some period of deliberation in which we weigh the pros and cons (a period that for some people is better measured in hours than in minutes), we usually manage to reach an overall judgement: a judgement that, all things considered, we should buy this or that piece or this or that combination of pieces. (Which overall judgement is reached after the weighing will of course vary from individual to individual, depending on personal taste, budget, etc.) I am now in a position to state the second principle, which Davidson calls the *principle of continence*, and which simply tells us to act on our overall judgement, to act on the judgement based on all the considerations we deem relevant. In the case at hand it tells us to actually buy the clothes that, all things considered, we had judged we should buy.

It will be clear that sometimes we do not act on our own best overall judgement, but I think that in those cases we must confess that we really do not understand, and would have a hard time explaining to someone else, why we acted as we did. Suppose one Friday evening I am on the bus from work to home. Somewhere halfway it suddenly strikes me that I have left a book on my desk, a book that I will probably need for the homework I plan to do during the weekend. I check my suitcase, and indeed: I do not carry the book with me. I do not act impulsively (get off the bus immediately to fetch the book, for example), but sit back and think. I think about the amount of trouble I would have to go through were I to fetch the book: I would have to wait for the bus in the opposite direction; since the building I work in is already closed, I would have to call a security guard to let me in; since I do not carry my ID card with me, I can only hope that the security guard knows me; in fact, if the security guard is not cooperative, I may not even be let in; furthermore, even if all goes well I will get home at least an hour later, and I am already pretty hungry as it is now -and well, perhaps I do not ever come to work this weekend, and even if I do, I will very well be able to carry on without the book. All things considered, I come to the conclusion that I should simply leave the book the book. Still … at the next stop I get off the bus to return to my office and fetch the book. Clearly, this is an irrational act of mine. I go against my own principle. And as an irrational act, it is an act that damages mutual understanding. For suppose that you are a witness of what happens next: you see me get off the bus, wait a quarter of an hour for a bus in the opposite direction, get off near the building I work in, make a telephone call, have a long argument with a security guard, eventually get into the building, take a particular book from my desk, and finally take a bus home. You cannot but conclude that it must have been very important for me to have that book with me during the weekend. And if I honestly were to tell you that … well, it is not really that important … you would be right in saying that it is hard to understand, then, why I went through all that trouble. And I cannot but admit that; I do not understand myself on this occasion.

The principle of continence also plays a role when we consciously choose among possible courses of action in the light of the various consequences each of them may have:

> [W]e value a course of action … because of the value we set on its possible consequences, and how likely we believe those consequences are, given that we perform the action … In choosing among courses of action … therefore, we choose one the relative value of those consequences, when tempered by the likelihood of those consequences, is greatest. Courses of action are usually gambles, since we don't know for certain how things will turn out. So to the extent that we are rational we take what we believe is the best bet available (we 'maximize expected utility'). (1980b)
>
> [This] does not mean that all the ways the [best bet available] may turn out are more desirable than any of the ways the alternatives may turn out, but that the weighted sum of the desirabilities of the outcomes of the chosen course of action is greater than the weighted sum of the desirabilities of the outcomes of any of the alternatives. The 'weights' are, of course, the probabilities [we assign] to the outcomes; in other words, [our] beliefs. (1985d)

The final principle I want to mention is closely related to the principle of continence. Following Carnap and Hempel, Davidson calls it the *principle of total evidence for inductive reasoning*. "[W]hen we are deciding among a set of mutually exclusive hypotheses, this [principle] enjoins us to give credence to the hypothesis most highly supported by all available relevant evidence" (1985a), or to let the degree of belief in each hypothesis depend on the support it gets from all available relevant evidence.[2)]

The need for norms to regulate the relations between beliefs, desires, intentional actions, etc, is related to the holistic nature of beliefs, desires, intentions, etc. To have (or to attribute) one belief, desire or intention, is to have (or to attribute) a whole array of them. Simply to have the intention to go to the cinema tomorrow evening, for instance, already presupposes lots of other things. I must know what a cinema is. I must see my way clear into reaching the cinema that I intend to go to. I may have read a review of the film that is on at the cinema. That review may have given me the idea that I am going to like the film. The expected enjoyment is in fact one of my reasons for intending to go to the cinema. I must not have other plans, or have made other appointments, for tomorrow evening. I will have to know how late the film starts and how long it will take me to get from my home to the cinema. Perhaps I also judge that it would be best to make a reservation, because tomorrow is Friday and I want to be sure that… and so on, and so on. (I do not want to say, of course, that having the intention to go to the

2. Note that thus formulated, this principle not only applies to inductive reasoning, but e.g. also to solving a murder mystery.

cinema tomorrow evening requires the background of this particular list, but that there must be some such list of interlocked beliefs and desires if anything is to count as the intention to go to the cinema tomorrow evening at all.) Given this holistic nature and the fact that the relations between beliefs, desires, intentions, etc, ramify in so many and complex ways, we simply could not do without regulative principles in order to keep track of all those relations.

As already noted, I have mentioned the above principles as illustrations of the kinds of norm of rationality that play a role in mutual understanding. I do not want to suggest that they are all the norms there are, nor that we always act in accordance with them, nor that people explicitly know the norms. The point is rather that we cannot do without some such norms (since norms are always involved in mutual understanding), that they must be largely shared, and that people normally act in accordance with them. So "[t]he way to improve our understanding of such understanding is to improve our grasp of the standards of rationality implicit in all interpretation of thought and action" (1990c; see also appendix 1). The point can also be made in several other ways:

> [T]he more flamboyant the irrationality we ascribe to an agent, the less clear it is how to describe any of his attitudes, whether deviant or not, and ... the more basic we take a norm to be, the less it is an empirical question whether the agent's thought and behaviour is in accord with it. (1985f)

> Relatively small differences take shape and are explained against a background of shared norms, but serious deviations from fundamental standards of rationality are more apt to be in the eye of the interpreter than in the mind of the interpreted. (1985a)

> The underlying paradox of irrationality, from which no theory can entirely escape, is this: if we explain it too well, we turn it into a concealed form of rationality; while if we assign incoherence too glibly, we merely compromise our ability to diagnose irrationality by withdrawing the background of rationality needed to justify any diagnosis at all. (1982)

4.2.2 Two interpretative devices for understanding thought and action

Whatever the norms of rationality are, they are all normative, not in the sense that they tell which particular beliefs and desires someone should have, but in that they tell how the beliefs, desires, intentions, etc, should be related to one another and to the way in which someone's behaviour is described in order to understand that behaviour as intentional action. The normative elements of rationality thus put constraints on patterns of beliefs, desires, intentions, etc. Unless a rational pattern -a pattern that satisfies these constraints- can be discovered in someone's behaviour, that behaviour cannot be described or understood as intentional action. This is why the normative elements are ineluctable for understanding and why they must be shared by all who want to understand others as, and want to be understood by others as, intentional creatures. For "to find someone else intelligible in the way that intentional actions are intelligible is to recognize one's own ground level norms realized in the behaviour of the other" (1985g).

To put it another way: I try to understand you in terms of attitudes like holding true, wanting to be true and intending to make true, and my task is to give content to these attitudes -to find out what you hold true, what you want to be true, what you intend to make true; what you believe, know, remember, notice or perceive is the case; what you want to be the case, what you hope or fear will be the case; what you intend to make the case; about what being the case you are pleased, astonished, surprised or proud, etc. It is in giving content to your attitudes -that is, in attributing to you beliefs that something is the case, desires that something be the case, intentions to make something the case, etc- that the beliefs, desires, intentions, etc, thus attributed get related. And so it is in giving content to your attitudes that the normative elements constrain me to do this in such a way that the beliefs, desires, intentions, etc, I thus attribute to you are related in accordance with the norms. That is, the norms are constitutive of my attributions of beliefs, desires, intentions, etc, to you; they play a constitutive role in my giving content to your attitudes, not by identifying particular beliefs, desires, intentions, etc, but by specifying the relations that should hold between them. The concepts of belief, desire, intention, etc, are intentional in nature, and as such have criteria of application that are governed by the norms of rationality. Those norms are not set by nature, but by us when we decide to view others, and ourselves, as intentional creatures. The unavoidable assumption that we share basic norms of rationality "comes to no more than this, that it is a condition of having thoughts, judgements, and intentions that the basic standards of rationality have application" (1985f).

A sharing of basic norms of rationality is one key to what makes mutual understanding as intentional creatures possible, and application of the norms is an important interpretative device. But, as noted, this device only puts constraints on patterns. It does not enable the identification of particular beliefs and desires. For that purpose another device has to come into play as well. This other device is based on the simple idea that in the most basic cases what a belief (or desire) is about is determined by what regularly causes the belief (or desire). If I believe that a car is approaching, it generally will have been an approaching car that has caused my belief; my desire to eat an apple may have been caused by my seeing an apple in front of me, in that case it is the apple in front of me that has inspired my desire to eat an apple. Conversely: the belief that is inspired by and only by approaching cars is apt to be the belief that a car is approaching; the desire that is caused quite regularly by sightings of apples may very well be the desire to eat an apple. This simple idea is a direct correlate of the common sense view of how we learn our first language: "in the simplest and most basic cases words and sentences derive their meaning from the … circumstances in which they were learned. A sentence which one has been conditioned by the learning process to be caused to hold true by the presence of fires will be true when there is a fire present; a word one has been conditioned to be caused to hold applicable by the presence of snakes will refer to snakes" (1989a). I will come back on this simple idea in section 4.3; in section 4.4.1 I will discuss its further, and profound, consequences for how we are to view, according to Davidson, the relations between a mind, other minds and the world. Now I just mention that with the second interpretative device, the one that is based on this simple idea, we have found our way into identifying the contents of particular beliefs (or desires) that someone has.

Let me summarize what has been established so far. Firstly, the norms of rationality are constitutive of thoughts, by specifying the relations that should hold between beliefs, desires, intentions, etc. Secondly, it is also constitutive of (at least the basic) thoughts that they are about what regularly causes them. Thirdly, it is the complex interplay of those two constitutive elements by which we come to understand others.

4.3 How the contents of basic thoughts are determined

According to Davidson, "[w]hat is needed in order to give objective content to … thoughts is … the right sort of causal interaction between [different] observers in their shared environment" (1988). This picture involves three elements: a society of two (or more); the right sort of interpersonal connections between the members of the society; a world that is shared by the members of the society and in which their interpersonal connections take shape. Davidson holds both that all three elements are necessary to give content to thoughts, and that they are irreducibly related in that they either stand together or fall together. I will try to illustrate the three elements and their interrelations at two cases in which the question of content-fixing causes for basic thoughts naturally arises.

4.3.1 Interpretation from scratch

The first case is interpretation from scratch: a situation in which two people who speak unrelated languages, and are ignorant of each other's languages, are left alone to learn to communicate. Let one of the imagined pair, she, take the initiative and speak; the other, he, tries to understand.

Some first steps towards mutual understanding

The best she can do is to be interpretable. She will use a finite supply of distinguishable sounds (or signs, or whatever she believes can be easily distinguished by him as well) and apply them consistently to objects and situations she believes are salient and believes he is in a good position to observe as well. If she chooses to utter sounds, she will not utter complicated strings of sounds (what in her language, let's assume that it is English, are full sentences) such as 'The small brownish animal that you see climbing in the third tree on your left is what I call a squirrel.' Rather she will draw his attention to the squirrel as well as she can (point at it, mimic its climbing motions), and sound very clearly and slowly: 'There's a squirrel' -or better still: the one-word sentence 'Squirrel.' She will try to focus his attention on often recurring features or activities and on objects she can touch, while uttering the appropriate one-word sentences: 'Eat'; 'Tree'; 'Stone'; 'Brown'; 'Mouth'; 'Moon'; 'Red'; 'Leg'; 'Apple'; 'Water'; 'Kiss'; 'Grass'; 'Sleep'; 'Cow'; 'Hard'; 'Sunrise'; 'Wet', etc.

The best he can do is assume that she intends to be interpretable; that by making the sounds she makes she is expressing thoughts that are meant to be understood by him; that she is bending all her efforts to make his task to find out what the contents of her thoughts are (or what she means by the sounds she makes to express them) as easy as possible by limiting herself to basic thoughts about what can readily be observed -about features in their shared environment she finds, and believes he will find, salient. It is clear that all he has to go on in fathoming her thoughts (or the meaning of the sounds she makes) is, on the one hand, the sounds themselves, and, on the other, the context in which she makes them: the things that are going on or are present in their shared environment; the further things she does (point, touch, …); the things he is doing or that they are doing together, etc. His task is, roughly, one of finding similarities and correlating: he must class together utterances that sound relevantly similar to him; for each class of similar sounding utterances, he must note, as complete as he can, the circumstances in which each member of the class has been uttered; he must then try to find a salient feature that is common to all those circumstances. This common and salient feature will then be his first guess of what that particular utterance means (what the particular thought that she expresses by that utterance is about). He will, as a first approximation, take this common and salient feature to be the cause of her thought and of her disposition to utter those particular sounds -as a first approximation, because he is aware that especially in the early stages of his project he is likely to get things wrong.

If he really wants to understand her, and wants to find out whether he has got it right or wrong, he should somehow make his present understanding available to her. Here is an example of what he does. He has noted a common and salient feature accompanying her utterances that sound to him very much like 'kras,' and that common and salient feature causes him to hold true his one-word sentence 'Zolp' -that is, he has noted that in all cases that she has applied her word 'kras', he has held his word 'zolp' applicable. What he does next is collect a bunch of things that for him are also clear cases in which his word 'zolp' is applicable, and show those things to her while echoing as well as he can her relevant utterance: 'Kras.'

Let us change point of view again. She sees him coming with a lettuce, some leaves, some beans and even an emerald; she hears him uttering, while he is pointing at all these things, something that comes very close to her 'Grass.' If she had not already been aware of it all the time, at least at this point she comes to realize how much she needs him too, in addition to the objects and events in their shared environment, in order to make herself understood. For unless he does not somehow make his present understanding available to her, she has no way to find out whether she has made herself understood or even whether she has been understandable at all. So she does not take him as pulling her leg, or as holding such strange beliefs as that lettuces, leaves, beans and emeralds are all kinds of grass. Rather she takes him as seriously intending to show her his present understanding, and realizes that now it is her task to find features that are common and salient both to the circumstances in which she previously uttered her 'Grass' and to his presentation of lettuces, leaves, beans and emeralds. She guesses that the common and salient feature in all those cases has been the presence of something green.

Now it is up to her again to choose some appropriate action. In fact, which course of action she chooses will depend on what she intends to achieve. She may, for instance, intend to make him speak and understand 'proper English,' perhaps for the somewhat imperialistic reason that everybody should be able to speak and understand 'proper English,' or for the simple reason that the people in the environment all speak and understand, at least to some extent, 'proper English,' so that it would be convenient for him to speak and understand 'proper English' as well. She then would somehow have to make available to him the following: how she thinks he has understood her utterances of 'Grass;' that that is not how she intended to be understood; how, in fact, she did intend to be understood; that an utterance of 'Green' would be her way of expressing the thought that she thinks he has taken her utterances of 'Grass' to express.

But if she merely intends to eventually be able to successfully communicate with him, there is no reason for her to take this course of action. She could simply praise him for his present understanding, try to further establish whether after this praise he is indeed disposed to utter 'Grass' in the presence of, and only in the presence of, something green, and if so, finally choose to conform to this practice herself as well. A basic element of their later successful communication would thus have been set up: her utterance of 'Grass' means what his utterance of 'Grass' means, since she holds it true when, and only when, he holds it true -their shared belief in the truth of the utterance is systematically caused by the same features of their shared environment. That by this move she is misusing her native language (that she is not speaking 'proper English') is of no import. If mutual understanding is all that matters, they might very well reach it in a language they create for themselves in the process of reaching it. In fact, if the two of them are stranded on this desert island, the idea 'misuse of a language' does not even have application. For what the sounds they utter mean is just what they take them to mean in their coming to understand each other. That simply *is* (defines, characterizes) 'their language;' it is a *product* of their mutual understanding, and not something that they already shared and subsequently applied to understand one another. And since there are no other hearers than just the two of them, there is also no particular reason to conform to the conventions of either's past social situation.[3)]

Much more needs to be done to reach mutual understanding

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3. Although the idea 'misuse of a language' does have application in cases other than that of two people stranded on a desert island, still this idea is quite generally of no use for an understanding of how we come to understand each other. For even if someone misuses a language, we usually have no problem in understanding that person. The idea 'misuse of a language' seems to depend on the idea of a reified language -some*thing* against which actual uses of language by speakers can be checked for correctness, e.g.: proper English. Perhaps for the reason to encourage conformity within a linguistic community we may want to, and often do, correct someone who in our opinion clearly misuses the common practice of that community. But also in that case we first have to find out what it is that that person means by the words he or she uses, because otherwise we would not know into what we had to correct his or her misuse. By introducing the idea of a reified language, we simply legislate what is to count as 'the' proper use of language. But at the same time we then sever the link from using language (in the sense of producing distinguishable patterns of sounds, signs, or whatever) to the purpose of using language (to understand and to be understood). So the idea of a reified language is of no use in trying to understand our linguistic competence: "[w]e must give up the idea of a clearly defined shared structure which language-users acquire and then apply to cases. And we should … give up the attempt to illuminate how we communicate by appeal to conventions" (1986b).

It will be clear that the above story is a far from complete account of how she and he come to understand one another. It could, for instance, happen that -contrary to the above case, where he had his word 'zolp'- in his 'native' language there is no single word to refer to the salient feature that he finds common to all the circumstances in which she has uttered a particular word.[4] This does not matter, as long as he is able, as in the above, to find out in which circumstances she uses the word and to check the correctness of his finding. From then on he may simply use her word.

The story also does not pay attention to how complex sentences, or predicates and sentences that are less directly geared to easily detected goings-on (the more theoretical concepts and statements), are going to be understood. It is here that the complex interplay with the first interpretative device even more clearly comes forward than in the above story -with the device, that is, that concerns the relations between thoughts (and the sentences used to express them). When she is going to compose complex sentences, words are going to appear in several sentences. His task then, roughly, becomes the following: to detect some types of composition; to find out what kind of relations hold between some complex sentence (of a given type) and simpler expressions that he already understands and that are contained in the complex sentence; to infer an understanding of complex sentences (of that given type) on the basis of those relations; to make his understanding available to her.[5] Her task is, as before, to make his task as easy as possible: by choosing easily detectable 'rules of composition;' by reacting as clearly as she can when he makes available her present understanding to her, etc. In trying to understand her more theoretical concepts and statements he will have to depend much on evidential relations. He will, for instance, have to find out which sentences (that he already understands) she takes as evidence for the application of her theoretical predicates or her belief in some theoretical statement. In all these cases she depends, as always, as much on him as he on her in their process to reach mutual understanding. It will also be clear that this process is never really finished, given that the ramifications of the relations between thoughts are so many and complex, and that from a finite vocabulary and a finite number of 'rules of composition' a potential infinity of sentences can be constructed to express those thoughts (cf appendix 1).

The story also does not mention that "[w]hat begins with mutually observed reactions

4. A case like this might arise if I were to understand Eskimos. If it is indeed true that they have more than twenty words for 'snow,' it is clear that not for all of those words there will be an existing Dutch (or English) word to translate it.

5. Suppose she has composed some simple two-word sentences: 'Cow brown;' 'Wet stone;' 'Grass apple,' which she utters consistently in the presence of brown cows, wet stones and green apples. He notes the simple 'rule of composition': saying two words, one after the other. He also notes that in the cases that she has uttered 'Grass apple,' he has held true both the sentence 'Grass' and the sentence 'Apple' (and the same applies *mutatis mutandis* for the other sentences). He conjectures the following relations: the truth of 'Grass apple' entails both the truth of 'Grass' and the truth of 'Apple' (and *mutatis mutandis* for the other sentences). From this he assumes the following for the truth conditions of the given type of composed sentence: an utterance of 'x y' is true if, and only if, it is uttered in the presence of something that is both x and y. From this assumption the conjectured entailments follow, since the truth conditions of 'x' (or 'y') simply are: an utterance of 'x' ('y') is true if, and only if, it is uttered in the presence of something that is x (y). He will make his present understanding available to her by uttering, for instance, 'Stone grass' in the presence of something that is both a stone and green (in fact, in the presence of the emerald that he gave her earlier).

to mutually observed phenomena soon graduates to something more useful" (1993a). They will, for example, use their mutually understood words to tell each other what they have seen that morning, what they expect to happen tomorrow, what they wished the other would do. In fact they can, and surely will, use their words for almost any extra-linguistic purpose they may happen to have: for informing, commanding, inquiring, lying, speaking metaphorically, "joking, story-telling, goading, exaggerating, insulting, and all the rest of the jolly crew" (1984a, p.165).

Summary

Although the simple story I have sketched surely is not the whole story, it is hard to believe that it is not a basic part of the whole story. It is the part in which the contents of basic thoughts (or the meaning of the words used to express them) is determined by the direct interactions between her, him, and the objects and events in their shared environment. Davidson often describes the determination as a kind of triangulation:

- she and he are two of the vertices of a triangle;
- from each of them originate two lines: the first is the expression of a thought (say, by making sounds) that is directed to the other person, the second is a 'line of thought' directed to what the thought is about according to the person that expresses it;
- a base line between her and him is established by a piece of successful communication: when she and he share, and know of each other that they share, the disposition to hold applicable a particular pattern of sounds;
- once a base line has been set up with respect to a particular pattern of sounds, a simple triangulation at the same time determines the third vertex -what both of them speak or think about when they utter that particular pattern of sounds; what the objective content of the thought they then share is: it is the intersection of their respective 'lines of thought.'

How much they depend on each other to fathom each other's thoughts follows, in this picture, from the fact that it takes two (or more, of course) to triangulate. And that they have to make their present understanding of the other(s) available to the other(s) -by means of "the right sort of causal interaction … in their shared environment; in a word, communication" (1988)- corresponds to the setting up of a base line that is needed for the triangulation to work.

I will close this subsection by mentioning one consequence of the above story. From the fact that the story does not mention or depend on the details of the mechanisms that constitute the causal chains from her to him (and him to her), and from spoken-of object or event to her to him (and him to her), it follows that those details cannot in themselves matter to how she and he come to understand one another and to what their thoughts are about (or what their words mean). The kinds of details that I have in mind concern such things as: the acoustical and visual signals that speed between her, him and what they speak of; the stimulations of their nerve endings; the processes in their nervous systems and brains -all those things do play a *causal* role, of course, but no *theoretical* role. The story only depends on the following device: she and he take their words and thoughts to have as subject matter the very publicly observable objects and events that are salient to both her and him. The criterion for salience is the establishment of a base line: she and he must share, and know they share, dispositions to appropriate verbal behaviour. This is the only interaction between her, him and their environment that matters to the story. It leaves everything else that happens in between out of the account of how she and he come to understand one another and of what their thoughts are about (or what their words mean). So if the story is correct (not as the whole story, but as a basic part of the whole story), then it shows in effect that such an account can do without considering anything else that happens in between. According to the story, as long as she and he share a disposition to appropriate verbal behaviour, the respective states of their neural networks or nervous systems may be just what they are -very different, for instance. This is not to deny, of course, that it is important that each of them has senses, a nervous system and a brain.

4.3.2 A fragment of first language acquisition

"It would be good if we could say how language came into existence in the first place, or at least give an account of how an individual learns his first language, given that others in his environment are already linguistically accomplished. These matters are, however, beyond the bounds of reasonable philosophic speculation" (1991a). Nevertheless, some fragment of the child's learning to use its first words seems obvious enough - that fragment where a parent teaches a child a word by reinforcing its random babbling on appropriate occasions. This fragment, which has some connections with the above story and which is somehow related to the question of content-fixing causes for basic thoughts, is the second case I want to consider.

A child's learning to use its first words versus interpretation from scratch

Put in greatly simplified terms, the primitive learning situation can be described as follows: "[t]he child babbles and when it produces a sound like 'table' in the presence of tables it is differentially rewarded; pretty soon the child says 'table' in the presence of tables" (1989b). Of course the parent must notice the child's utterances of 'table,' notice the presence of a table, notice that the child is in a position to observe the table, and make it as clear as possible to the child that it is rewarded for, and for nothing but, its utterance of 'table' (by repeating the utterance, by rewarding the child immediately after its utterance, etc).[6] The parent thus stimulates the child to display verbal behaviour that the parent finds appropriate and a first success of the conditioning process is achieved when the child produces sounds that the parent finds relevantly similar in situations that the parent finds relevantly similar. (The parent will usually also condition the child to make the appropriate sounds, and correct the child's mispronunciations into, for instance, 'proper English'-pronunciations. If the parent does consciously entertain any reasons for making such corrections at all, it may be for the reason to enhance the child's chances for successful future communication within their linguistic community. But in principle, or if all that matters is the future communication between child and parent, such corrections are not necessary. If the child were to utter 'cable' in the

6. I do not want to suggest that a parent always does these kinds of things deliberately. A lot of it happens naturally and spontaneously, of course. What matters is that the parent knows when to reward the child.

presence of, and only in the presence of, tables, the parent could choose to leave it at that, at least for the time being.)

Let me now compare the previously discussed case, in which she and he were left alone to learn to communicate, with this fragment of first language acquisition. In the former case she and he come to understand one another's basic thoughts by reference to the publicly observable objects and events that are salient to both her and him. Each of them reacts both to the other's utterances and to their shared environment. Each of them explicitly considers and formulates hypotheses concerning the features of their shared environment that the other's basic thoughts are about or that the other thinks one's own basic thoughts are about. Each of them consciously treats as evidence the combination of the other's utterances and features of their environment accompanying those utterances in order to test such hypotheses. The criterion for the acceptance of a hypothesis is the establishment of a base line by means of successful communication: each of them is aware (and is aware that the other is aware, etc) that they share a disposition to hold an utterance applicable.

In the latter case the parent conditions the child to exhibit a piece of appropriate verbal behaviour by reference to observable objects and events that the parent thinks are hard to miss for the child. The parent reacts both to the child's utterances and to features in the environment. The parent consciously treats as evidence the combination of the child's utterances and features of the environment accompanying those utterances in order to be able to differentially reward the child. The criterion for the success of the conditioning is the establishment of some sort of base line by means of appropriate rewards: the parent consciously rewards the child when its behaviour is appropriate.

What is common to both cases is the reference to publicly observable objects and events, and that in the end both parties have matching (dispositions to) pieces of behaviour (she is disposed to utter 'Grass' whenever he is; the child utters 'table' whenever the parent is jjljljljl disposed to utter 'Table')[7]. What is different is that in the former case both she and he consciously used the reference to publicly observable objects and events, and that both she and he were aware (and aware of the other's awareness) that they shared dispositions to pieces of behaviour, while in the latter case it can only confidently be said that the parent uses the reference to publicly observable objects and events and is aware of a sharing of dispositions to pieces of behaviour. Already being at home with the business of linguistic communication, both she and he are aware of the existence of a triangle, one vertex of which is he, another she and the third their common world. Furthermore, both she and he take each other's simple verbal behaviour as responses to (or basic thoughts about) aspects of their common world, where the aspect that oneself or the other is thinking about is determined by matching pieces of verbal behaviour -by gauging each other's responses (basic thoughts). Analogously the parent, being linguis-

7. As already noted, it is not necessary that the pieces of behaviour are identical. All that is needed is that they match: it would do equally well if she is disposed to utter 'Grass' whenever he is disposed to utter 'Zolp', or if the child utters 'cable' whenever the parent is disposed to utter 'Table.'

tically accomplished, takes her or his own simple verbal behaviour as responses to (or basic thoughts about) aspects of the world. And since the parent holds applicable the sentence 'Table' (has the basic thought that a table is present) whenever the child utters 'table,' the parent can see the child's utterances of 'table' as responses to tables.

Behaving in different ways in different circumstances versus expressing thoughts about the world

But does the child also see itself as responding to tables, does it by uttering 'table' intend to express the thought that a table is present, does it express any thought at all, does it have the concept of a particular object or kind of object (e.g., the concept 'table')? To get the point of these questions, it is perhaps useful to make a comparison. Just as the parent conditioned the child to display a particular kind of behaviour (an utterance of 'table') in particular situations (whenever a table is present), so we can condition a dog to display a particular kind of behaviour (say, jump on a chair) in particular situations (say, whenever a bell rings). If the conditioning has succeeded, *we* can see the dog's jumps on a chair as responses to a kind of event in the world (a ring of a bell). But does the dog also see itself as responding to rings of a bell, does it by jumping on a chair intend to express the thought that a bell is ringing, does it express any thought at all, does it have the concept of a particular event or kind of event (e.g., the concept 'ring of a bell')?

Let me try to reformulate the problem in a familiar way. Whereas it is doubtful whether the child and the dog are aware that they are reacting to something in the world, it seems safe to say that they are experiencing certain sensations. Please do not complain that we do not know what is directly experienced in sensation, or that we have no way of finding out what the sensations of others are. I accept the complaints, and I admit that an appeal to phenomena such as experienced sensations is an appeal to phenomena more postulated for the sake of the problem than independently open to study and observation.

For the primitive learning to take place, the child and the dog (and we too, of course) must have some built-in selective mechanism that allows them (and us) to discriminate among sensations, to experience some sensations as more alike than others. One experienced sensation must be enough like another for the child to provoke similar behaviour (an utterance of 'table'); one experienced sensation must be enough like another for the dog to provoke similar behaviour (a jump on a chair); one experienced sensation is enough like another for us to provoke similar behaviour (an utterance of 'The child utters "table"' or 'The dog jumps on a chair'). We can say that the child, like us, is able -more or less naturally, or after some minimal learning by conditioning- to class together the experienced sensations of various seeings of something that is a table; analogously, the dog is more or less naturally able, like us, to class together the experienced sensations of various hearings of something that is a ring of a bell; we are more or less naturally able, like the child, to class together the experienced sensations of various hearings of something that is an utterance of 'table' by the child, or the experienced sensations of various seeings of something that is a jump on a chair by the dog.

What *we* can do, is take our provoked behaviour (say, an utterance of 'The dog jumps on a chair') as an expression of a simple perceptual belief: for us, the experienced sensation (the seeing of something that is a jump on a chair by the dog) is related to our coming to have a belief (our seeing that there is something that is a jump on a chair by the dog). By uttering 'The dog jumps on a chair' we express the belief that there is some event in the world that is of a certain kind (that is a jump on a chair by the dog). Similarly, by uttering 'The child utters "table"' we express the simple perceptual belief that there is some event in the world that is an utterance of 'table' by the child. Whereas our experienced sensations are principally inaccessible to others, our simple perceptual beliefs have objective content because they claim the existence of events (or objects) of a certain kind that are publicly observable. Our claims may of course be false, and we may even intentionally make false claims. We may for instance lie: represent ourselves as holding true our utterance 'The dog jumped on a chair' with the intention that others will understand us as claiming that an event occurred that is a jump on a chair by the dog, while we know that no such event occurred.

The problem now is whether the child, or the dog, apart from experiencing a sensation (the seeing something that is a table, or the hearing something that is a ring of a bell), also comes to have a simple perceptual belief (that there is something that is a table, or that there is something that is a ring of a bell); whether the child by uttering 'table,' or the dog by jumping on a chair, claims the existence of an object or event in the world that is of a certain kind (that is a table, or a ring of a bell); whether the provoked behaviour has objective content for the child, or the dog; whether the child, or the dog, also has the attitudes 'holding true' or 'holding false'; whether the child, or the dog, can lie: utter 'table', or jump on a chair, with the intention that others will understand it as claiming the presence of an object that is a table, or the occurrence of an event that is a ring of a bell, while it knows that there is no such object present, or that no such event occurred.

One requirement for a creature's experienced sensations to be related to simple perceptual beliefs is that it has the concept of the cause (the stimulus) -the idea that its experienced sensations are caused by some stimulus that exists independently of its experiencing the sensations. Having this idea, the creature can then take itself as reacting differentially to stimuli -as responding similarly to what it takes to be similar stimuli. But this requirement is not enough and it is even doubtful whether a single creature by itself could have the concept of the stimulus. The problem is that the single creature has no way of locating the stimulus: is it reacting to a brain state or change, to events in its nervous system, to arrays of light striking its retina and sound waves striking its ear-drum, to objects or events further away from its skin and if so, to which of them?; where in the causal chain is it to locate the relevant cause? Or to put it in another way: "[t]he criterion on the basis of which a creature can be said to be treating stimuli as similar, as belonging to a class, is the similarity of the creature's responses to those stimuli; but what is the criterion of the similarity of the responses?" (1991a). Without a second creature that is in interaction with the first, there can be no answers to these questions; only the responses of the second creature to the responses of the first creature (and *vice versa*) can provide the criterion. What is needed is that each creature comes to note (and by means of the right sort of interaction with the other comes to note that the other comes to note, etc) that whenever it takes itself as responding to similar stimuli, the other's responses are similar as well. So the criterion is the establishment of a base line: both creatures' awareness (and awareness of the other's awareness) that their similarity responses match. Once a base line has been established, once they share, and know they share, for example the disposition to utter 'Table', each creature can then take an utterance of 'Table' (both by itself or by the other) as a response to a *common* stimulus -a stimulus that is located, because it is common, in a world that is external to what is going on inside of each of them and that they share. This is what gives them their sense of objectivity, "the concept of objects and events that occupy a shared world, of objects and events whose properties is independent of [their] thought" (1991b). Indeed, each of them can then take an utterance of 'Table' (both by itself or by the other) as a thought they share about the world they share -the thought that there is an object in the world that is a table. So the second requirement for a creature's experienced sensations to be related to simple perceptual beliefs is that there is a second creature, and that both creatures are aware (and are aware of the other's awareness) of the existence of a triangle of which they are two vertices, and of which the third vertex is a common stimulus -an object or event in a world thus made common. For them to know that they are so related requires that they be in communication; only communication can create the awareness that they share thoughts and a world with each other. Each of them must understand, and be understood by, the other.

I still have not answered the questions whether the child (the dog), after it has been successfully conditioned to utter 'table' (to jump on a chair), does see itself as responding to tables (to rings of a bell), does by uttering 'table' (jumping on a chair) intend to be understood as expressing the basic thought that a table is present (that a bell is ringing), or does have the concept of a particular object or event, or kind of object or event, e.g. the concept 'table' ('ring of a bell'). But I have formulated the conditions under which these questions can be answered in the affirmative: the child (the dog) must be aware of the existence of a triangle; it must be in communication with others; it must understand, and be understood, by others. It is no secret that at some stage the child begins to understand the basic verbal behaviour of others as making claims about an external world; begins to speak itself in order to make claims about the external world; discovers the possibility of lying, of uttering 'table' with the intention that other people will take the utterance as its claim that there is an object present that is a table while it knows that no such object is present; begins to communicate with others about what it thinks is the case, about what it expects will be the case, about what it intends to make the case, about what being the case it is surprised, etc. This is, of course, merely a restatement of the great *mystery* of first language acquisition. We know that children begin to do these kinds of things at some stage, while we never see dogs doing these kinds of things. We know *that* it happens with children, but not *how* it happens. (Of course we do know that, when compared to human brains, canine brains lack a part, so that it is likely that the dog's lack of such a part will be the cause of what prevents it from happening with dogs, while the presence (and workings) of that part in the child's brain will play a causal role in what allows it to happen with children.)

Some further remarks on first language acquisition

Although first language acquisition remains as great a mystery as it has always been, some consequences follow from the above. Firstly, the child's discovery of itself as a thinking being (as a speaker and hearer), is at the same time also its discovery of other thinking beings (of speakers and hearers other than itself), and of a world that it shares with those other people and about which it shares many thoughts with them. The subjective, objective and intersubjective -or knowledge of one's own mind, knowledge of the world, and knowledge of other minds- are irreducibly related: none can be based on one or both of the others, they all presuppose each other, and they emerge together (I will come back on this in section 4.4.1). Secondly, although the presented fragment of first language acquisition is by far not the whole story of first language acquisition, it is a basic part of the whole story. The reason is that the objects and events in the world by reference of which the parent has conditioned the child to display pieces of verbal behaviour are, when in the end the child itself takes these pieces of verbal behaviour as expressions of thoughts about the world, the very objects and events that those thoughts are about. Thus, finally, what in the most basic cases our thoughts are about (and the words we use to express them mean) is determined by the circumstances in which we learned, and used, the words; "this much 'externalism' is required to explain how language can be learned, and how words and [thoughts] can be identified by an interpreter" (1987a).

As already noted, the above fragment is a far from complete account of first language acquisition. I certainly do not want to claim that a child learns to use all its words by means of a direct exposure to the objects and events that the words normally refer to: some words may be learned by paging through picture books, watching television, etc.

> Someone who has learned from books what a guanaco looks like may never have been caused to accede to 'That's a guanaco' by seeing a guanaco, and yet be prepared (having seen pictures of guanacos perhaps) to accede when he does see one. Or, to take a harder case; someone may know, in some reasonable sense, what a guanaco is, and that it is not a llama, and yet be regularly caused to assent to 'That's a guanaco' in the presence of llamas. In both these cases, the contents of the belief that there is a guanaco present is determined, not by exposure to guanacos, but by having acquired other words and concepts, such as those of llama, animal, camel, domesticated, and so forth. Somewhere along the line, though, we must come to the direct exposures that anchor thought and language to the world. (1991b)

The fragment does not consider how the child comes to understand beliefs by their relations to other beliefs. Nor the related issues of its learning to use more complex sentences and sentences it has never heard or spoken before, and its coming to use more theoretical predicates and statements. All these things will involve the child's grasp of the basic norms of rationality (the norms that regulate the relations between beliefs, desires, intentions, etc). In summary, and to stress both the two constitutive elements of thought and the public availability of thoughts (as well as the words used to express them):

> There are no words, or concepts tied to words, that are not to be understood and interpreted [and learned, KK], directly or indirectly, in terms of causal relations between people and the world (and, of course, the relations among words and other words, concepts and other concepts). (1989a)

But most importantly, and this is the gist of much of the foregoing, the fragment cannot be the whole story because it is essentially behaviouristic and as such suffers from the same deficiency that behaviourism suffers from quite generally: it leaves out the mind altogether.[8)]

> A creature may react with the world in complex ways without entertaining any propositions. It may discriminate among colours, tastes, sounds and shapes. It may 'learn', that is, change its behaviour in ways that preserve its life or increase its food intake. It may 'generalize', in the sense of reacting to new stimuli as it has come to react to similar stimuli. Yet none of this, no matter how successful by my standards, shows that the creature commands the subjective-objective contrast, as required by belief. (1985c)

A sharing of naturally experienced similarity

I have already mentioned that the child, the dog and we must have some built-in selective mechanism that allows them and us to discriminate among sensations, to naturally experience some sensations as more alike than others, to instinctively class together experienced sensations. I think it is safe to say that all creatures must have some such built-in mechanism in order to survive (evolution will have had something to do with it). In order to set up some sort of a base line with another creature (whether by conditioning or communication), I do not have to know anything about the details of my own built-in mechanism or that of the other creature. But there is one obvious requirement that must be met for the establishment of a base line to work: if I instinctively experience the sensations I have on different occasions as similar, the other creature must on the same occasions have sensations that it too (more or less naturally or after minimal learning by conditioning) experiences as similar. The other creature's sensations may be whatever they are, as long as it experiences (because of the way that *it* is constructed) its sensations as similar whenever I (because of the way that *I* am constructed) experience my sensations as similar. Experienced similarity is all that I need to share with the other creature, and nothing else -even the way in which we are constructed may be different (as dogs and humans are differently constructed and, of course, already different human beings are to a larger or smaller extent differently constructed).

The criterion for a sharing of experienced similarities, I hope by now this no longer is a

8. Behaviourists will, of course, claim that what I call its deficiency is in fact the great virtue of behaviourism: all that there is to the mind -thought, intentional action, meaning, attitudes like holding true, wanting to be true, etc.- is 'nothing but' or (by definition) reducible to observable input and output that are described in non-mental terms (and ideally in terms of the ultimate physics). I have already noted that Davidson rejects all 'nothing but' and (definitional) reductionist approaches -"I despair of behaviourism and accept frankly … attitudes … such as holding true" (1984a, p.231)- while he still maintains that thought, intentional action and meaning are entirely determined by readily observable behaviour. In section 4.4.2 I will come back on Davidson's views on the relation between body and mind -the physical and the mental, the non-intentional and the intentional, the non-rational and the rational.

surprise, is a matching of similarity responses: she is disposed to respond similarly (with an utterance of 'Grass') whenever he is disposed to respond similarly (with an utterance of 'Grass'); the child 'responds' similarly (with an utterance of 'table') whenever the parent is disposed to respond similarly (with an utterance of 'There's a table'); the dog 'responds' similarly (with a jump on a chair) whenever we are disposed to respond similarly (with an utterance of 'A bell is ringing'). Without a sharing of experienced similarities between she and he, the child and its parent, the dog and us, there would be no way to establish these matchings of similarity responses.

I have some while ago introduced the phenomenon of experienced sensation in order to formulate the difference between behaving in different ways in different circumstances (*we* can also see sunflowers and earthworms as doing that), and expressing thoughts about the world (as we have seen only communicators can do). But since what is required for two people to have basic thoughts and to determine the contents of each other's basic thoughts is their recognition of a triangle of which they are two of the vertices and the third is what their (shared) thought is about, and since the determination of the contents of those basic thoughts depends on no more than their awareness (and awareness of the other's awareness) of a matching of similarity responses, it follows that the phenomenon of experienced sensation plays no theoretical role in determining the contents of those basic thoughts: "although sensation plays a crucial role in the causal process that connects beliefs with the world, it is a mistake to think it plays an *epistemological* role in determining the contents of those beliefs" (1989a). It is important for empirical knowledge and the acquisition of language that we have senses, a nervous system, a brain, etc, and it is important to recognize that the senses, their deliverances and the workings of the nervous system and the brain do play a causal role in knowledge and the acquisition of language, but they are not and do not provide or supply an epistemological foundation (an ultimate source of justifying evidence) for meaning or empirical knowledge. In fact, and I will come back on this in section 4.4.1, meaning, belief and empirical knowledge not only do not have such an epistemological foundation, they do not need a foundation of this kind. Rather, a "community of minds is the basis of knowledge; it provides the measure of all things" (1991a).

So although "[t]here is an abundance of puzzles about sensation and perception, … these puzzles are not … foundational for epistemology. The question [for example] of what is directly experienced in sensation, and how this is related to judgements of perception, while as hard to answer as it ever was, can no longer be assumed to be a central question for the theory of knowledge" (1989a). The same goes for the question what the details are of the built-in selective mechanism that allows humans (or dogs) to discriminate among sensations, to behave in different ways in different circumstances. It is not a question for the theory of knowledge, but a question in the research of human (or canine) physiology -a research question in, for examples, biophysics or neurophysiology. Given what humans (dogs) naturally and easily class together (for humans: seeings of tables, seeings of something green, seeings of jumps on a chair, hearings of 'table', etc; for dogs: seeings of other dogs, seeings of cats, hearings of rings of a bell, etc), given how they instinctively 'generalize' (come to behave similarly to sensations that are experienced as similar), biophysical or neurophysiological studies in perception will try to uncover the mechanism that accounts for those facts about human (canine) nature: "the facts about salience, attention and tendencies to generalize in some ways rather than others" (1991c). When these kinds of questions get answered in biophysics or neurophysiology, the answers will tell us a lot about how a human (dog) is constructed, about what similarities in the respective ways that humans and dogs are constructed account for the fact that both humans and dogs are able to instinctively class together seeings of dogs, seeings of cats, hearings of rings of a bell, etc, and about the details of parts of the causal processes that connect the provoked behaviour of a human (dog) with the world; but the answers will not enable us in any way to say whether some provoked behaviour of a human (dog) is to count as an expression of a thought or as an intentional action, let alone to determine the contents of thoughts or intentions (I will come back on this in section 4.4.2.)

4.4 Implications and additions

In the above I have presented a rather (I admit:) detailed elaboration of some rather (I hope you admit:) simple ideas about what is involved in, and makes possible, mutual understanding: the two interpretative devices, their complex interplay, a society of interacting minds in a natural world they share, the establishment of a base line by communication, etc. In appendix 1 I somewhat further elaborate these ideas in the direction of a theory of interpretation: a theory which incorporates a structure that, on the one hand, the observable behaviour of an agent must exhibit near enough if the agent is to have beliefs, desires, intentions, etc at all, and on the other hand enables an interpretation of that behaviour as intentional action and meaningful speech. In this section I further elaborate some themes that have already, more or less implicitly, emerged in the above: the relation between knowledge of one's own mind, knowledge of other minds and knowledge of the world, and the relation between the physical and the mental.

4.4.1 Three varieties of knowledge

In the foregoing it has already quite explicitly been stated that knowledge of one's own mind, knowledge of other minds and knowledge of the world are irreducibly interrelated. To briefly recapitulate some steps:

> [U]ntil the triangle is completed connecting two creatures, and each creature with common features of the world, there can be no answer to the question whether a creature, in discriminating between stimuli, is discriminating between stimuli at the sensory surfaces or somewhere further out, or further in. (1991a)
>
> The problem is not … one of verifying what objects or events a creature is responding to; the problem is that without a second creature interacting with the first, there can be no answer to the question. And if there can be no answer to the question what a creature means, wants, believes or intends, it makes no sense to hold that the creature has thoughts. (1989b)

> Until a base line has been established by communication with someone else, there is no point in saying a person's thoughts or words have a propositional content. (1991a)
> If I did not know what others think I would have no thoughts of my own and so would not know what I think. If I did not know what I think, I would lack the ability to gauge the thoughts of others. Gauging the thoughts of others requires that I live in the same world with them, sharing many reactions to its major features, including its values. (1991a)

A society of minds that share, and know they share, a world and a way of thinking about the world is the basis of all three varieties of knowledge; all three varieties of knowledge "are located conceptually in the world we inhabit, and know we inhabit, with others" (1991a); "all three varieties of knowledge are concerned with aspects of the same reality; where they differ is in the mode of access to reality" (*ibid*). Although I will come back on the differences somewhat later, it is perhaps useful to now take away one possible worry that may have arisen: the worry "that if all our knowledge ... is objective, we will lose touch with an essential aspect of reality: our personal, private outlook" (*ibid*). This worry will be seen as groundless, however, once it is recalled from the foregoing that "objectivity itself [has been traced] to the intersections of points of view [of two (or more) personal, private outlooks, KK]; for each person, the relation between his own reactions to the world and those of others" (*ibid*). For then we recognize that our knowledge "has its basis not in the impersonal but in the interpersonal. When we look at the natural world we share with others we do not lose contact with ourselves, but rather acknowledge membership in a society of minds" (*ibid*).

The public and correct nature of thought

Given that each of the three kinds of knowledge necessarily both depends on and is indispensable for the others -that "there could not be thoughts in one mind if there were no other thoughtful creatures with which the first mind shared a natural world" (1989b)- it follows that it is not problematic whether there are other thinkers, whether there is a world, or whether knowledge of other minds or the world is possible.

As such Davidson's position contrasts with the common idea that the subjective (knowledge of one's own mind) is the measure of all things -that there is a subjective world prior to everything else. If this conception allows the existence of an external world or other minds at all, it gets burdened with all sorts of gaps that are principally unbridgeable: between 'my' world and 'the real' world; between 'my' world and 'your' world; between my understanding of you and your understanding of yourself, etc. Davidson's position leaves no room for such priority of the subjective and for the existence of such unbridgeable gaps "since it predicates self-knowledge on knowledge of other minds and the world. The objective and the intersubjective are thus essential to anything we can call subjectivity, and constitute the context in which it takes form" (1991a).

Furthermore, the very methods that enable a determination of the contents of thoughts, at the same time make for the establishment of an intersubjective standard of correctness and for a sharing of thoughts that are, according to this standard, largely correct. This public and correct nature of thought springs "from the nature of interpersonal understanding. Linguistic communication, the indispensable instrument of fine-grained interpersonal understanding, rests on mutually understood sentences, the contents of which are finally fixed by the patterns and causes of sentences held true", desired to be true, intended to be made true, etc (1990c; see also appendix 1). In the end, everything rests on a sharing of similarity responses and norms of rationality -on sharing, and knowing that one shares, a world, many reactions to its major features and a way of thinking about it, with someone else. No further epistemological foundations for thought or knowledge are needed.

Conceptual relativism and scepticism

It will be clear that Davidson's position entails that there are limits to how much individual or social systems of thought can differ, and thus opposes a particular reading of conceptual relativism. "If by conceptual relativism we mean the idea that conceptual schemes and moral systems, or the languages associated with them, can differ massively -to the extent of being mutually unintelligible … or forever beyond rational resolve- then I reject conceptual relativism" (1989a). The problem is that this idea requires a device that enables one person to say that someone else has concepts, and to say what those concepts are concepts of, without understanding that other person. But as we have seen there cannot be such a device, because to say that someone else has concepts is to understand and be understood by that person. No such problem arises if we read conceptual relativism as the (pedestrian) idea that there are differences between various epochs, cultures or individuals -differences of kinds that we all recognize and struggle with: with respect to style, taste, habits, areas of interest, directions in which thought has developed, etc- without embracing the idea that there might be more comprehensive differences. But also on this reading it must be remembered that the differences can only take shape or made sense of against a large background of shared and correct thoughts.

That our thoughts are largely correct does not imply that they cannot be wrong. In fact, each and every belief can be false (even a simple perceptual belief can be caused by misleading sensations), each and every desire can be bad, etc. A first thing to note is that it does not follow logically, from the premise that each and every thought could be wrong, that the lot of them could be wrong or that they could be wrong all together. If this reasoning was valid, it would also follow, from the premise that each and every person that takes part in a lottery could win the first prize, that the lot of them could win the first prize or that they could win the first prize all together.

So the sceptic who wants to maintain that all our knowledge could be false all together, must base his argument on something else than the fact that each and every one of our beliefs could be false. But, and this is Davidson's answer to the sceptic, given the way in which beliefs are identified it simply cannot happen that the lot of them are false or that they are false all together: "enough in the framework and fabric of our beliefs must be true to give content to the rest. The conceptual connections between our knowledge of our own minds and our knowledge of the world are not definitional but holistic" (1991a). By and large how we think the world is put together "is how it is put together, there being no way, error aside, to distinguish between these constructions"

(1985b).

The principle of charity
The insight that thought is by nature generally correct has made evaporate the traditional problem in epistemology how we know that our knowledge is generally true, but in its place condenses another problem: how to cope with error and false belief. Given that a shared standard of correctness is the measure of everything, including our own thoughts, incorrect thought cannot really be accommodated. Or to put it another way, given that mutual understanding grows by extending a mutual standard of correctness, any attribution of false belief or error to someone else damages mutual understanding and thus also the validity of the claim that that person has a false belief or has made an error. Instead of attributing false belief or error to someone else, we may as well wonder whether *we* have understood that person correctly. So the general policy is and remains to interpret (or to adjust our interpretation of) someone in such a way that he or she comes out right as often as possible or, alternatively, that the shared standard of correctness extends further and further and further. This policy is Davidson's *principle of charity*: in a slogan-like form it says that we must devise an interpretation that finds the other "consistent, a believer of truths, and a lover of the good" (1980a, p.222). I hope it is clear that the principle of charity is not, as the name might suggest, a friendly methodological advice "resting on a charitable assumption about human intelligence that might turn out to be false" (1984a, p.137). It rather emphasizes that a shared standard of correctness is the measure of all things, that without such a shared standard there would be no thought at all, and that by extending the shared standard we do not only improve our understanding of others but along with that also the clarity and effectiveness of our own concepts.

As a matter of principle, the principle of charity does not allow error or false belief. Or to put it the other way round, error and false belief are what keeps the process of interpretation going on: whenever our present understanding of someone forces us to attribute error or false belief to that person, the principle of charity counsels us to revise our present understanding. We should not think of mutual understanding as a project that is finished at a certain time. Of course, we do not always have the time, opportunity or motivation to actively engage ourselves in this project, and on this pragmatic level:

> [t]he best we can do is cope with error holistically, that is, we interpret so as to make an agent as intelligible as possible, given his actions, his utterances and his place in the world. About some things we will find him wrong, as the necessary cost of finding him elsewhere right. As a rough approximation, finding him right means identifying the causes with the objects of his beliefs, giving special weight to the simplest cases, and countenancing error where it can best be explained. (1990d)

Here are some ways to countenance error by explaining it: he mistook that sheep for a goat, because he was not very well placed to observe the sheep (or did not wear his glasses); he reached this false conclusion from these premises, because the inferential chain was very long and he did not take enough time to work it out, etc. I could choose to thus attribute error and false belief to him, and leave it at that. But in principle I ought to ask myself: how well placed was I myself to observe what he called a goat (did

I wear my glasses)?; was it really that sheep he was talking about?; does he use the word 'goat' as I do (did I wrongfully assume identity of meaning)?; did not I myself conclude to hastily by attributing a reasoning mistake to him (did I perhaps make a mistake somewhere in the inferential chain)?; was I right about what I think were his premises and his conclusion (did I wrongfully assume identity of meaning)?; could it be that on some reinterpretation of his premises and conclusion he did not make any reasoning mistake at all?, etc.

Let me put it in yet another way. The best way, in principle, to deal with cases where we suspect someone has made a mistake (has formed a false perceptual belief, has made a reasoning error, has acted against his or her own best judgement, etc) is to try to resolve the matter with that person. It is clear, however, that the resolution can only work if both parties know of each other what the other is talking about and what 'the matter' to be resolved actually is. And for both parties to know that of each other requires that they have already tried to extend their mutual standard of correctness as far as possible. Only on this condition might a subsequent exchange lead to a clarification for both parties: perhaps the other will admit the mistake; perhaps we will find out that we have made a mistake or misunderstood the other; perhaps the exchange will for both parties lead to an adjusted view of the matter, etc. The resolution will, as always, involve the complex interplay of the two interpretative devices or, alternatively, the complex interplay of the two methods to extend the intersubjective standard of correctness.

Here, of course, we touch on "a good Socratic intuition: it is only in the context of frank discussion, communication, and mutual exchange that trustworthy truths emerge" (1990e, p.15). Although we do not know, and will never know, *which* of our thoughts are correct or *which* truths have emerged in mutual exchange, what we do know is that on the whole our thoughts are correct and that we have methods that lead to an extension of our shared standard of correctness and thus to an increase in correct thought.[9)]

9. It is, perhaps, worth noting that this position falls outside the familiar *isms*, which all have in common that they somehow try to define or characterize *which* statements, or sets of such, are true. For realists, for instance, those statements are true which correspond to an observer-independent definite world structure. Opposed to realism are the various brands of what is called anti-realism, which "humanize truth by making it basically epistemic" (1990c), and which introduce "a dependence of truth on what can somehow be verified by finite rational creatures" (*ibid*). For empiricists, for instance, the truth of some statements (observation sentences) is directly tied to experience (to patterns of excited nerve endings, for example), while an empirical theory is true (empiricists would probably use words like 'empirically adequate' or 'viable') just in case it predicts and explains true observation sentences. That is, "[i]f truths about observables are called 'phenomena', then a theory is empirically adequate just in case it saves the phenomena, *all* the phenomena" (Fine, 1986, p.143). Other brands of antirealism (that partly overlap with each other or with empiricism) have in common that they portray the truth of a statement (or set of statements) as amounting to the fact that certain people would accept that (set of) statement(s) under certain circumstances. Fine (1986, p.138) describes three antirealisms that all fit this description but differ with respect to the 'certain people (subjects)' and the 'certain circumstances': "If we let the subjects be 'perfectly rational' agents and the circumstances be 'ideal' ones for the purposes of the knowledge trade … then we get the picture of truth as ideal rational acceptance, and this is the picture that Hilary Putnam … paints for his 'internal realism.' If the subjects are not perfectly rational and yet conscientious and well intentioned about things, and we let the circumstances be those marking a serious dialogue of the kind that makes for consensus, where consensus is attainable, then we get the Wittgensteinian

"What is certain is that the clarity and effectiveness of our concepts grows with the growth of our understanding of others. There are no definite limits to how far dialogue can or will take us" (1991a). The dialectic imposes on both parties the constant burden of interpretation -of applying the principle of charity, of applying the very methods that eventually lead to an increase in correct thought. And of course it will be very useful to "turn to a third party and a fourth to broaden and secure the interpersonal standard" (*ibid*).

Differences between the three varieties of knowledge
In the above I have emphasized the interrelation between the three varieties of knowledge. Let me now also point at some of the differences between them. A basic difference between my knowledge of the contents of another mind and my knowledge of the contents of my own mind is this. The former is necessarily inferential, and depends (among other things) on my consciously taking as evidence, and my framing of hypotheses about, observed correlations between on the one hand the speech and other behaviour of the person to be interpreted and on the other the objects and events in our communal environment. The latter, on the other hand, is usually direct in that I normally know what I believe, want, intend, or mean by my words without having to rely on this kind of evidence or inference. A thought I have and the thought I believe I have simply *are* one and the same thought, while a thought you have and the thought I believe you have can only *become* the same thought (a shared thought) as a result of our process of coming to understand one another. This asymmetry between interpreted and interpreter cannot be obliterated but only be 'smeared out' by exchanging the roles of interpreted and interpreter, i.e., by interacting and, in particular, communicating.

The basic difference between knowledge of the natural world and knowledge of another mind (or one's own mind) is that we do not aim to discover rationality in nature, whereas we cannot but understand another (or our own) mind as answering to (shared) norms of rationality. Of course, also in studying the natural world we necessarily employ our own norms (what else?). So the point to emphasize is not that *we* as explainers and observers employ our norms in understanding the actions (including the speech) of others. "The point is rather that in explaining action we are identifying *the phenomena* to be explained, and *the phenomena* that do the explaining, as directly answering to our own norms; reason-explanations make others intelligible to us only to the extent that we can recognize something like our own reasoning powers at work" (1987b, my italics).

4.4.2 The physical and the mental

position that Richard Rorty … calls 'epistemological behaviourism.' Finally, if our subjects are immersed in the matrix of some paradigm and the circumstances are those encompassed by the values and rules of the paradigm, then we get the specifically paradigm-relative concept of ruth … that is characteristic of Thomas Kuhn's … antirealism."
According to Davidson and Fine, these isms (in so far as they can be made intelligible at all) are all misguided by the idea that we are in need for characterizations or definitions of truth. For a further discussion of these matters I refer to Davidson (1990c, part II) and Fine (1986, chapters 7 and 8).

Anomalous monism

An issue somewhat related to the relation between knowledge of the natural world and knowledge of a mind concerns the relation between mind and body, the mental and the physical, the social and the physical sciences. Davidson has dubbed the position he occupies with respect to the mind-body problem '*anomalous monism*.' In short, "it resembles materialism in its claim that all events are physical, but rejects the thesis, usually considered essential to materialism, that mental phenomena can be given purely physical explanations" (1980a, p.214). Below I further elaborate this position. Let me first discuss the two components of anomalous monism: monism and anomalism.

According to Davidson, the mental and the physical should not be understood as ontological categories but as conceptual categories: to say of a state or event that it is mental (physical), is to say that we can describe it in mental (physical) terms. Davidson's monism says that states or events that are described in mental terms are also describable, taken one by one (as opposed to taken type by type), in physical terms. Descriptions in mental terms contain normative concepts such as belief, desire and intentional action. So the following are examples of mental states and events: his knowing that London is in England; his seeing that it's raining; her coming to believe that a car is approaching; my wanting that this thesis is finished; her raising an arm to catch her teacher's attention; his being proud that he has a beautiful car, etc. Descriptions in physical terms draw only upon concepts in terms of which the basic laws of nature are formulated. Since basic physics aims at a closed system of strict laws in the light of which ultimately all that happens can be explained or predicted, in the ultimate physics every event will be a physical event, i.e., describable by means of the concepts in which those laws are formulated.

The other component of anomalous monism is: anomalism (of the mental). 'Anomalous' should here not be read as odd or irregular, but as a-nomological, i.e., non-lawlike, failing to fall under strict laws. Anomalism of the mental says that states or events do not fall under strict laws when described in mental terms. This claim depends on the distinction that Davidson makes between states (or events or objects) and *types* of state (or event or object), and on the realization that laws deal with types of state (or event or object). Particular states (or events or objects) only fall under a law if they can be described as being of a type with which the law deals. It are states (or events or objects) *as described* that instantiate laws.

> Suppose a hurricane, which is reported on page 5 of Tuesday's *Times*, causes a catastrophe, which is reported on page 13 of Wednesday's *Tribune*. Then the event reported on page 5 of Tuesday's *Times* caused the event reported on page 13 of Wednesday's *Tribune*. Should we look for a law relating events of these *kinds*? It is only slightly less ridiculous to look for a law relating hurricanes and catastrophes. The laws needed to predict the catastrophe with precision would, of course, have no use for concepts like hurricane and catastrophe. (1980a, p.17)

Like there are no strict laws relating events of the types just quoted, Davidson's anomalism of the mental says that there are also no strict laws relating mental events of a certain type and mental events of another type or relating mental events of a certain type and physical events of a certain type, i.e., that there are no strict psychological or psychophysical laws. Strict laws do not employ mental concepts.

Anomalism of the mental (Davidson's arguments for which I shall turn to presently) implies that freedom and natural necessity can very well co-exist in the same human behaviour, because by lack of psychophysical laws the laws in the physical realm do not carry over to the mental realm.

> The nomological irreducibility of the psychological means … that the social sciences cannot be expected to develop in ways exactly parallel to the physical sciences, nor can we expect ever to be able to explain and predict human [thought and action] with the precision that is possible in principle for physical phenomena. This does not mean there are any events that are in themselves undetermined or unpredictable; it is only events as described in the vocabulary of thought and action that resist incorporation into a closed … system [of strict laws]. These same events, described in appropriate physical terms, are as amenable to prediction and explanation as any. (1980a, p.230)
>
> Even if someone knew the entire physical history of the world, and every mental event were identical with a physical, it would not follow that he could predict or explain a single mental event (so described, of course). (*ibid*, p.224)

Even if the laws of physics are completely deterministic, action and thought can still be viewed as autonomous. And conversely, if physics turns out to be incurably indeterministic, we do not need the indeterminacy of physics as providing some room for free thought and action.

Toward the end of this section I will present Davidson's argument that anomalism, along with some further premises (among which the premise that the content of mental states or events is determined by causal relations to objects and events in the outside world), implies monism: 'free to act' and 'subject to a closed system of strict laws' are necessarily united in the same behaviour.

The irreducible difference between mental and physical concepts

I will now first discuss Davidson's arguments for the impossibility of strict laws relating the mental and the physical -that "the basic concepts of [the mental] vocabulary cannot be reduced, or related by strict laws, to the vocabularies of the physical sciences" (1987b). The main reason has already been mentioned: the basic concepts of the vocabulary of thought and action have normative criteria of application, whereas the physical concepts have non-normative criteria of application; therefore they cannot be connected by strict laws.

> Suppose we try to say, not using any mental concepts, what it is for a man to believe there is life on Mars. One line we could take is this: when a certain sound is produced in the man's presence ('Is there life on Mars?) he produces another ('Yes'). But of course this shows he believes there is life on Mars only if he understands English, his production of the sound was intentional, and was a response to the sounds as meaning something in English; and so on. For each discovered deficiency, we add a new proviso. Yet no matter how we patch and fit the non-mental conditions, we always find the need for an additional condition (provided he *notices*, *understands*, etc.) that is mental in character. …
>
> Beliefs and desires issue in behaviour only as modified and mediated by further beliefs

and desires, attitudes and attendings, without limit. (1980a, p.217)

Furthermore, in establishing the correctness of our attributions of beliefs, desires, intentions, etc, to an agent we are forced "to bring more and more of the whole system of the agent's beliefs and motives directly into account. But in inferring this system from the evidence, we necessarily impose conditions of coherence, rationality, and consistency. These conditions have no echo in physical theory" (*ibid*, p.231), and cannot "be stated in a purely physical vocabulary" (*ibid*, p.259).

It is a constitutive element of giving content to attitudes like holding true, wanting to be true, intending to make true, etc, that the norms of rationality have application. Therefore there are no necessary and sufficient conditions that allow us to attribute beliefs, desires, intentions, etc to someone, to characterize a particular piece of behaviour as an intentional action performed with a certain intention, or to interpret a particular sound that someone makes as having a particular meaning. We must tailor all these attributions, characterizations and interpretations to the principle of charity, and "we must stand prepared, as the evidence accumulates, to adjust our theory [our attributions, etc, KK] in the light of overall cogency: the constitutive ideal of rationality partly controls each phase in the evolution of what must be an evolving theory" (*ibid*, p.223). We must always "consider how best to render the creature being interpreted intelligible, that is, as a creature endowed with reason" (1991a).

Of course, physical concepts too have constitutive elements, but those are not governed by the norms of rationality. The concept of weight, for instance, depends on the existence of a relation between objects (heavier than) that is transitive and asymmetric, and of some empirical criterion on the basis of which we may assert that this object is heavier than that object (a pair of scales' tipping to this side, for instance). Along with some further constitutive axioms of the theory of measurement for weight, we can then assign numbers (weights) to the objects such that a heavier object gets assigned a higher number (weight), the weight of two objects equals the sum of the weights of the two objects, etc, and such that the numbers are unique once a particular object has been chosen as the unit of weight (cf appendix 1). The constitutive elements of the concept of weight allow us formulate the necessary and sufficient conditions under which we are to attribute a weight of, say, 1.46 Newton to an object. And when concepts like those of weight are going to appear in lawlike statements, it are the constitutive elements of such physical concepts that allow us to determine in advance whether or not the conditions for application of the law are satisfied. In fact, "the existence of lawlike statements in physical science depends upon the existence of constitutive … laws like those of the measurement of length [and weight] within the same conceptual domain" (*ibid*, p.221). Of course it may happen that in an advanced physics there is no longer a use for the concept of weight, but then that advanced physics would have to depend on other concepts with strong constitutive elements in terms of which a closed system of laws with precise conditions for application can be formulated.

One further consideration is this. Mental concepts are causal concepts, i.e., concepts that have the notion of causality irreducibly built into them. An intentional action is one that is caused (in the right way) by beliefs and desires; beliefs and desires are in part identified by the sorts of intentional action they tend to cause, and in part by the sorts of event or object that regularly cause them. Of course, not only mental concepts are causal, most of the concepts that feature in commonsense explanation are.

> Many of us can do no better in trying to explain why some iron-filings moved than to say there was a magnet in the neighbourhood; we know, of course, that magnets tend to move iron filings. The concept of a magnet is a causal concept: something wouldn't be a magnet if it didn't cause iron filings to move under certain conditions. (1993b)

When causal concepts are used in an explanation, this always depends on the assumption that "a vast number of (unspecified and unspecifiable) factors that might have intervened between cause and effect did not" (1993c). When objects, states or events are described in terms of causal concepts, they do not instantiate strict laws, but rather rough generalizations that cannot be made, and are not meant to be made, precise and exceptionless. Generalizations, that is, that make use of causal tendencies, potentialities or dispositions, and that are of the following type: an object (or state, or event) that is of a certain kind has, under appropriate conditions, a cause of a certain kind or an effect of a certain kind. E.g.: a magnet causes iron filings to move under appropriate conditions; a slippery road causes appropriate objects to slip under appropriate circumstances; a belief that there is a dog before me is under normal circumstances caused by the presence of a dog before the person who has the belief; under appropriate circumstances, a desire to attract the teacher's attention causes an action of the person who has the desire of which that person believes that it will result in it being the case that the teacher's attention is attracted.

In order to arrive at strict laws, a developing physics will extrude causal concepts from its vocabulary, as the concept of a magnet is no longer needed (in an advanced physics) once it can be said explicitly what the properties are that create magnetic fields. So since mental concepts are causal, strict laws do not employ them, just like strict laws do not employ, e.g., the concepts of a magnet or slipperiness.[10)]

What the above arguments, in one way or another, all come down to is that "[t]here are no strict psychophysical laws because of the disparate commitments of the mental and physical schemes" of description and explanation (1980a, p.222). "We have such a keen interest in the reasons for actions and other psychological phenomena that we are willing to settle for explanations that cannot be made to fit perfectly with the laws of physics. Physics, on the other hand has as an aim laws that are as complete and precise as we can make them; a different aim" (1991a).

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10. It may also be that, for example, chemistry cannot be reduced to physics. Then there would be no strict chemico-physical laws relating types of chemical state or event with types of physical state or event -laws, for instance, that relate every chemical predicate C to some physical predicate P in a statement such as: for every state (event) x, if x is C then x is P.
    Note however that an argument for the irreducibility of chemistry (or biology, or solid state physics, or geology, …) to fundamental physics must be different from the above argument for the irreducibility of the mental to the physical. For the latter irreducibility derives from the normative character of mental concepts, whereas chemical, biological, etc, concepts do not have normative criteria of application. Still the latter concepts may be causal, and if they are there will be no strict laws that employ them.

Monism

As Davidson notes, it is certainly not a new point "that complete knowledge of the physics of man, even if this covers, under its mode of description, all that happens, does not necessarily yield knowledge of psychology … [In fact, it is] a point made long ago by Plato's Socrates" (1980a, p.250). Furthermore, "[t]he step from the categorical difference between the mental and the physical to the impossibility of strict laws relating them is less common, but certainly not new. If there is any surprise, then, it will be to find the lawlessness of the mental serving to help establish the identity of the mental with that paradigm of the lawlike, the physical" (*ibid*, p.223). But although its conclusion (monism) may be surprising, the argument itself is fairly simple.

The argument depends on three premises. Davidson (1980a, p.208) calls them: the principle of causal interaction, the principle of the nomological character of causality, and anomalism of the mental.

> The first principle asserts that at least some mental events interact causally with physical events. … Thus for example if someone sank the *Bismarck*, then various mental events such as perceivings, notings, calculations, judgements, decisions, intentional actions, and changes of belief played a causal role in the sinking of the *Bismarck*. In particular, … the fact that someone sank the *Bismarck* entails that he moved his body in a way that was caused by mental events of certain sorts, and that his bodily movement in turn caused the *Bismarck* to sink. Perception illustrates how causality may run from the physical to the mental: if a man perceives that a ship is approaching, then a ship approaching must have caused him to come to believe that a ship is approaching. (*ibid*)

This principle is related to the interpretative device that counsels an interpreter, in the most basic cases, to take a speaker's words and thoughts to be about the sorts of object and event that normally cause them (a device, of course, that always has to be used in combination with the other device that regulates the relations between thoughts, actions, etc).

The second principle asserts that events related as cause and effect fall under strict laws. That is, the laws, conjoined with a sentence that says one of the events (described appropriately) occurred, entail a sentence that asserts the existence of the other event (described appropriately). The key phrase here is 'described appropriately.' The principle of the nomological character of causality does not say that under every description two events related as cause and effect instantiate strict laws, but only that they have descriptions that instantiate the laws. For example, if the event reported on page 5 of Tuesday's *Times* caused the event reported on page 13 of Wednesday's *Tribune*, the principle does not say that under the descriptions 'the event reported on page 5 of Tuesday's *Times*' and 'the event reported on page 13 of Wednesday's *Tribune*' these events instantiate strict laws (and, obviously, they don't), but only that there are appropriate descriptions of these very same events that do.

The third principle is anomalism of the mental, which has just been discussed: there are no strict psychological or psychophysical laws.

Let me now give the argument for monism. It applies to mental events that causally interact with physical events, and so to all mental events in case "all mental events ultimately, perhaps through causal relations with other mental events, have causal intercourse with physical events" (1980a, p.208). Now, suppose *m*, a mental event, caused *p*, a physical event. Then, according to the principle of the nomological character of causality, under some description *m* and *p* instantiate a strict law. This law can only be physical, according to anomalism of the mental. "But if *m* falls under a physical law, it has a physical description; which is to say it is a physical event. An analogous argument works when a physical event causes a mental event" (*ibid*, p.224).[11)]

Conclusion
The ultimate physics has just been depicted as a closed system for describing and explaining that covers, under its mode of description, all that happens, and that does not contain mental concepts (or any other causal concepts). I hope it will be clear, however, that according to Davidson's position the ultimate physics should not be thought of as a replacement of or improvement on schemes that do contain mental concepts (like natural languages). Firstly, mental concepts cannot be reduced to physical concepts, and the explanations we use to render human behaviour intelligible in the way that intentional action is intelligible cannot be reduced to the explanations we use in physics. Secondly, to understand, explain or learn physics we depend, as always, on our interactions with others (knowledge of physics cannot be considered independently of knowledge of the contents of one's own and other minds), and interpersonal knowledge acquisition cannot do without mental concepts: it depends on understanding what the other is talking about, on understanding each other's reasons for believing something, on communicating with others in order to reach agreements (on how to measure weight, for instance), etc. Mental concepts and our ways to understand human thought and action are essential to all understanding, including an understanding of science.
So it does make sense to think of science as an "irreducible or semi-autonomous [system] of concepts, or [scheme] of description and explanation, but only as [it is] less than the whole of what is available for understanding and communication" (1980a, p.244). This leads to a view of "the language of science not as a substitute for our present language, but as a suburb of it" (1985b). The developing language of science, as a fragment that lacks mental concepts, needs a more comprehensive language "in which to incorporate or explain the fragment" (1980a, p.244), and which develops along with the development of the fragment. Furthermore, an understanding of science, like everything else, depends on a largely shared and correct view of the world, and its further development aims at an extension of this view. "Science can add mightily to our linguistic and conceptual resources, but it can't subtract much" (1985b).

11. Note that this argument need not only apply to mental events. If, for example, chemistry were not reducible to physics (if there are no strict chemico-physical laws that relate types of chemical event with types of physical event), it would still follow that chemical events that causally interact with physical events are also describable, taken one by one, in purely physical terms. A second note is that some mental events may also be identical with, for example, chemical, biological or physiological events, that is, have a description in chemical, biological or physiological terms.

5 A problem-posing approach to science education

5.1 Introduction

5.1.1 A crude picture of (the development of) science[1)]

In section 4.4.2 it has been argued that "[s]cience can add mightily to our linguistic and conceptual resources, but [that] it can't subtract much" (Davidson, 1985b). The addition consists, on the one hand, in the introduction of specific ways of classifying objects or events, and of relating objects and/or events to one another, and on the other in the recognition of regularities when objects or events are described in terms of these specific ways of classifying and relating. This recognition of regularities may, in the course of an empirical investigation, lead to the formulation of generalizations (inductive hypotheses), e.g.: whales are mammals; whenever a piece of metal is heated it expands. If apart from being confirmed by their instances such generalizations also support counterfactual and subjunctive claims, they may be called lawlike. Someone who knows what their positive instances are and how they cohere with those instances will then have good reason to expect that they will cohere with other instances as well, to project them to unobserved cases and to invoke them to advance counterfactual claims. This does not necessarily imply that they will also be lawlike in the sense of being very precise and exceptionless, although they may provide good reason to believe that there are more precise and more widely applicable generalizations at work and perhaps even point at ways to formulate such improved generalizations. A further addition may then consist in the introduction of ways of classifying and relating with more precise and objective criteria of application, in order to formulate more precise and wider applicable generalizations. The final goal will be generalizations whose positive instances provide good reason to believe that they may be sharpened indefinitely by drawing upon the same ways of classifying and relating in terms of which they are already formulated. It will be clear that this final goal will only be reached, if ever, in fundamental physics.

5.1.2 A few modifications and additions

Of course, the above is just a crude and very simplified picture, so let me make a few

1. This section is inspired by Davidson, 1980a, pp.207-227.

attempts to paint a somewhat more realistic one (without in any way pretending to be exhaustive). For one thing, the above does not throw any light on the actual development of science. In this respect, Poincaré distinguishes two opposite tendencies in the history of the development of science.

> On the one hand, new relations are continually being discovered between objects which seemed destined to remain for ever unconnected; scattered facts cease to be strangers to each other and tend to be marshalled into an imposing synthesis. The march of science is towards unity and simplicity. On the other hand, new phenomena are continually being revealed; it will be long before they can be assigned their place -sometimes it may happen that to find them a place a corner of the edifice must be demolished. In the same way, we are continually perceiving details ever more varied in the phenomena we know, where our crude senses used to be unable to detect any lack of unity. What we thought to be simple becomes complex, and the march of science seems to be towards diversity and complication. Here, then, are two opposing tendencies, each of which seems to triumph in turn. (1952a, p.172-3)

The crude picture may also give the wrong impression that the development of science is a straightforward process. It does not do justice, for instance, to the acts of genius and major breakthroughs that have been involved. Sometimes a specific way of classifying or relating "is so important that with its addition a whole department of science takes on a new look" (Davidson, 1984a, p.183), e.g.: the specific, though simple, way of relating events as 'occurring simultaneously' that Einstein has defined.

The process is also not straightforward in the sense that there may be competing theories, competing ways of describing and/or competing sets of hypotheses. This is quite alright, of course, as long as there is *meaningful disagreement* between the proponents of competing theories, i.e., as long as they correctly understand each other's ways of describing, know the evidence by which each other's hypotheses are supported, and so on (all of which depends, as argued in chapter 4, on common ground: a shared world, both causally and conceptually, and shared norms of rationality). They can then challenge each other and, e.g., think of experiments in which the different theories lead to different predictions, and so on.

Furthermore, the development of science has not always proceeded without difficulties. It has not always been and is not always the case, for instance, that the proponents of competing theories reach a meaningful disagreement, but instead experience sheer unsurmountable difficulties in their attempts to understand one another, even to the extent of giving up such attempts altogether. It then almost seems as if they "practice their trades in different worlds" (Kuhn, 1970a, p.150). In this connection, Kuhn has introduced the notion of 'incommensurability:' "In the transition from one theory to the next words change their meanings or conditions of applicability in subtle ways. Though most of the same signs are used before and after a revolution -e.g. force, mass, element, compound, cell- the way in which some of them attach to nature has somehow changed. Successive theories are thus, we say, incommensurable" (1970b). Now, of course, these changes of meaning are in principle harmless: they are not intractable and correct interpretation will identify them as such. In practice, however, the subtle changes of meaning with respect to some words may easily give rise to situations in which two scientists fail to recognize that they do not use those words in the same way, and as a result think they disagree on issues. In the terms of section 2.2 it can be said that they then do not properly solve the problem of interpretation: by wrongly assuming identity of meaning they come to attribute beliefs to the other that the other does not, in fact, hold, and thus come to misunderstand each other's theory. Ramberg therefore suggests to not so much think of incommensurability as a relation between theories, world views, social practices or paradigms, but rather as "a characteristic of the discourse that results when we proceed *as if* we are using the same vocabulary, and so interpret others by applying linguistic conventions to which they are not party" (1989, p.132). In any case, the communication breakdowns between proponents of successive or competing theories must be characterized as communicative failures. Whereas the 'communicators' involved may come to think of each other as "living in different worlds, [they may in fact], like those who need Webster's dictionary, be only words apart" (Davidson, 1984a, p.189).

As any human enterprise, finally, the scientific enterprise is of course also subject to all sorts of human failings. Apart from the above mentioned communicative failures, one may also think of errors in calculation and, more seriously, acceptance of doctrines on inadequate evidence, neglect of ethical issues, fraud, obsession with power, blindly following authorities, and so on.

5.1.3 Science education

The picture of (the development of) science that has been presented in section 5.1.1 gives rise to the following picture of science learning: it is a process in which pupils, by drawing on their existing conceptual resources, experiential base and belief system, come to add to those (by arriving at new ways of classifying and relating, studying events that never before they have witnessed or paid attention to, framing new inductive hypotheses, and so on), in order to further and further characterize and explain more and more aspects of the natural world. Just as in section 5.1.2 I have briefly indicated that the former picture is far too crude and simplified, I will in the remainder of this chapter illustrate and argue, in somewhat more detail, that a process of science learning too, if it is to make sense to pupils, involves much more than painted in the latter picture.

Many of the expressions that correspond to the scientific terms that are to be introduced, for instance, are also used in ordinary language, and very often in a way that differs from the way they are going to be used in the scientific theory. The introduction of scientific terms may thus involve *changes of meaning* with respect to some expressions.

Moreover, if pupils are to meaningfully engage in an activity there should be a sense in which they know why they are going to do it. They will have to develop some sense of purpose for going to study events they have never witnessed or paid attention to; the inductive hypotheses should become reasonable for them; an intention to improve on already established generalizations should come forward, etc. Furthermore, if the process of science learning is to take place at all, in the minimum sense that pupils are prepared to learn about some scientific topic, they should at least take sufficient interest in it and be sufficiently motivated to participate in a serious way. In short, pupils' process of science learning, if it is to make sense to them, not only involves additions to their beliefs and conceptual resources, with accompanying changes of meaning, but also, and irreducibly related to these, *evaluative attitudes* (desires, aims, interests, etc) and changes therein, both on a global and local level.

In sections 5.2 and 5.3 I try to illustrate that the two aspects just mentioned, the introduction of scientific terms as part of pupils' entrance into some scientific theory and providing pupils with a sense of purpose and direction respectively, are often neglected, or insufficiently or inadequately taken into account in science education. I also try to illustrate that science education is not likely to contribute, and may instead even damage, a process of insightful science learning if the two aspects are neglected or inappropriately taken into account.

In section 5.4 I sketch an approach to science education that explicitly takes these aspects into account, and whose point is, more generally, to make pupils *want* to add to their conceptual resources, experiential base and belief system, in a way that leads to their understanding of science. I do not propose this approach, which I call *problem-posing*,[2)] as a general theory of teaching and learning. I rather propose it as a programmatic view of the possibilities for improving science educational practice at a content-specific level, which are to be further explored and empirically realized by science educational research. The results of this research will then be what in section 5.4 I call *didactical structures*, roughly: examples of good science education.

5.2 The introduction of scientific terms, as part of pupils' entrance into some scientific theory

This section can be read as a continuation of section 2.2 in the sense that it further elaborates the educational consequences of the, what I consider to be, trivial point that many expressions that correspond to scientific terms are also used in ordinary language, and very often in a way that differs from the way they are used in the scientific theory that pupils are supposed to learn. It is also a continuation in the sense that I will illustrate these consequences at the (different) ways in which expressions containing the word 'force' are used in mechanics and in pupils' intuitive theory of motion (cf section 2.2.3). I hope it will become clear that the lessons which can be drawn from this particular case carry over to other cases as well.

5.2.1 Linking up with pupils' existing knowledge includes linking up with their existing uses of language

In section 2.2.3 I have summarized an intuitive theory of motion that is formulated in

2. I have chosen this name for two reasons. First, because it is part of a problem-posing approach to bring pupils in such a position that they themselves come to pose the main problems they are going to work on. Secondly, I intend problem-posing to be understood as sort of opposite to problem-solving, which in my opinion receives much to much attention, both in science education itself and in research on science education.

terms of expressions containing the word 'force' and that, thus formulated, pupils hold true. I have also noted that on the face of it (more precisely, if identity of meaning is assumed with respect to those expressions), pupils' intuitive theory is in flat contradiction with Newton' laws. However, by drawing attention to the interdependence of belief and meaning (cf section 2.2.1), I have observed that the fact that pupils hold true the intuitive theory as formulated does not yet throw any light on what it is that they believe. The problem of interpretation is that it still needs to be found out which beliefs are represented by their holding true the intuitive theory. What I have subsequently done in order to solve this problem, is to take note of the circumstances under which they hold true (fragments of) their intuitive theory, and to assign such meanings to their expressions containing the word 'force' that, thus reformulated, their intuitive theory translates into a correct pattern of beliefs. In chapter 4, moreover, I have argued that it is simply part of what it is to have beliefs at all, that correct interpretation necessarily requires us to so assign meanings to the words of others that by and large their sentences are true (according to us) under the circumstances that they hold those true. In doing so, I have also made explicit that pupils' uses of expressions containing the word 'force' cannot be interpreted in accordance with scientific usage. Their use of the expression 'to exert a force on,' for example, is such that they use it in sentences of the form '*A* exerted a force on *O*,' where *A* is an agent and *O* an object, and hold those sentences true just in case (1) there was an action of which *A* was the agent, and (2) something happened to *O*, and (3) *A*'s action caused what happened to *O*.

Let me now reverse the above line of reasoning to simply point out that it must be part of their learning mechanics that they learn to use and understand, e.g., the expression 'to exert a force on' differently from how they use and understand it before education. For if Newton's laws are understood in accordance with their pre-instructional usage, those laws are on the face of it in contradiction with the plainly correct beliefs that are represented by their holding true their intuitive theory.

5.2.2 Without linking up with pupils' existing uses of language it is unlikely that they arrive at a proper understanding of science

It is a striking feature of common courses in mechanics that they do not take into account the above simple observation that it must be part of pupils' learning mechanics that they learn to use and understand, e.g., the expression 'to exert a force on' differently. It is not only the case that no attempt is made to indicate *how* this expression is used in mechanics (and *why* it is thus used), but it is not even indicated *that* in mechanics the expression is (going to be) used differently. What comes closest is that after a presentation of Newton's first law it is usually remarked that this law seems to be in contradiction with the fact that in normal circumstances moving objects come to a stop when left on their own, but that the contradiction is only apparent because closer inspection of the circumstances reveals the presence of retarding frictional forces.

So it is pretty much up to pupils themselves to figure out, on the basis of how Newton's laws are applied in various situations by the textbook and the teacher, *both* how to describe situations in terms of expressions like 'to exert a force on' *and*, given an appropriate such description of a situation, how to subsequently apply Newton's laws to it. After some training, pupils usually acquire some ability to perform the latter step. In particular, given the forces that are exerted in a given situation, pupils are often able (apart from mathematical difficulties) to apply Newton's second law in order to calculate, e.g., the braking distance of a car. At the same time, however, many pupils (and even university students, including myself as it turned out during teacher training) are often not able to perform the first step: given relatively simple (but non-standard) situations, they are often unable to describe those correctly (i.e., in accordance with scientific usage) in terms of expressions like 'to exert a force on' (see, e.g.: Warren, 1971; Viennot, 1979; Clement, 1982; McCloskey, 1983). They do not describe situations in terms of pairs of objects that exert mutually opposed forces on each other; in the situation of a car or a bicycle travelling on a flat road they identify a balance between the 'driving force of the engine' or the 'force of the cyclist' and the resistance of the air and the road; as they used to do before instruction, they describe situations in terms of expressions like 'to have a force' and 'to get a force from,' and so on. In short, also after instruction much of their talk is to be best understood as in section 2.2.3, i.e., as in line with the intuitive theory of motion.

I think the above represents the sort of hybrid between the intuitive theory of motion and Newtonian mechanics that many pupils arrive at after common courses in mechanics, and I agree with the researchers who have established it that this is an unsatisfactory outcome. But as already noted in section 2.2.3 I do not agree with the researchers who seek the source of this outcome in the failure of those common courses to address pupils' intuitive theory in order to overcome it. It need not be overcome simply because, if appropriately interpreted, it is correct.

My own analysis of the source (or at least one of the basic sources) of this outcome is based on the observation that correctly applying Newton's laws cannot be separated from a specific way of describing situations (such that they are amenable to Newton's laws).[3] According to me, the failure of common courses in mechanics is that they neglect this 'specific way of describing' part. As a consequence, it is more or less up to the pupils themselves to fill in this part, and I think it is not surprising that this is to demand too much of many of them. But then, not being provided with additional conceptual resources, it is also not surprising that after instruction many of them only use the conceptual apparatus that they already commanded before instruction in describing (non-standard) situations.

5.2.3 Incommensurable discourse

3. **Note that this observation corresponds, more generally, to what has been argued in section 4.4.2, namely that explanations by means of laws are sensitive to how the events, situations or states to which they are to be applied are described. The reason is that laws deal, not with particular events, situations or states, but with *properties* of such. Therefore, events, situations or states only instantiate a law, and hence can only be explained in the light of a law, in as far as they have the relevant properties (the properties with which the law in question deals).**

In common courses in mechanics (as in science education more generally), there is an emphasis on quantitative exercises concerning standard and pre-fabricated situations, and I have already noted that in this area pupils usually make some progress. This one-sided emphasis may, on the one hand, further account for the fact that many pupils make little conceptual progress (cf Warren, 1979) and, on the other, explain why during those courses themselves this limited progress does not surface very often and only comes forward by research that explicitly explores conceptual progress.

The below fragment of a lesson in mechanics, however, does present an example in which, I think, the above mentioned failure of common courses in mechanics does come forward. In the lesson preceding the one from which the below fragment is taken, the pupils watched a specially developed video, which is about the forces that are acting while riding a bike. The below transcript begins with the teacher, who intends to summarize and elaborate on the video by means of the well-known air track. His introductory question, in which he asks for the forces acting on the glider when it rests on the not yet operating track, is meant to simply remind the pupils of the supposedly well-known static forces that are acting in that situation. Then the following discussion occurred, which took about twenty minutes.

1 Teacher: The video has been about forces that act when cycling. Well, here [points to the glider on the track] I have a kind of bicycle. Let me now first ask what forces are acting on it. Just try: what forces do you think are acting at this moment; are there any forces acting?
2 Eric: Gravity.
3 Teacher: Gravity, Eric says. What if gravity were the only force, what would happen then?
4 Eric: Then it would go down.
5 Teacher: Then it would go down. Ernie, what other forces could be acting?
6 Ernie: Eh ... well ...
7 Teacher: What prevents it from falling down?
8 Ernie: The track.
9 Teacher: Right, the track. So the track has to supply a counterforce to prevent the glider from falling down. Just for the sake of completeness: Eric, which direction has gravity?
10 ?: [joking] Upwards.
11 Eric: No, downwards.
12 Teacher: So, Orson, the force of the track is upwards. Right?
13 Jane: How's that?!
14 Orson: Well, otherwise it would fall down.
15 Teacher: Otherwise it would fall down, he says. So: if it did not rest on the track and I dropped it, then only gravity would act and it would fall down. If the track wants to stop it, then it will have to push the glider upwards.
16 Jane: But the track does not push, does it?
17 Teacher: The track does not push.
18 Jane: No...
19 Orson: Well, the track is just there.
20 Jane: ...it's just there.

21 [Some pupils are mumbling things like: 'Don't make such a fuss. Just accept it.']
22 Teacher: If you drop it, it will fall down, a force will act upon it.
23 Jane: Sure, if the track is not there.
24 Teacher: Okay. If you put it on your fingers... I can't take it off. [The teacher cannot get the glider off the track, and takes a small weight instead.] It's the same with this thing [the weight], isn't it. If you drop it, it will fall down. Now I want to stop it [places the weight on the tips of his fingers]. Since it is such a small weight, you don't feel much. But if you put a heavy weight on your fingers, you will feel it.
25 Jane: Okay.
26 Teacher: That is because you will have to exert a counterpressure. So you do have to...
27 Jane: Sure, if you're doing that yourself.
28 Teacher: If I place a heavy weight here, then my fingers will go down. If I want to keep it in place, I will have to push it upwards. The track will do that too, it's just that we don't notice that. We don't notice that the track does it, the track doesn't move...
29 Carl: Yes, but the track can't push upwards, can it?
30 Teacher: ... but the track in fact does it as well.
31 Carl: Yes, but the track can't do that, can it?
32 Teacher: Oh yes, it can do just that.
33 Carl: You can push upwards with your fingers, but the track can't.
34 Teacher: Let me take something else, something more flexible than metal. [fetches a piece of foam rubber and puts it in front of him] Here goes. So I will now try to convince you that the track really exerts an upward force. That is, I did agree with Orson, Jane did not, let's see whether we can come to an agreement. [puts the small weight on the foam rubber, which gets pushed in a bit] If I put this thing here, the foam rubber gets pushed in, doesn't it? Well, actually I need something a bit heavier...
35 Jane: Oh, well I do believe you as it is.
36 Teacher: Do you? So you do actually believe that. [laughter] So: the foam rubber will get pushed in, if you put something heavy on it. And if we don't put something heavy on it, but push it in and let go [does so with a finger], what will happen then?
37 Jane: Then it will come up again.
38 Teacher: Then it will come up again. Why's that?
39 Jane: Well, because there's nothing on it.
40 Teacher: Sure, but what does it do then, when it comes up? Then it pushes upward, doesn't it?
41 Jane: What?
42 Teacher: [somewhat more pressing] Then it pushes upward, doesn't it?
43 Jane: No, then it just gets back to its original state.
44 [Some pupils seem to suggest that Jane is just being stubborn.]
45 Jane: No, I don't think that has got anything to do with it.
46 Teacher: Don't you? I push the foam rubber in, put something on it, and the foam

rubber pushes it upwards. Then that is an upward force.
47 Jane: Well, I think that's really very strange.
48 Teacher: Do you?
49 Jane: Yes. That is not ... well ... no, that is not a force. I don't think it really is a force.
50 Teacher: If you want to push something up, then for that purpose you will have to exert a force. And now: [pushes the weight into the foam rubber and then lets the foam rubber spring back] it is pushed in and it pushes the weight back up.
51 Jane: Okay.
52 Teacher: But you don't think that's a force.
53 Jane: Right.
54 Teacher: You don't think that's a force. For it is the same, isn't it? And do you consider this to be a force, when it falls down?
55 Jane: Sure, that's gravity.
56 Teacher: So: the downward motion is due to a force, but if it moves up [lets the weight again move up from the foam rubber] then that is not due to a force?
57 Jane: Right.
58 [Laughter from the class. The teacher remains serious.]
59 Teacher: What if I now ... I throw it upwards, like this.
60 [Jane also begins to laugh about the awkwardness of the whole situation.]
61 Teacher: Is that a force or not?
62 Jane: [laughing] It is, of your hand it is.
63 Teacher: Of my hand it is. And now I let the foam rubber do it [again does so] and then it is no longer a force.
64 Jane: [still a bit laughing] Right.
65 Teacher: What, then, is the difference?
66 Jane: [serious again] Well, that motion just goes all by itself. That's just the way things go. [laughter] Well, I really do think that's strange.
67 Teacher: So because it goes all by itself, that is why according to you it is no force. If it now of itself gives a slap, then that will be a force.
68 Jane: Yes.
69 Teacher: I see. Well, so it seems that we haven't been making much progress. I do think there will be a force if you push it in, and Jane still doesn't think that that is a force. I'll leave it at that for a while. For the time being, everybody may think about it as he wishes. I would like to know, however, what the others do think about it.
70 [Of the others, most indicate that they agree with the teacher, while no one indicates to agree with Jane. Some pupils, among which Orson and Carl, are in doubt.]
71 Teacher: Alright. Let's leave it at that for now. Perhaps I will be able to convince you at a later time. According to me, the difference between the foam rubber and the metal is that it can't be noticed that well that the metal is springy. But also the metal has got some spring that allows it to push back. So the metal is harder and -but now I speak for myself- it gets pushed in, but it does spring back and

> thus exerts a counterforce. Okay. It is sort of funny, though, that we still don't agree.

Let me give an analysis of this transcript. A first thing to note is that the teacher analyzes his discourse with Jane as their having a *difference of opinion* about whether "the track really exerts an upward force" (34, 69). Accordingly, he sees it as his aim to convince Jane that his opinion is the correct one (34, 71). He does so, not by arguing in terms of Newton's laws as he probably quite rightly assumes this to be inappropriate at this stage, but by more or less ostensively and comparatively pointing at ever more clearly visible cases of 'acting forces.' In the end, the teacher considers his attempt a failure: "I do think there will be a force if you push it in, and Jane *still* doesn't think that that is a force" (69). Given that this is how he evaluates the situation and that he probably cannot think of any other way to convince Jane, it is a fair thing of him to explicitly state that, for the time being, he will let the matter rest (69). He even emphasizes: "It is sort of funny, though, that we still don't agree" (71).

But is the teacher right in analyzing his discourse with Jane as their having a difference of opinion? I do not think so. Of course Jane agrees that the glider's being supported by the track is similar to the weight's being supported by the teacher's fingertips in the sense that in both cases an object's falling down is prevented. Of course Jane agrees that throwing a weight upwards and letting the foam rubber do it are similar in the sense that in both cases the weight is made to move upwards. And of course the teacher agrees that the piece of foam rubber and the metal track cannot of themselves push something upwards or give a slap in the way that we can (16, 29, 33, 67-68), and that the foam rubber springs back without us having to do anything, that it goes all by itself (66). And without doubt Jane could also come to agree with the teacher (perhaps along the lines suggested by Minstrell, 1982) that the metal track is like the piece of foam rubber in the sense that it is sort of springy too, but unlike metal in the sense that metal is harder and that its springiness cannot be observed that well (28, 71).

So the teacher and Jane actually *agree* on all the similarities and dissimilarities between the various situations. Moreover, towards the end of their discourse the teacher is sort of able to predict when Jane will say that a force is exerted and when not (56, 63, 67). Nevertheless, they have an ongoing and unresolved quarrel. If they were asked the question 'Does the track exert an upward force?,' or 'Does the foam rubber exert an upward force?,' the teacher would answer 'Yes' and Jane would answer 'No' (34, 71).

According to me their discourse runs aground in this yes-no stalemate, not because they really have a difference of opinion, but simply because they do not in fact answer the same question -more particularly, because they do not assign the same meaning to the expression 'to exert a force on.' In other words, their discourse is incommensurable (cf section 5.1.2). The teacher uses the expression in accordance with scientific usage. Jane, on the other hand, uses it more or less as indicated in section 2.2.3. More precisely, I think her use of the expression is to be interpreted as follows. She uses it in sentences of the form '*A* exerted a force on *O*,' where *A* is an agent and *O* an object; she holds those sentences true in case there was an action of which *A* was the agent, and something happened to *O*, and *A*'s action caused what happened to *O*, or in case *A* supports *O* (prevents that it falls down). Again, I think this interpretation is correct simply because, thus interpreted, whenever she answers 'Yes' (or 'No') to the question 'Does this exert a force on that?' she is, according to me, right in doing so. I agree with her, for instance, that when the glider rests on the track, an utterance of *her* sentence 'The track exerts a force on the glider' is not true, simply because the track is not an agent. It could not, of itself, cause something to happen to the glider, e.g.: throw it upwards. Moreover, by asserting *her* sentence 'The foam rubber does not exert a force on the weight,' she is not denying that the weight moves upwards nor that the foam rubber has been involved in the weight's upward motion, but only, and rightly so, that the foam rubber, of itself, has caused the weight's upward motion. It is rather the teacher who, by pushing the weight deeply into the foam rubber and then letting the foam rubber get back to its original state (43), in effect has caused the weight's upward motion. So I conjecture that Jane would have answered 'Yes' if concerning this situation she was asked 'Does the teacher exert a force on the weight?' In terms of the intuitive theory of motion it might be said that the teacher hands over his force to the weight via the foam rubber.[4)]

On my analysis, the conflict that the teacher and Jane themselves think they are having (34, 69) is just an apparent one, and their discourse a communicative failure. The source of the miscommunication relates, I think, to the fact that common courses in mechanics simply neglect the 'specific way of describing' part: Jane has not picked up *that* in mechanics the expression 'to exert a force on' is used in a way that differs from ordinary usage; the teacher does not even seem to consider the possibility *that* Jane might use the expression in a way that differs from scientific usage. So if the failure of common courses of mechanics surfaces in those courses themselves, it is likely to manifest itself in the form of incommensurable discourse. The result then is that teacher and pupils will feel a gap between them or, as ten Voorde (1990) calls it, a gulf of ununderstandableness, without being able to bridge it. In the above example the teacher may have felt the gulf as his being unable (despite all his efforts) to convince Jane. Jane may have felt it by the teacher's tireless attempts to convince her of something she just cannot believe: "I really

4. I refer to Klaassen & Lijnse (in press) for a more elaborate comparison between my interpretation and one that others might give. I suppose, for instance, that Clement would attribute to Jane the, as he calls it, 'deep seated' alternative conception of 'static objects as barriers that cannot exert forces' (1993). If this supposition was correct, Clement would not sufficiently disentangle the notions of belief and meaning. That is, whereas he would, I guess, admit that pupils do not use and understand expressions containing the word 'force' as a scientist does, in his formulation of what Jane believes he nevertheless would use such expressions: Jane believes that static objects are barriers that cannot exert forces. He could thus in some sense be said to be aware of the problem of interpretation, i.e., that an identification of what Jane believes cannot be separated from an identification of the meanings she assigns to the expressions she uses to state her beliefs, but he could not be said to have solved it. For the statement 'Jane believes that static objects are barriers that cannot exert forces' is not informative as long as it is not specified what Jane means by her expression 'to exert a force on.'
Furthermore, whereas Clement would aim to make Jane "overcome the dominance of an alternative conception" (*ibid*), on my interpretation there is no need to aim at that simply because Jane's beliefs are quite alright. I do see a need, however, to make explicit and plausible a new way of using the expression 'to exert a force on.'

do think that's strange" (47; 66).

5.2.4 Creating appropriate places in pupils' existing conceptual apparatus

If Jane and her teacher had realized that their discourse was incommensurable, they would also have been able to find a way out of it: "what the participants in a communication breakdown can do is recognize each other as members of different language-communities and then become translators" (Kuhn, 1970a, p.202), instead of remaining vain convincers. The teacher might e.g. have proposed something like this: to use the expression 'to exert a force on' in sentences of the form 'O_1 exerts a force on O_2,' where O_1 and O_2 are objects and, in particular, O_1 need not necessarily be an agent; to assent to a sentence of that form just in case something happens to O_2 (or, is prevented to happen) that would not have happened (or, would have happened) if O_1 had not been there. All parties would then have assented to 'The track exerts a force on the glider,' if only because, if the track had not been there, the glider would have fallen down. All parties might eventually also have assented to 'The glider exerts a force on the track,' after it had been established that the track does get a bit deformed when the glider is placed on it. Along the same lines it might be established that then also the glider gets a bit deformed, perhaps via appropriate intermediate situations, e.g.: if one pushes down a spring with one's hand, the hand is pushed in a bit as well. The above proposal might accordingly be modified by deleting the parts between parentheses. All parties would then still assent to 'The track exerts a force on the glider.' Moreover, from the way this modification has come forward, they might even begin to wonder whether there are in fact situations in which they would assent to 'O_1 exerts a force on O_2' but dissent from 'O_2 exerts a force on O_1.'

Let me try to draw some lessons. Note, first of all, that I have only brought forward the above proposals in order to illustrate that Jane and her teacher might have got out of their incommensurable discourse. I have not meant to suggest that the proposals are useful intermediate steps if one aims to devise a course in mechanics in which pupils do arrive at a proper understanding. What I do want to suggest, however, is that in such a course it will at least be necessary, in order to prevent incommensurable discourse, to make *explicit* agreements concerning the way that, e.g., the expression 'to exert a force on' is going to be used. What I would also like to suggest is that this will be necessary but not yet sufficient. For suppose that the last proposal above is indeed useful in the light of a further development towards Newtonian mechanics, and that it is indeed explicitly brought forward *that* the expression 'to exert a force on' is going to be used thus. What is still lacking then, is that pupils need not yet appreciate *why* they should thus use the expression, i.e., what the point is of having available a relation that holds between two objects whenever something happens to the one object that would not have happened if the other had not been there.

In my opinion this poses an important educational task, and not just in the case of mechanics. It concerns, more generally, the introduction of scientific terms in a for pupils meaningful way, as part of their entrance into some scientific theory, namely: to *induce* in pupils a *need* or, at least, *good reasons* for having available the terms that one intends to introduce. This need or these good reasons are to create, so to say, a place in pupils' conceptual apparatus for the term to be introduced to occupy.[5)] I also think that in general this task is non-trivial, because generally pupils' reasons, or need, for having available a particular term cannot, at the stage that it is to be introduced, coincide with what may be called the teacher's or curriculum deviser's reason to introduce it, namely that having available such a term is useful in the light of a further development towards a scientific theory. For the case of mechanics, I have not yet given this important task enough thought and therefore I now refrain from making any suggestions. I refer to chapters 6, 8 and 11 for some suggestions concerning cases that I have given some thought.

5.3 Providing pupils with a sense of purpose and direction

This section concerns the evaluative attitudes that, as I have already indicated in section 5.1.3, ought to be explicitly taken into account in science education (along with the cognitive attitudes, of course). The evaluative attitudes that I have in mind here not so much concern pupils' perception of the affective climate of the learning environment (cf Créton & Wubbels, 1984; Wubbels & Levy, 1993b; see also section 10.2), but rather pupils' perception of their learning process with respect to content. This is not to say, of course, that I consider the former unimportant or independent of the latter, but simply that my focus of attention is on the latter, if only because I think that the latter receive far too little attention in (research on) science education.

As a consequence I do not focus on interpersonal teacher behaviour that is appropriate in order to create and maintain a classroom atmosphere that pupils appreciate as positive, but on content-oriented ways of planning and guiding that are appropriate in order to create and maintain a learning process that pupils appreciate as an internally coherent one with a certain direction, and in whose development with respect to content they take an active interest. Or rather, in this section I focus on ways of planning and guiding that are not particularly appropriate in this respect. It is perhaps good to note at the outset that by criticizing these ways of planning and guiding I do not intend to offend anyone, but to make a plea for explicitly taking into account the content-directed evaluative attitudes in planning and guiding science education, and to show that appropriately doing so poses a non-trivial educational task.

5.3.1 Traditional science education

With varying degrees of emphasis, I think the traditional setting in which much science education tak s place is as follows. There is a textbook whose main line is a story in which the authors present, explain and illustrate the theory. The pupils are to read (study) this story, often as homework, and during lessons the teacher tells the story in his or her own words and answers pupils' questions about it. In the textbook the story is regularly interrupted by suggestions for experiments, which usually are to further illustrate the

5. Note that this task is also relevant if the introduction of the scientific term does not involve a change of meaning, i.e., if there is no ordinary use of the expression corresponding to the term.

theory, and by exercises with various degrees of difficulty, by means of which pupils are to digest the theory. The experiments are carried out by the teacher or, if they are not too difficult and time-consuming, by the pupils (often in small groups). The teacher selects the exercises that the pupils are to make, usually as homework. Later on (e.g., in the next lesson), the teacher makes clear what the right answers to the exercises are, e.g., by showing (or letting pupils show) how to arrive at those answers, or by pointing out what pupils who have arrived at the wrong answer have done wrong (or by letting other pupils point that out). At regular times, finally, there are tests, in which pupils are to solve some problems that (mostly) do not deviate much from the earlier exercises.

Below I somewhat further elaborate this traditional setting, in order to indicate that it does not seem very suited to actively involve pupils in the development of their learning process with respect to content.

Following a rational reconstruction

The pupils are hardly challenged to play an active role in the establishment of the theory. They rather are expected to (be able to) *follow* the story in which the authors present, explain and illustrate the theory, by reading the textbook and listening to the teacher. The story itself, moreover, is often of a kind that does not really stimulate pupils to take an active interest in following it. For it is often cast in the form of, what may be called, a rational reconstruction. That is, the content is sequenced in a way in which someone who has already mastered the knowledge may, in hindsight, conveniently reconstruct or summarize it, or build it up from first principles. In chapter 3 I have, in this respect, pointed at the common practice of basing a treatment of the topic of radioactivity upon micro-level explanations. One may also think of the common practice to almost immediately present Newton's laws in introductory courses in mechanics, to quite early introduce molecules in chemistry courses, and so on. The story is thus not really written from where pupils are, but rather from where they should end. Moreover, for someone who has not already mastered the knowledge, the point of earlier parts of the story can, at best, only come forward in hindsight, in later parts of the story (or by making the exercises).

Explaining from above

I think it is also quite common in a traditional setting that in their explanations teachers do not really involve pupils. For although teachers usually do their utmost to make themselves understood, they often do not involve pupils in the process of making themselves understood or in finding out whether they have made themselves understood as intended (and thus fail to do what, as argued in chapter 4, is an essential ingredient of mutual understanding). Of course, teachers do ask questions in order to check whether they have been understood, but then this check usually consists in checking whether a pupil gives the correct answer, i.e., the answer they themselves would give. If not, teachers often do not try to understand the pupil's answer (e.g., what exactly it is that the pupil answers, and why) but make sure that the correct answer comes forward, perhaps by asking another pupil and still another until eventually the correct answer is given, or else by giving the correct answer themselves. And if a pupil asks a question, teachers often do not make a real effort to understand that question (what exactly it is that the pupil asks, and why), but simply give the correct answer to the question as they understand it. The below fragment is an example of the latter. It is taken from a lesson in a middle ability class that used the unit *Radiation, you cannot avoid it...* (cf. chapter 3). The lesson was about chapter 4 of that unit (cf. figure 3.1). Earlier in the lesson the teacher had shown a Geiger counter to the pupils and had held it close to a jar containing some radioactive stones.

1	Sandy:	But Sir, I've seen a film [probably Silkwood] and that was in a nuclear power station...
2	Teacher:	Yes.
3	Sandy:	...and somebody there was contaminated. Then they are cleaned with a steel brush. But it will have gone inside, won't it?
4	Teacher:	Yes, but were they ...? Then some radioactive substance had come on them.
5	Sandy:	And then you heard a bell ring when you passed underneath.
6	Teacher:	Right.
7	Sandy:	They wore a suit and things like that...
8	Teacher:	Yes.
9	Sandy:	...but it will have gone through, won't it? And still they are...
10	Hank:	Well, you had to hold your hands in this way on that thing.
11	Sandy:	Yes.
12	Teacher:	Well, perhaps it will be on the suit, won't it.
13	Sandy:	Yes, but you had to hold your hands before it, didn't you.
14	Hank:	When you've got too much of it on your hands, it will ring
15	Sandy:	So that's what they had ... when you've got that, it will ring very loudly.
16	Teacher:	Yes. Well, you could ... Look, suppose an accident happens in that power station, Sandy. Or you do something wrong, take hold of radioactive substances or something. Of course you can take hold of a stone like that [points to the radioactive stones in the jar] and then there will always come some small bits on your skin and on your clothes ... always. And when you then walk underneath or past a Geiger counter, you will hear it tick. Well, that's roughly how the system works.
17	Sandy:	Never mind.
18	Teacher:	[somewhat surprised] Yes. Well, that is indeed ... that is a safety measure.

Note, first of all, that by building on the information that the pupils provide (some people were contaminated, 3; a bell rang when they passed underneath, 5, or held their hands before it, 13-15), the teacher gives a correct explanation of the situation: some radioactive substance had come on them (4) or on their suits (12); perhaps because they had accidentally taken hold of some radioactive material, just like if we took hold of one of those radioactive stones, some small bits would come on our skin or clothes (16); what they passed underneath or held their hands before, was a Geiger counter (16); the Geiger counter would tick if we, with small bits of one of the radioactive stones on our skin or clothes, walked past it (16). Thereby the teacher has also answered what he takes to be Sandy's question: what the point is of brushing contaminated people.

Nevertheless, Sandy does not accept the teacher's explanation and, in the end, withdraws: Never mind (17). The reason is, I think, that in her opinion the teacher has not answered *her* question. For her question is what the point of brushing is when it has already gone inside (3, 9). 'It' here probably refers to what in section 2.5 I have called radiation*: the highly penetrative instrument that, as long as it is inside an object, causes damage to that object. So by talking about radioactive stones and Geiger counters (16), she may have felt that the teacher is simply parrying her question. *We* know, of course, why the teacher is talking about radioactive substances and Geiger counters. For the teacher and we know that a Geiger counter does not tick near a person that has been close to, but has not touched, a radioactive object: one does not get contaminated by irradiation. Sandy probably does not know this, and most likely uses the expression 'is contaminated' as indicated in section 2.5: as applying to objects that have received radiation* (and therefore may do damage to their surroundings). So when she now hears that the apparatus underneath which the nuclear workers had to walk or before which they had to hold their hands is a Geiger counter, just like the one she has seen earlier in the lesson, for her (unlike for the teacher and us) this does not imply that the nuclear workers who caused the bell to ring must have carried radioactive material on them. After the teacher's explanation, therefore, her question still stands.

As in the fragment discussed in section 5.2.3, we may say that here too there is a gulf of ununderstandableness. Sandy's withdrawal may show that she has felt the gulf. The teacher's surprise after Sandy's withdrawal may show that he has felt it too: he may feel he has given a clear explanation (as indeed he has for those who know enough), and still Sandy does not seem to understand.

I think that the phenomenon of explaining from above, i.e., of giving explanations that are clear for those who already know enough, is quite common in traditional settings, but that its consequences do not often come forward as clearly and immediately as in the above fragment (namely in the form of an explicit withdrawal). I think that implicit withdrawals are its more common consequences, e.g.: not paying attention to the explanations; stop asking oneself and the teacher questions; simply taking the explanations for granted; only trying to meet the teacher's standards and to say what the teacher wants to hear.

I also think that the tendency to give an explanation from above, in the expectation that pupils will be able to follow it, is related to the earlier mentioned tendency to so sequence the content in textbooks that someone who already knows enough understands it, in the expectation that thus presented pupils will at least be able to follow it.[6] Both tendencies, however, at least do not really stimulate pupils to take an active interest in following, simply because no real effort is made to make pupils see the point of following (or to check whether pupils already know enough in order to be able to follow).

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6. Towards the end of section 5.2.3 I have pointed at a similar relation. The fact that in the fragment discussed there the teacher did not even seem to consider the possibility *that* pupils might not quite use their words as he does, is in my opinion related to the failure of common science courses to pay any special attention to the introduction of scientific terms, as part of pupils' entrance into some scientific theory (in the case discussed there: Newtonian mechanics).

Cookbook experiments
I think that also the experimental work in traditional settings does not really involve them in the development of their learning process with respect to content. For the experiments that are performed by the teacher are usually part of an explanation from above, in which the teacher explains the experimental setting, indicates what to observe, draws the conclusions, etc, while the pupils sit and watch. The situation is not essentially different, moreover, concerning the experiments that the pupils themselves perform. For usually, and up to university levels (see, e.g., van Keulen, 1995), these experiments are of a cookbook nature: it is prescribed, step by step, what to do, and not infrequently also what to perceive and conclude.

Thus, pupils not only do not really learn to experiment (to plan, devise, control, etc), but also do not really come to appreciate the point of experimentation in science. It may even be said that in traditional settings experimentation does not play a functional role in pupils' conceptual development. Although experimentation may, e.g., serve to bring some variation in lessons or to increase pupils' ability to handle equipment, as far as following the story of the authors is concerned, I think it does not really matter whether the experiments are actually performed (by teacher or pupils) or just verbally explained by the teacher and read by the pupils.

Emphasis on (the right answers to) exercises
I think it is a familiar fact that in traditional settings there is an emphasis on exercises. It is also in these exercises that, in a sense, the pupils take an active interest. It is not so much that the exercises contribute to pupils' taking an active interest in the development of their learning process with respect to content: the problems that are posed in the exercises commonly are not pupils' problems; they are usually simply presented to pupils, without any attempt to give those a point for pupils; instead the problems are most often pre-fabricated from above such that the theory can be applied in a standard way; the answers to the exercises are usually explained from above, in order to clearly bring forward the standard ways of applying the theory, etc. I think the pupils rather take an active interest in the exercises because those are related to the tests. It is in their best interest, so to say, to try to meet the teacher's standards by training themselves to solve problems like the teacher has solved similar ones. For if, with the help of the teacher, they manage to find out how to solve the standard problems, that will increase their chances at getting sufficient results at tests. In the worst case, the whole point of their learning process for pupils reduces to getting the right answers, in one way or another, to the exercises.

I think that this emphasis on exercises (at least partly) accounts for the familiar finding of science education research that, on the one hand, pupils generally make some progress in solving standard problems but, on the other, little conceptual progress (see section 5.2.2 for an example). In particular, as remarked in section 5.2.3, the emphasis may both account for and mask their limited conceptual progress. In the worst case, the result may be, e.g., applying formulas without insight, memorizing tricks to solve standard problems, verbalism, or compartmentalization. As Poincaré has put it for the case of mechanics: "There is one thing that strikes me, and that is, how far young people who have received a secondary education are from applying the mechanical laws they have been taught to the real world. It is not only that they are incapable of doing so, but they do not even think of it. For them the world of science and that of reality are shut off in water-tight compartments" (1952, pp.137-8).

5.3.2 Approaches that centre around 'overcoming alternative beliefs'

In recent years some approaches to planning and guiding science education have been proposed, usually under the banner 'constructivism,' that, as far as I understand them, capitalize on the idea that what pupils already know is often in contradiction to the scientific knowledge that they are to learn. One may think here of the status-changing-model proposed by Posner *et al* (1982), of conflict strategies (e.g., Nussbaum & Novick, 1982) and bridging strategies (e.g., Clement, 1993), of the constructivist teaching scheme proposed by Driver & Oldham (1986), and so on. The emphasis in all of those is, in one way or another, on the alternative beliefs that pupils are to overcome in their process of learning science. I will not comment in any detail on those approaches, most of which are of a rather general nature, but just make some general comments on them and then discuss in somewhat more detail a concrete constructivist teaching sequence.

Let me begin with the general comments. The first one is that in all of the above approaches pupils are given the opportunity to take a much more active role than in a traditional setting. They are, e.g., challenged to engage in activities such as group discussion, designing posters and predicting the outcome of experiments. It turns out that pupils are not only willing and able to take a more active role, but also enjoy that. All this is very positive, of course, because it will increase their involvement in the process. So concerning this aspect of encouraging pupil contributions I am with those approaches.

My second comment is that concerning the other general aspect that those approaches have in common, namely their emphasis on the alternative beliefs that pupils are to overcome, I am not with them. In section 2.2.3 I have tried to illustrate at a few concrete cases that pupils' existing ideas are quite alright and not, as held by proponents of the above approaches, alternative or in contradiction with scientific knowledge. In chapter 4, moreover, it has been argued at some length that correct interpretation forestalls the possibility of finding that a great deal of the beliefs of others are incorrect. So, according to me, much of the point of the above approaches falls away. Although, as remarked in section 2.2.3, I do not mean to imply that pupils will never have to subtract anything from what they believe, it makes no sense to centre an educational approach around pupils' supposedly alternative beliefs. As suggested in section 2.2.3, we should rather search for an approach whose emphasis is on making pupils want to add (substantially) to what they already believe in a way that leads them to a proper understanding of scientific knowledge.

Let me now discuss a paradigmatic example of a concrete teaching sequence that centres around pupils' supposedly alternative beliefs, namely the CLISP-approach to teaching the particulate theory of matter (1987). I will argue that this approach, precisely because of its emphasis on the supposedly alternative beliefs that pupils are to reject in favour of appropriate scientific ones, fails to involve pupils in a learning process that might eventually lead to a proper understanding of scientific particle models.[7] As a side-line I also indicate what, according to me, the educational task of making pupils see the point and direction of such a process consists in. In doing so it will also come forward that this is a non-trivial task.

Let me first briefly describe how the devisers of the CLISP-approach themselves account for it (see, e.g., Driver, 1988; Johnston, 1990; Scott, 1992). The approach begins with asking pupils for their own ideas about a number of simple phenomena relating to the behaviour of matter (e.g., how smell reaches you). By means of a number of theory making games that are set in non-scientific contexts (e.g., solving a murder mystery), pupils are then encouraged to reflect on their understanding of theories and how those are developed. Next pupils are asked to put forward their own ideas about the properties of solids, liquids and gases and are stimulated to reach a consensus on a pattern of properties. Subsequently pupils are to generate a theory as to what solids, liquids and gases are like inside, while they are reminded of the general nature of theory making and encouraged to base their theory making in the case at hand upon the pattern of properties of solids, liquids and gases. Although up to this point pupils are left completely free in what they bring forward, it turns out, as was expected and/or intended by the devisers, that in a wide range of classes pupils reach consensus on a similar sort of pattern of properties (e.g., solids have a definite and fixed shape, liquids take the shape of the container, gases have no shape but rather completely fill the container), that they generate particle models in order to account for the behaviour of solids, liquids and gases as described by the pattern (e.g., a solid cannot be compressed because its particles are so close together that they cannot be pushed any closer), that some of their particle ideas are alternative (e.g., they attribute macroscopic properties such as expanding to particles or hold that there is air between particles), and that some ideas of the school science view are lacking in their particle models (e.g., particles have intrinsic motion). The heart of the CLISP-approach then consists in making pupils remove their alternative ideas and adopt the appropriate scientific ones (e.g., by thought experiments to encourage them to consider the possibility that there might be nothing between particles, by diffusion demonstrations to make them recognize that particles have intrinsic motion, or by direct explanations of what scientists think).

A first thing to note about this account is that particle ideas or particle models are attributed to pupils because they use words like 'atom,' molecule,' or 'particle,' and/or draw discrete entities in their pictures of what something is like inside. Furthermore, some of their particle ideas are counted as alternative because they attribute macroscopic properties such as melting or expanding to particles.

Now, one is of course free to call what pupils bring forward 'particle ideas' or 'particle models,' but I think one should then also clearly bear in mind that their ideas are not about the particles that figure in scientific particle models and that their models are of a different nature than scientific particle models. For, as already explained in section 2.2.3,

7. Similar arguments can be given concerning other concrete teaching sequences with the same emphasis.

if one clearly separates the notions of belief and meaning, it is clear that from the way pupils use words like 'particle of ...' or 'atom of ...,' one cannot do better, in order to make them make sense, than interpret those as 'tiny bit of ....' So the statement that pupils come up with ideas about particles/atoms, some of which are alternative, then simply amounts to the statement that pupils believe that a substance can be divided in little bits that, apart from their size, are just like larger amounts of the substance (have the same macroscopic properties, are subject to the same macroscopic regularities, and so on). Their particles simply are small-scale macroscopic objects, and their particle models simply are macroscopic accounts.

However, because of its emphasis on the supposedly alternative particle ideas that pupils are to reject in favour of appropriate scientific ones, the CLISP-approach in effect *does* equate pupils' particles to the particles that figure in scientific particle models, and *does* treat their particle models as on a par with scientific particle models. Or, to put it from the pupils' point of view: in the CLISP-approach they are to replace some of their existing ideas about *their* particles by other ideas about *their* particles, which are then called 'scientific.'

So in my opinion the CLISP-approach misfires. If appropriately interpreted, there are no alternative beliefs to overcome (e.g., there is no need to make pupils abandon the idea that *their* particles expand when heated) and to be replaced by 'scientific' ones (e.g., there is no need to make pupils learn that *their* particles have intrinsic motion or that there is nothing between *their* particles). Moreover, by unjustly equating pupils' particles to the particles that figure in scientific particle models and by treating their particle models as on a par with scientific particle models, the CLISP-approach also cannot lead to a proper understanding of scientific particle models. At best, pupils will arrive at a hybrid between their particle models and scientific particle models. So it comes as no surprise to me that between two parallel groups, of which one used the CLISP-approach and the other the school's traditional approach, "there was little difference ... overall in the conceptual change produced" (Driver, 1988).

Let me now close this section with an indication of what the educational task of making pupils see the point and direction of a process that eventually does lead to a proper understanding of scientific particle models might consist in. I think for instance, that it should not only become clear to pupils that devising a scientific particle model is a form of theory making that, just like e.g. solving a murder mystery, involves framing tentative hypotheses on the basis of available clues etc, but foremost also that it is the making of a theory of a *special* kind and that making it of this special kind imposes constraints on the framing of hypotheses.

What is special about a scientific particle model, or at least a classical one, is that it aims to explain, under the assumption that an object is a certain collection of particles with specified masses, all macroscopic changes of that object solely in terms of changes of position and velocity of those particles due to their mutual interactions. The explanation, moreover, is also of a special kind and involves the use of hypotheses of two kinds: hypotheses that allow one to derive, given the positions and velocities of the particles at some time, their positions and velocities at a later time (e.g., hypotheses concerning the way the particles collide, or concerning the interactions between the particles); hypotheses that link the state of the collection of particles to macroscopic properties of the object (e.g., the mean kinetic energy of the particles in the collection is the temperature of the object). This crudely indicates the general form of any scientific particle model.[8)]

The above can also be said to indicate the general framework within which further specific hypotheses are to be made in order to arrive at some specific scientific particle model. I therefore think that the above mentioned educational task, of making pupils see the point and direction of a process that eventually does lead to a proper understanding of scientific particle models, consists in making pupils arrive at a sufficient insight in why the general framework is as it is. For once they have this insight, what they are going to do next, namely devise and modify specific scientific particle models, can be given a point that they understand, while they are then also provided with a sense of control over what comes next in that they themselves can judge whether the further specific hypotheses that are made satisfy the constraints the framework imposes. The framework will then function, so to say, as a stable background that enables pupils to perceive the further process as an internally coherent one with a certain direction: the specific models may change in order to explain better or more, but the general framework remains the same.

Meeting the educational task, i.e., making pupils arrive at a sufficient insight in why the general framework is as it is, is of course far from simple. Among other things, the following should become clear to pupils. Why one would want to improve on macroscopic explanations of macroscopic phenomena in the first place. Why, if there is a need for improvement, it is plausible, in order to attain the desired improvement, to assume that an object is a collection of particles. In what sense these particles differ from

8. Note, first of all, that the particles that figure in any such model are not pupils' particles. Within any such model it simply is not allowed to use in an explanation, e.g., the hypothesis that particles expand: everything has to be explained solely in terms of changes of position and velocity of the particles due to their interactions. Furthermore, the only property that is attributed to the particles in any such model is that they have a fixed mass. This is not to say that, e.g. when picturing the particles, one is not allowed to attribute colour and shape to them or even to draw something other than particles between them, as long as in explanations one makes no use of the colour and shape thus attributed to them or of the something that is imagined between them.

Note, further, that the above scheme not only indicates the general form of classical particle models but also applies, with appropriate modifications, to the formalism of quantum field theory. One modification in that case concerns the properties that are attributed to the particles. Apart from their mass, also their charge, spin, charm, strangeness, etc are specified. Another modification concerns the hypotheses of the first kind: in quantum field theory the interaction between the various kinds of particles are specified in the form of a particular Lagrangian density, by means of which it is possible to calculate, by specified procedures, the transition probability from an initial many particle state to some final many particle state. The initial many particle state specifies how many particles of this kind with this momentum, this component of the spin along a specified direction, etc, how many of that kind with that ... etc, are present before the interaction takes place; the final many particle state how many particles of this kind with this ... etc, are present after the interaction has taken place. One of the differences with a classical model is that there may be a non-vanishing transition probability to a final many particle state in which a different number of particles (of some kind) is present than in the given initial many particle state.

small-scale macroscopic objects. Why one wants to give explanations solely in terms of changes of position and velocity of the particles, and why it is plausible to expect that all (or at least a great number of) macroscopic changes can be explained in these terms. Why, in order to give such an explanation, one needs the two kinds of hypotheses mentioned above, and what the explanation then consists in. How further specific hypotheses can be arrived at. In what sense some specific particle model can be called better than another one.

I hope this suffices to not only make clear that the real educational task is non-trivial, but also that the CLISP-approach does not meet it at all and, in fact, draws one's attention away from it. What I would like to retain from the CLISP-approach is to give pupils an active role in the process. They enjoy that and will thus be more involved in the process. But whereas in the CLISP-approach their involvement consists in their bringing forward ideas about their particles, I would like it to consist in their seeing the point and direction of, and their having control over, constructions and reconstructions of specific scientific particle models.

5.4 Didactical structures

5.4.1 A problem-posing approach: making pupils want to add to their conceptual resources, experiential base and belief system

As will have become clear from the preceding sections, I think that the main possibilities for improving science educational practice at a content-specific level are to be sought in appropriately taking into account the content-directed evaluative attitudes (and not, for instance, in taking into account supposedly alternative beliefs). That is, as far as the cognitive attitudes are concerned it has been argued that pupils' science learning should be thought of as in the crude picture presented in section 5.1.3: it is a process in which pupils, by drawing on their existing conceptual resources, experiential base and belief system, come to add to those (with accompanying changes of meaning). What I think needs to be added to this picture is that, if the process is to make sense to them, pupils must also be made to *want* to add to those (with accompanying changes of meaning), in a way that leads to a proper understanding of science. An approach to science education that explicitly aims at this I call *problem-posing*. If one adopts this approach, one will not unquestioningly assume (as in many traditional science curricula) that pupils simply stand ready to absorb new knowledge, such that all one has to do is present them this new knowledge. Rather, the emphasis of a problem-posing approach is on bringing pupils in such a position that they themselves come to see the *point* of extending their existing conceptual resources, experiential base and belief system (with accompanying changes of meaning) in a certain direction. Let me give some examples.

In section 5.2.4 it has been argued that if the introduction of a scientific term is to make sense to pupils, it should have a point for them. They should feel some kind of need for, or at least have good reasons for, having available a term of the kind one intends to introduce. This need or these good reasons are to create a place in pupils' conceptual apparatus for the term to be introduced to occupy. The need or good reasons, moreover, will in general have to be induced in one way or another. For if they already existed, i.e., if the place was already created, it most likely would already be occupied, i.e., there most likely would be no need to introduce the scientific term because pupils would already have it at their disposal.

In general there will also be no existing want of pupils to learn the particular content one intends to make them learn, if only because they do not yet know that particular content. So in general one will have to induce such a want. A first step in this direction might consist in connecting the content that one eventually intends pupils to arrive at with their existing interests. These existing interests may then induce in pupils, what may be called, a global motivation for at least beginning to study the topic at hand, and at the same time provide them with a, without doubt still very vague, sense of purpose and direction concerning where their study will lead them to. As already noted, this can only be a first step.

Further, and more specific, wants will have to be induced in the further process, e.g.: a want to enlarge their experiential base in a certain direction, in order to find an answer to a question that has, in turn, been induced earlier in the process. In order to comply with that want they may subsequently devise an experimental setting, by means of which they expect to so enlarge their experiential base that they will find an answer to the question. They will then evaluate their subsequent experimentation in the light of this expectation, as a result of which a need may come forward for an improvement of the experimental setting, for further experimentation, and so on.[9)] In the course of their experimentation, moreover, they may come to recognize regularities and come to frame inductive hypotheses. Since they have then played an active part in the establishment of the hypotheses (on which evidence the hypotheses are based and how the evidence coheres with the hypotheses), they will also appreciate how, when, and when not to apply those. Perhaps they also come to see some of the limitations of the established hypotheses, which may then, in turn, create a need to improve on those. And so on.

From the above examples it will be clear that it is an essential ingredient of a problem-posing approach that pupils' reasons for being involved in a particular activity are induced by preceding activities, while that particular activity in turn, together with its preceding activities, induces pupils' reasons for being involved in subsequent activities.[10)] Thus their process of science learning is, at any stage, provided with a local point, which is to locally involve them in the development of the process with respect to content. Another essential ingredient of a problem-posing approach is that their process is provided, at appropriate stages, with a global point, e.g. by making them see a connection with existing interests, or by bringing them in such a position that they themselves come to pose a main problem that they intend to work on. A global point is to induce a (more or less precise) outlook on the direction that their process of science learning will take, and thus to increase their involvement in the further development of the process with respect

9. Note that thus, other than in traditional settings (cf section 5.3.1), experimentation *does* play a functional role in the development of pupils' learning process with respect to content.
10. Ten Voorde (1977) speaks in this respect of '*being prepared by*' and '*preparing for*.'

to content.

It is perhaps worth noting that it is *not* the point of a problem-posing approach that everything should come out of the pupils themselves. If, for instance, pupils themselves have framed some problem they intend to work on, the teacher might well offer some elements of its solution. The point then rather is (1) that the teacher can explicitly offer these elements as possible elements of a solution to their problem, (2) that the pupils, given that they intend to solve the problem, will be willing to investigate whether these elements do contain clues for a solution, and (3) that they will be able to do so, given that they have a clear understanding of the problem since they themselves have formulated it. More generally, the point of a problem-posing approach is to enable pupils to themselves perceive their process of learning science as an internally coherent one with a certain direction, which in important respects is being driven by their own questions and over which they have some control.

5.4.2 Planning pupils' science learning as a dynamical process of rational accommodation

In planning a problem-posing approach to teaching some scientific topic, one not only needs to think about which new scientific terms will have to be introduced to pupils, which experiments they will have to perform in order to learn which new knowledge, etc. Irreducibly related to that, one also needs to think about the interests, aims, desires, intentions, etc, that one will have to link up with, change or induce. A detailed planning of how, for the topic at hand, a given order of tasks and teacher interventions, in relation to pupils' reactions to those tasks and interventions, is expected to lead to which changes of meaning, additions of belief, changes of intention, etc, I call a *didactical structure* of that topic. It contains, for example, statements of the following kinds: which experiments pupils will think of, given what they believe and what they want to achieve; which conclusions and questions they will formulate as a result of their experimentation; what point those questions will give to the next task, etc. Note that if we are to account for such statements, we will have to make such assumptions as the following: when thinking of experiments pupils will think of ones that, given what they believe, can reasonably be expected to lead to a desired result (e.g., an answer to a question they themselves have posed); they will base their hypotheses in a sound way on the relevant evidence; they do not accept contradictions in their system of beliefs and, if such threaten to occur, intend to resolve the matter (e.g., by withdrawing an over-generalization), etc. What such assumptions come down to, is that we can view pupils as rational agents, who share with us a largely correct view of the world and basic standards of rationality.

When pupils are viewed as rational agents, the development of their learning process with respect to content can be planned as a dynamical process of rational accommodation, in which pupils intentionally act to keep their system of thoughts as coherent as possible by adjusting it as rationally as possible as new thoughts are thrust on them. The outcome of an experiment they have performed for reasons that made good sense to them, for example, will cause them to add to their stock of beliefs. Rational accommodation of that belief may lead to new questions that pupils want to find an answer to, to the formation of an intention to focus their attention on some aspect of an event, to their seeing the point of classifying events in a particular way, etc.

Let me make some additional comments. Note, first of all, that it is only when the evaluative attitudes and changes therein are explicitly taken into account in pupils' science learning, that it makes sense to try to give a dynamical account of the development of their learning process with respect to content. This observation corresponds to, and is inspired by, Davidson's observation that the evaluative attitudes do also play a fundamental role in interpretation (cf chapter 4 and appendix 1).

A second comment is that, as argued in chapter 4, the policies that are required in a process of rational accommodation derive from understanding someone else, and making oneself understood by others, as a rational agent. These policies, which in chapter 4 have been taken together under the heading 'principle of charity,' are therefore most naturally called for in an interaction with others. For this reason I think pupils should be allotted an active role in their learning process and, in particular, be challenged to work and discuss with each other. An additional reason, already mentioned in section 5.3.2, is that pupils generally like group work and having an active role, and thus will be more involved in the process when they are working in groups and are given the opportunity to take an active role.

A final comment is that a didactical structure of some scientific topic (as a planning of pupils' science learning in the form of a dynamical process of rational accommodation) should not be confused with a rational reconstruction of the topic of the kind mentioned towards the beginning of section 5.3.1. The point of the former is to plan pupils' process of learning the topic in such a way that all along the pupils themselves know what they are doing and why, and that by building on what they already know are given ample chance to further extend what they already know, driven by what they themselves are doing, by their reasons for doing it, and by the conclusions they reach and problems they encounter as a result of doing it. The point of the latter is to reconstruct the topic in hindsight, not by describing the actual route along which it has been mastered but, having already mastered it, by conveniently building it up from first principles. As such, it may have a place in a problem-posing approach, but only towards the end of the learning process, as a kind of summarizing activity.

5.4.3 An outlook

What I have written above on a problem-posing approach and on didactical structures is rather programmatic (and intended as such). What it suggests, and what I take as an important task of science educational research, is to devise, empirically test, improve, etc, *concrete* didactical structures, with as eventual aim an empirically based didactical structure of science (Lijnse, 1995), which I think of as constituting science educational theory. In the remaining chapters I will take a few steps in this direction. In chapter 6 I will mention some possibilities for outlining a didactical structure at a global level. In chapter 7 I discuss some aspects of devising a didactical structure. In chapters 8 and 9 I present and evaluate a concrete didactical structure, namely of the topic of radioactivity. In chapter 11 I present some (preliminary, fragmentary and immature) suggestions for future steps.

Let me close by making a few remarks on two aspects that I have neglected up to now:

the role of the teacher and the role of teaching materials in a problem-posing approach. Although their roles are different than in traditional settings, in a problem-posing approach too both the teacher and teaching materials play an important role, namely in guiding and structuring the process of rational accommodation that pupils establish and give shape. Whereas in a traditional setting the teaching materials usually consist in a textbook, whose main line is a story in which the authors present, explain and illustrate the theory, and which the pupils are supposed to follow (cf section 5.3.1), in a problem-posing approach the teaching materials consists in a collection of tasks, whose purpose is to help pupils in writing their own story (cf section 8.2). In chapter 10 there is more on the role of the teacher. Let me here just note that, whereas in a traditional setting the teacher's role often comes down to explaining from above (cf section 5.3.1), in a problem-posing approach the teacher's role is rather one of, what may be called, guiding from below.

10 The teacher's role

10.1 Introduction

In the preceding I have repeatedly pointed at (the importance of) the role of the teacher. In chapter 8 I have noted that the teacher's role in working with a didactical structure as the one outlined there is different from the teacher's role in more traditional approaches. For example, giving pupils more control over, and thus more responsibility for, their progress with respect to content implies a shift in the teacher's control and responsibility: a shift towards procedural control and responsibility for managing the process. In section 7.4.3 I have noted that it also involves a shift from wanting to make pupils say and do particular things (with the associated danger of 'hearing and seeing much more' in what the pupils say and do), towards the teacher's being more prepared to find out what the pupils actually do say, believe, want, etc and to (re)determine his or her goals on the basis of what they actually say, believe, want, etc. In section 7.3 I have noted that even if a didactical structure as such can be judged as 'good enough,' which is the maximum attainable, it still needs the creativity of a good teacher for it to lead to successful education.

In section 7.3 I have also noted that at least the evaluation of a didactical structure should take place in cooperation with the teacher that has worked with it. In section 9.2.1 I have mentioned that I cooperated quite closely and intensively with one teacher. He not only worked with the second version of the didactical structure outlined in chapter 8, but had also worked with the first version, and was involved in the construction and evaluation of both versions. By this cooperation it was tried to secure as well as possible that the teacher had made himself so familiar with the essence of the didactical structure and his role in it that he would not deviate essentially from it.

In this chapter I somewhat elaborate the above themes. But I now first briefly report on some experiences during the first year of my research, which have made me realize that a cooperation with a teacher should be very carefully set up and that it should be set up with a teacher that has good managing qualities.

In the first year of my research I observed two series of lessons in middle ability classes that used the unit *Radiation, you cannot evade it...* (Knoester & Lancel, 1988; cf section 3.3 for some findings of the observations). One of these series was taught by a teacher that possibly was to further participate in my research, and the main aim of my observation of the series of lessons taught by her was to find out whether there was a basis for further cooperation. Before the series of lessons I told her my at that time still very vague ideas about the aim and nature of my research: I wanted the pupils to meaningfully learn about the topic of radioactivity, and for that purpose one should somehow start from pupils' existing knowledge; I later was going to write a series of lessons on the topic myself, and to get some ideas for that I would like her to try out some additional activities while teaching the unit *Radiation, you cannot evade it...*. The teacher then indicated that she was somewhat sceptical about my aim. Her scepticism did not so much consist in a denial that pupils have ideas of their own, but rather in her experience that the gap between their own ideas and those of physics was rather large and hard to bridge. In fact, she indicated that in her worst moments she sometimes sighed that all that can be achieved is that pupils learn to solve standard exercises for examinations. Nevertheless, she said that she herself constantly tried to bridge the gap and so she was quite prepared to participate and to try my proposals. In fact, she already saw the unit *Radiation, you cannot evade it...*, of which she was one of the authors, as making a serious attempt to bridge the gap.[11)]

During the series of lessons her scepticism was not noticeable at all (at least not by me). She was enthusiastic, put quite a lot of time in it, tried to carry out my proposals for additional activities as well as possible, and regularly indicated to enjoy it all. I too was satisfied about the series of lessons in the sense that I was confirmed in my suspicion that the structure of the unit I was going to write myself had to be quite different from the structure of the unit *Radiation, you cannot evade it...*. Moreover, from how the tried out additional activities worked out I got some ideas about activities that might be useful for the unit I myself was going to write.[12)] There was also a source of trouble, however, relating to the teacher's order-keeping abilities. The situation in her classroom could most of the time best be described as a 'non-aggressive disorder' (cf Créton & Wubbels, 1984). She did not show much leadership, and quite often the lessons were poorly structured. She generally tolerated quite some disorder, and the pupils very often were not task-

1. Because the unit is based on micro-level explanations (cf section 3.2), I myself could not see it that way.
2. Some of the tried out additional activities are indeed precursors of activities that figure in the first and/or second version of the didactical structure.

oriented. Although she was quite concerned about the class and willing to explain things over and over to pupils who had not been listening, the whole situation was usually so unstructured that only the pupils in her direct neighbourhood were attentive, while the others would do other things such as talk with each other or make some homework. They were not provocative, however, i.e., their other activities were not directed against her, and she usually ignored them while talking loudly to the pupils near her. Her few efforts to also involve the other pupils were usually delivered without emphasis and mostly had little or just a short-term effect. Though most of the pupils seemed to like her and she certainly liked most of the pupils and took a great deal of interest in them, the interaction between her and the pupils very often resulted in a non-productive equilibrium in which all of them sort of seemed to go their own way. The teacher's limitations especially came forward during the additional activities, most of which were of the 'class discussion'-type. For even though the teacher really attempted to involve all pupils, she mostly did not succeed. The result was that the discussion was also hard to follow for the few pupils that were attentive, because of the many times that it was interrupted by the teacher's (vain) attempts to call the other pupils to order. The teacher was well aware of all this, and although she herself also did not find her teaching style particularly good, she also maintained that, at least for the time being, it reflected her best way of surviving in the classroom. So if there was to be a further cooperation with this teacher, it would have to be accompanied by an in-service training in managing order problems.

However, and at the time quite unexpectedly for me, the teacher herself decided that there was not going to be a further cooperation. The results of the test that followed the series of lessons had reawoken her old scepticism. The test consisted for about two-third of rather standard tasks (about half-life, the different penetrating power of the different kinds of radiation, the number of protons neutrons and electrons that a given isotope consists of, etc, i.e., exercises of the type that could come up in the examination), and for about one-third of tasks that demanded some insight (in e.g. the point of distinguishing between contamination and irradiation). It turned out that generally the pupils answered the standard tasks sufficiently well, though not overwhelmingly so, but the insight-tasks rather poorly. I did not make much of those test results, or at any rate I found them quite understandable. For, as I have already noted, the additional activities, which explicitly aimed at insight, went past most pupils. Furthermore, the additional activities were not backed up by worksheets and also did not fit nicely into the unit *Radiation, you cannot evade it...*. For me, all this meant that adding just a few activities was not sufficient. Although some of them might be useful, they had to integrated in a structure that was quite different from the structure of the unit *Radiation, you cannot evade it...*, and had to backed up by written material that would serve as a hold for pupils. In short, I would have to write my own series of lessens and that was precisely what I was going to do. For the teacher, however, the results of the tests confirmed her earlier scepticism. Below I give some fragments of her verbal explanation of her decision to quit.

> If I look at the enormous amount of time I have spent on it and that the part that does later come up for examination, that already that part is not really right, and that this [the part relating to insight, KK] apparently also has not got across, then I say... well, this is wrong, this is a waste of my time, period.

> These pupils [middle ability pupils, KK] have been taught tricks and memory aids from primary school on, otherwise they do not make it through that school. And then you cannot in six weeks all at once aim at insight... and forget that there is something like an examination waiting for them that they will have to do. So I think that in this context it is indeed unfeasible [to aim at insight, KK].
>
> I have followed your road all along, and if I now look at what it has yielded then I think... well, if I had done it my way it would have taken me, a, less time and the test would have been made better. [...] Not the second part [the insight-tasks, KK], the multiple choice [the standard tasks, KK]. Then I would have shifted the emphasis. And then I think, simply from the point of view of my pupils, that is what they have to know. And then I will do my best to also bring in those other things, but already beforehand I accept that that will largely be a wasted effort. I told you so at the beginning: you can try it, but I don't think that it will work. And then I am working on it and then I am really enthusiastic and then... and I did terribly enjoy doing it, I would like to always work like this, but... well, I just notice that it has had little or no effect up to now.
>
> I think we have done all that we could have done in this context [she later specifies this to: with these pupils, in these times, with this previous education; KK]. I would not know what else you should have done.

Whereas for me the whole thing still had to begin, for the teacher it was all over; whereas I thought the time was ripe to lay my own road, she thought she had already followed my road all along, and with little or no effect.

In order to find a new teacher some heads of physics were approached with the question whether they knew a good and experienced teacher that might be willing to participate in an educational experiment. In this process the teacher that I worked with for the rest of my research came forward. In section 10.2, this teacher is characterized. In order to carefully prepare a productive working relation, the teacher and I took quite some time to get acquainted. In section 10.3, I report on this preparatory period. In section 10.4, I go into some aspects of our cooperation during the (re)construction of the didactical structure. In section 10.5, finally, I try to go beyond this one teacher and more generally address the question what it means for a teacher to work with a didactical structure that is 'good enough.'

10.2 Characterization of the teacher

The teacher I worked with was born in 1945. He graduated from a college of education in 1967, but only taught for about two months at a primary school. By means of some refresher courses he in 1969 acquired a qualification to teach physics and chemistry at the LBO and MAVO types of education and at the first three years of the HAVO and VWO types of education (cf section 9.2.1). From 1969 to 1984 he taught physics and chemistry at a school which consisted only of a MAVO-stream. In 1984 this school merged with another school to form a school for MAVO, HAVO and VWO. It is at this school that up to this day he has taught physics and chemistry at the levels he is qualified for. It is thus also the school at which he has worked with the various versions of the didactical structure. The above may suffice to illustrate that he is a very experienced teacher.

The head of physics that recommended him also assured us that he is a good teacher, i.e., a teacher of whom pupils say that he is a good teacher. I also got this impression by observing some of his lessons in the preparatory period (cf section 10.3). There was a pleasant and productive working atmosphere in his lessons, there were hardly any order problems and if some cropped up the teacher usually managed to immediately and effectively deal with them. I would have characterized him as 'strict, but nice' or 'nice, but strict.' In order to somewhat further substantiate these claims, the so called Questionnaire on Teacher Interaction (QTI) was administered to the teacher and several of his classes. The QTI, which was developed in the early eighties by Créton & Wubbels (1984), is an instrument to characterize the affective climate of the learning environment, as perceived by the participants (pupils and teacher). If we roughly discern two aspects of teacher behaviour, a methodological one that relates to content presentation and instructional methods and an interpersonal one that has to do with the teacher's interpersonal actions that create and maintain a positive classroom atmosphere, the QTI can be said to capture the latter aspect of teacher behaviour. By discerning these two aspects I do not mean to deny, of course, that they are interconnected. Wubbels & Levy (1993b) note in this respect that "[i]f the quality of the classroom environment does not meet certain basic conditions the methodological aspect loses its significance." In fact, concerning the teacher whose lessons I observed during the first year of my research I have made a similar remark (cf section 10.1).

The QTI leads to a characterization of interpersonal teacher behaviour in terms of eight different types of interpersonal behaviour, which can be represented in a two-dimensional plane (cf figure 10.1).

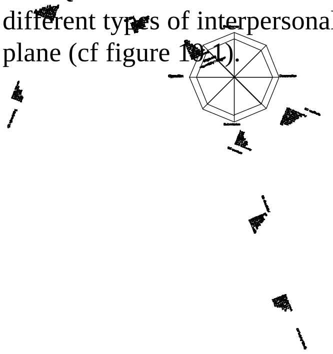

Figure 10.1 The model for interpersonal teacher behaviour. (Figure 2.2 in Wubbels & Levy, 1993a.)

The two dimensions of the plane have been labelled 'proximity' and 'influence.' The 'proximity-dimension' indicates the teacher's degree of cooperation with or closeness to pupils, on a scale between Opposition (O) and Cooperation (C). The 'influence-dimension' indicates the extent to which the teacher directs or controls the interaction with pupils, on a scale between Submission (S) and Dominance (D). In figure 10.1 the eight different types of behaviour are represented by the eight sectors DC, CD, etc, "according to their position in the coordinate system (much like the directions on a compass). For example, the two sectors DC and CD are both characterized by Dominance and Cooperation. In the DC sector, however, the Dominance aspect prevails over the Cooperation aspect" (Wubbels, Créton, Levy & Hooymayers, 1993). In figure 10.1, each of the eight sectors is also characterized in words, both briefly (DC by 'leadership,' CD by 'helping friendly,' etc) and somewhat more elaborately in terms of characteristic teacher behaviour.

The questionnaire itself, the QTI, of which there is a Dutch and an American version, "is divided into eight scales which conform to the eight sectors of the model. In the Dutch version each sector scale consists of about ten items (seventy-seven in total) which are answered on a five-point Likert scale. The American version has sixty-four items and a similar response scale" (*ibid*). For a discussion of the reliability and validity of the QTI, I refer to Brekelmans *et al* (1990).

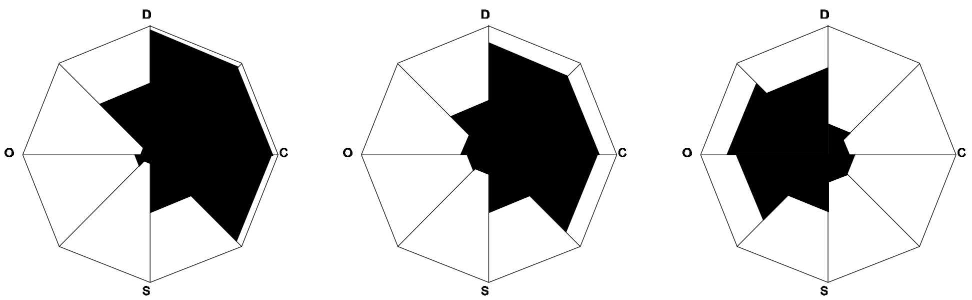

Figure 10.2 Average teachers' perceptions of ideal teacher behaviour and average students' perceptions of best and worst teachers in the United States. (Figure 3.7 in Wubbels & Levy, 1993a.)

"Each completed questionnaire yields a set of eight scale scores which are then combined into a profile ... Scale scores equal the sum of all item scores and are reported in a range between zero and one. A scale score of 'one' indicates that all behaviours in a scale are always (or very much) displayed. A 'zero' is the opposite: the absence of scale behaviours. The profile represents the teacher's communication style as perceived by the teacher or his or her students. It is usually depicted in a graph with scale scores represented by shading in each sector" (Wubbels, Créton, Levy & Hooymayers, 1993). Figure 10.2 contains three examples of such graphically represented profiles. They derive from three different types of data. "Students in The Netherlands, the United States and Australia were asked to rate their best teachers on the QTI. Also, teachers in the three countries provided self-perceptions about their ideal behaviour. Finally, a smaller group of Dutch students completed the QTI for a teacher they thought of as their worst. Figure [10.2] shows the average scores for these three groups in the United States. The results are similar for the other countries" (Levy *et al*, 1993). Figure 10.3 may be another profile of interest. It "shows the average of 463 students' perceptions for a random sample of 118 Dutch teachers." (*ibid*). So in a sense it represents the communication style of the mean Dutch teacher, as perceived by students.

Figure 10.3 Average students' perceptions of random sample of Dutch teachers. (Figure 3.2 in Wubbels & Levy, 1993a.)

By using a variety of clustering procedures and similarity measures, Brekelmans (1989) has established a reliable and stable typology of eight types of communication style, such that each profile out of a large number of profiles of Dutch, American and Australian teachers belongs to one of these eight types. By combining QTI data with descriptive data of classroom atmosphere, Brekelmans has also given a description of each of the eight communication styles in terms of teacher/student behaviours and learning environment characteristics. Brekelmans *et al* (1993) contains, for each of the eight communication styles, both the mean profile corresponding to it and its description in terms of learning environment characteristics.

I hope the above gives sufficient information on the QTI. As I have already noted, the QTI has also been administered to the teacher and to several of his classes that worked with a version of the didactical structure.

Figure 10.4 The teacher's perception of ideal teacher behaviour (a); the teacher's perception of his interpersonal behaviour in one of his classes (b); that class' perception of the teacher's interpersonal behaviour (c).

The profile in figure 10.4a is the result of the teacher's completion of the QTI in terms of his ideal behaviour; figure 10.4b is the resulting profile of the teacher's completion of the QTI for his behaviour in one particular class (in fact, one of the classes in which the first version of the didactical structure was tried); figure 10.4c represents the teacher's communication style as perceived by the pupils in that particular class (it corresponds to the class means of their completion of the QTI). The profiles corresponding to the teacher's perception and the pupils' perception of the teacher's communication style in other classes are similar to figures 10.4b and 10.4c respectively. In fact, in terms of Brekelmans' typology all those profiles are of the type that she has labelled 'Authoritative.' In Brekelmans *et al* (1993) it is characterized as follows.

> The Authoritative atmosphere is well-structured, pleasant and task-oriented. Rules and procedures are clear and students don't need reminders. They are attentive, and generally produce better work than their peers in the Directive [another category in the typology, KK] teacher's classes. The Authoritative teacher is enthusiastic and open to students' needs. He or she takes a personal interest in them, and this comes through in the lessons. While his or her favourite method is the lecture, the Authoritative teacher frequently uses other techniques. The lessons are well planned and logically structured. He or she is considered to be a good teacher by students.

The teacher's ideal communication style (i.e. the one that corresponds to the profile of figure 10.4a) is of the type that Brekelmans has labelled 'Tolerant and Authoritative.'[13)] In Brekelmans *et al* (1993) it is characterized as follows.

> Tolerant/Authoritative teachers maintain a structure which supports student responsibility and freedom. They use a variety of methods, to which students respond well. They frequently organize their lessons around small group work. While the class environment resembles Type 2 [the above 'Authoritative' type, KK], the Tolerant/Authoritative teacher develops closer relationships with students. They enjoy the class and are highly involved in most lessons. Both students and teacher can occasionally be seen laughing, and there is very little need to enforce the rules. The teacher ignores minor disruptions, choosing instead to concentrate on the lesson. Students work to reach their own and the teacher's instructional goals with little or no complaints.

Hereby I hope to have sufficiently characterized the interpersonal aspect of the teacher's classroom behaviour. Let me close this section by noting that the quality of the classroom environment that he manages to create is such that the methodological aspect, on which my research mainly focuses, could indeed be given full consideration. In devising the didactical structure we have been in the luxurious position that whatever technique or instructional method we proposed (be it group work, class discussion, experimental work, or complex combinations of these), we could always count on the teacher's ability to satisfactorily handle them.

10.3 A preparatory period

Before the teacher and I decided to cooperate on an educational experiment, we had an exploratory talk in which I told something about my ideas concerning the experiment and the teacher about his attitude towards it. I told him that I wanted pupils to meaningfully learn about the topic of radioactivity, that recent research had shown that this aim was very often not reached (not just for the topic of radioactivity, but for almost any topic), and that part of this failure might be due to the fact that most approaches do not start from where pupils are. It almost seems as though for pupils the scientific knowledge they 'learn' is something alien that only has application in the science classroom. I also told

3. I want to thank Rob Houwen for the analyses of the QTI data: for producing the profiles like those in figure 10.4, and for determining the type of communication style to which each of them belongs.

him about the cause of our having this exploratory talk: another teacher's decision to quit, and why that other teacher had decided so (cf section 10.1). Of course, I would like to prevent a repetition of that situation. In order to do so I told him I had first of all planned a quite extensive period to carefully prepare a productive working relation. So taking an active part in this preparatory period would be one thing I expected him to do, if he decided to cooperate. Other things would be that he helped in writing new teaching materials (in the first instance in a commenting role), worked with these new materials (while the relevant lessons were being videotaped), etc. What he would get in return were two non-teaching periods and a piece of in-service training that, hopefully, was going to be useful for him.

Of course I also wanted to know how he felt about the aim of my research, however vague it was. In particular I wanted to know, in the context of preventing a repetition of the situation with the previous teacher, whether or not he shared her sceptical attitude. The teacher said to recognize that knowledge does not always function, in the sense that pupils cannot apply it. He told that he thinks that is a problem: it frustrates. So he suspected that he somehow worked on that problem, although it was not a conscious element of his teaching practice. At any rate, from what I had told him he said to have gathered that participating in my research would give him the opportunity to explicitly think and learn about an attempt to tackle that problem, and he certainly did not already beforehand consider such an attempt to be a lost cause. In fact, he said to see no reason why insight would be impossible for middle ability pupils. Finally, the teacher said to hope that by participating in my research he could learn something that might also be of use for other topics than the topic of radioactivity. From this I gathered that at least he had a non-negative attitude towards (the aim of) my research.

On the basis of this exploratory talk the teacher and I decided to cooperate. In this section I report on the first stage of our cooperation: the preparatory period. In section 10.3.1, I sketch the aims, procedure and outline of this preparatory period; in section 10.3.2, I sketch the way it developed and mention some of its main outcomes.

10.3.1 Aims, procedure and outline

The main aim of the preparatory period was to prepare a productive future working relation with respect to writing, trying, etc new teaching materials. In a process in which he came to familiarize himself with (the aim of) my research and I came to familiarize myself with his way of teaching we would have to develop a common way of talking about teaching and learning in general, and about teaching and learning the topic of radioactivity in particular.

The preparatory period took place during the fall of 1989. In that period I visited about one lesson per week, mostly in one of the classes in which later in the school year the first version of the didactical structure was going to be tried. Furthermore, the teacher and I had eleven meetings of about two hours each. The teacher's preparation of a meeting consisted in his doing some homework (of about two hours per meeting). Mostly the homework tasks were given by me, e.g.: study the similarities and dissimilarities between two units on the topic of radioactivity; study some transcripts of interviews with pupils about molecules or radioactivity and relate these to your own teaching about those topics; study some transcripts of fragments of lessons on the atomic model (what are pupils' difficulties and do you recognize these difficulties from your own experience?); study a description of pupils' existing knowledge about radioactivity (along the lines of section 2.5 of this thesis) and comment on it. Occasionally the teacher also set his own homework task, e.g.: carry out a small scale questionnaire study in one class at his school and analyze the results. My preparation usually took me about one working day. It consisted of things like: selecting useful homework tasks for the teacher; anticipating his reactions to it and thinking of ways to build on that in order to clarify some of my ideas about teaching and learning (the topic of radioactivity); studying the conversation we had during a previous meeting (the meetings were recorded on audiotape), and making a reflective report of it in order to identify themes that deserved a further treatment in later meetings; thinking of ways to integrate what I had noticed during visits of lessons in our meetings.

Some of the themes that came up during the meetings were: the aim of the preparatory period and an outline of it; the tendency to base units on the topic of radioactivity on particle models (cf section 3.2); the way such 'models' are often understood by pupils and its consequences for their learning about radioactivity (cf section 3.3); parallels between the teacher's and my learning process during the meetings on the one hand, and pupils' learning on the other; the teacher's role with respect to content: holding back versus steering; the knowledge that seems to be required for an adequate understanding of (the possible dangers of) daily life situations having to do with radioactivity; the usefulness of the meetings.

The teacher's homework for the final meeting of the preparatory period was to write a review of it: on what he had learned from it, on whether through it he felt prepared for a further cooperation, etc. In the final meeting we discussed his review. The totality of my reflective reports of each meeting can be seen as my review of the preparatory period. Section 10.3.2 is based on it.

10.3.2 Development and outcomes

At the beginning of the preparatory period I had some ideas about themes that I wanted to bring up for discussion (cf the previous section), but I did not really have much ideas about how to structure each of the meetings, about a suitable order in the themes I wanted to bring up for discussion, about useful homework tasks for the teacher, etc. In fact, the latter ideas gradually developed during the meetings and also as a result of my making reflective reports of each of the meetings. Below I sketch and exemplify these developments, the use of my regular visits to lessons given by the teacher, and some of the main things the teacher and I have learned from the meetings.

The structure that the meetings gradually assumed

After a while the structure of the meetings between the teacher and me was based on our awareness that we approached educational matters differently and with different experiences, and took the form of trying to make explicit each other's approach and experiences while discussing concrete material (transcripts of lessons and interviews with pupils, results of questionnaires, textbooks, things that happened in a lesson I visited, etc). Below I exemplify how an analysis of the earlier meetings gave rise to this structure and how this structure was made explicit.

The first meeting was a brief one and concerned the procedural aspects of future meetings (how often, how long, how much preparation, etc). The second meeting was the first one in which we discussed issues. The theme I wanted to bring up then was the obviousness of the tendency to base a unit on the topic of radioactivity on particle models. In order to first of all make clear this tendency, I selected two such units (the unit in the textbook the teacher normally used and the unit *Radiation, you cannot evade it...*), which, although they are quite different with respect to e.g. content presentation, essentially have the same structure. So the homework task I gave to the teacher was to study those two units and capture the main lines of the way each of them is build up. I expected that thus he would also find that the two units are essentially the same and, in particular, both begin with the presentation of a nuclear 'model.' (This would then allow me to ask whether it is obvious to begin in that way.) More or less for the sake of completeness I added to the homework assignment the question what the differences between the units are. It turned out that the teacher had indeed noticed the similarity in structure, which he framed as 'what atoms are; what radiation is; how radiation emerges; what the effects of radiation are,' but that he was most struck by the differences between the two units. He found the unit *Radiation, you cannot evade it...* much more pupil-friendly, especially for middle ability pupils: better geared to them and more surveyable for them. For it consists of relatively short and easily readable pieces of information, each of which is followed by some questions that directly refer to it, it contains regular and short summaries, etc. The other unit, in contrast, contains many long stretches of text with too high a level of difficulty, which, as was the teacher's experience, a middle ability pupil simply cannot get through.

Our different approach can in this case be characterized as our laying a different emphasis. Although I noticed the difference in content presentation (and had, in fact, selected the two units because of this difference), I emphasized the similarity with respect to structure. And although the teacher noticed this similarity, he emphasized the difference in content presentation. The teacher's emphasis can be said to reflect his practical and pragmatic approach, with an immediate link to his everyday teaching experience. One of the first things he asked me when discussing the two units was: what do you have in mind, something like this unit or something like that one? My own emphasis can be said to reflect my more theoretical approach, which is also related to existing teaching practice but more in the sense of looking at it from some distance and bringing it up for discussion -in this case, the obviousness of the existing tendency to base a unit on the topic of radioactivity on particle models.

What enabled the teacher to also bring in his points was the part of the homework assignment that asked for dissimilarities between the two units. I have already mentioned that at the time I more or less accidentally included that question in the homework assignment, or had at any rate not included it in order to allow the teacher to bring forward his points. If only for the reason that in a period of getting acquainted the teacher should also be given the opportunity to bring forward his own points, for future meetings I very consciously tried to devise such homework tasks, that the teacher, with his more pragmatic approach, and I, with my more theoretical approach, could each bring forward our own points, thus make explicit each other's approach and experiences, and thus also learn from each other. Indeed, it was not just out of politeness that the teacher was given the opportunity to bring forward his own points, and the fact that in the meetings I naturally had to take the initiative did not imply that only the teacher was supposed to learn something. I also learned from the teacher. The teacher's comparison of the two units, for instance, made me realize that in the later writing of new teaching materials I would have to seriously deviate from my normal writing style. Instead I would have to write relatively short and simply constructed sentences that would have to be organized in a whole that is easily surveyable for middle ability pupils. At least in that respect, so I learned from the teacher, I should take the unit *Radiation, you cannot evade it...* as an example.

In later meetings I also tried to make this structure of our meetings explicit: by illustrating it at examples like the one above; by explicitly telling one another what each learned from the other and how that relates to the other's approach; by drawing parallels between our learning from each other and pupils' learning from their teacher (or teacher's learning from his or her pupils). In the fifth meeting, in which among other things we looked back on the previous meetings, the teacher also recognized the structure that the meetings had assumed:

> I do also sense it like that. That we are feeling out, catching up from each other. I hear new things, you learn new things. Obviously you take the initiative. Well, that's how I see it: you are... I'm here for you. I think you have to take the initiative. I think I get all room. If I dwell on something, then there simply is time for that, then we simply keep on talking about that subject. I... up to now... I actually think it's getting easier and easier for me. The first time I thought: Jesus, it looks like an examination or it looks like... I have the feeling that I'm being interrogated about what I do and do not know. And now I don't have that at all. We're simply feeling out: how do we think about some things?

Later on the teacher told me that his initial feeling also derived from his not feeling very safe at the time. He, the dumb teacher, had to go to a place where he did not really belong: The University.

Of course the teacher and I gradually grew closer to each other. When in later meetings we e.g. discussed some transcripts of lessons, the teacher would bring forward points that I also found relevant, and for very much the same reasons. The main difference between us then was that I usually brought forward more similar such points, which the teacher, after I brought them forward, mostly also recognized as similar. At first this difference in quantity gave the teacher the impression that he had not done his homework well enough and, in fact, made him feel sort of guilty. Of course, I then told him that there was no need for such impressions and feelings. On the contrary, the fact that he focused on very much the same points as I did was evidence for the fact that our approaches converged with respect to some themes. The difference between us then no longer was a matter of different approaches, but rather of different amounts of time spent on homework assignments.

Shifts in theme: from content to didactics

There usually also was a shift in theme in each meeting, which at first again occurred rather accidentally but, after I had noticed it in earlier meetings, was planned more consciously in later meetings. I would characterize the shift as one from content to didactics. Let me again try to illustrate this at the meeting in which the two units were compared. The question concerning the similarity between the two units can be said to deal with content, in the sense that its answer is that with respect to content the two units are essentially the same. On the basis of that answer, which as already noted the teacher had also given, our discussion gradually developed in a didactical direction in the sense that the structure of the content presentation was related to teaching and learning. To my question why the units begin with atomic models, the teacher's initial response was as follows.

> This book simply assumes that... I later have to tell about those isotopes with which something special is up, so I first have to tell what isotopes are. [...] In order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you can't explain it. But you think it can be done differently?

The teacher's argument is of course valid within the existing structure of the units. But it was this structure that I wanted to bring up for discussion. I tried to do so by noting that beginning with atomic models is like beginning on the most advanced level. Is it not possible to already say something about radioactive phenomena without using particles, without immediately going deeply into the theory behind them? This at least made the teacher understand that I wanted something that differed from the existing structure.

> You don't want to begin with... straight to the smallest particle and everything is connected to those smallest particles. You want to begin with... what does happen, how could that be, search... arouse interest... and first spend some time on that before we go more deeply into it, right?

I then tried to link up with his 'to arouse interest' in the sense of 'to induce a need for a deeper explanation,' an explanation at any rate of something they already know at a phenomenological level. The teacher put this in his own words as follows:

> Would they be more inquisitive, that really is... more eager to learn about the particle model if they are going to hear about it later? First, what is it and what do we notice of it and effects, slowly settling in, and only then the explanations.

This 'to make pupils eager to learn about something,' which fitted into my developing ideas about a problem-posing approach, is a didactical theme that often recurred in our subsequent meetings.

Another more didactical theme that the teacher had picked up from this meeting is the following: is one thing really needed as a preparation for something else? This turned out when several meetings later he came back on his earlier statement that "in order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you cannot explain it," and concluded that it is possible to talk about isotopes without first having to talk about atomic models, which was in fact *his* first step in loosening himself from the existing structure. His reasoning was that all that is really needed to understand the concept of isotopes is the idea of slightly different things. He used the example of a bag of a hundred white marbles, of which on closer observation it turns out that one has a little crack and one a little black spot. By calling the three possibilities (perfect white marble, marble with little crack, marble with little black spot) three isotopes of white marbles, pupils could thus get the idea of what an isotope is without having to know anything about atomic models. He went on by noting that also in a subsequent treatment of atomic isotopes, there really would be no need to talk about protons, electrons or differing numbers of neutrons. All that needs to be said is that some atomic isotopes are different in the sense that something special can happen to them. I then elaborated on the theme the teacher brought forward, for I believed that he was very close to noticing that it is possible to talk about 'the something special that can happen to them' in other terms than changes in microscopic structure. I tried to do so by admitting his conclusion that it is possible to talk about isotopes without having to talk about atomic models, and by going one step further: is it also possible to talk about radioactivity without having to talk about isotopes? The teacher thus came to the insight that it is possible by simply calling something radioactive if a Geiger counter starts ticking in its vicinity. I could then also inform the teacher that I had this possibility in mind as a means to start up the series of lessons we were going to devise.

The didactical theme brought up here by the teacher also came back in later meetings. When later on we e.g. discussed the general constraints on the series of lessons we were going to devise, it returned in the following form: an activity should be meaningfully prepared by preceding ones and meaningfully prepare following ones.

When thinking about a suitable order in the themes I wanted to bring up for discussion, I also tried to make use of the idea 'making someone eager to learn about something.' That is, I tried to arouse the teacher's interest in a new theme on the basis of previous themes. In some cases I succeeded in this. The teacher for example understood why on the basis of the meeting in which the two units were discussed, I gave him the homework assignment to study some interviews in which pupils were prompted to give particle explanations.

> You want to get rid of that particle model in your new planning. [...] We teach them that all right, those particles and how all of that... but can they themselves handle that too? For, of course, if you find out, they cannot handle that at all and haven't formed any idea at all of.., then you will be on strong ground in saying we have to try it in a different way.

When shifting to a didactical theme I often used such concrete examples from our own meetings as a means to bring it up for discussion. If possible I would, for the same purpose, also use concrete examples from the lessons I visited.

Apart from shifts from content to didactics within one meeting, in retrospect I notice a similar shift in the course of the meetings as well. In later meetings we more often and more directly discussed didactical themes, e.g.: pupils enter the classroom as empty vessels versus pupils have a background and this background influences their participation; explaining versus challenging pupils to find things out by themselves (as a form of making them eager to learn about something); asking pupils questions versus making pupils ask questions (as a form of making them eager to learn about something).

In discussing such themes, the teacher was of course especially interested in the consequences for his own role in the classroom. In fact, our discussion about his role was one an ongoing one. It continued during the following construction, try-out, reconstruction, etc of the didactical structure (cf section 10.4). In the preparatory period we often talked about the teacher's role in relation to yet another didactical theme: holding back versus steering. We tried to sort of take stock of the various ways in which these terms might be given content, if possible by using concrete examples. Steering or helping pupils, for instance, need not only consist in explaining. Pupils might e.g. also be helped in their learning process by making them arrive at some problem that they themselves come to see as worthwhile to work on. 'Holding back,' on the other hand, is not meant as 'withdrawing' or 'laisser faire.' It might e.g. be given content in the form of 'getting into the skin of the pupils' and 'trying to learn along with the pupils.' Since the preparatory period was also meant as a preparation for the coming construction of a series of lessons, in the later meetings we more and more began to talk about that as well (as part of our shift towards more didactical themes). In that context it was concluded that a substantial steering role should also emanate from the design of the series of lessons. In the construction of the series of lessons, we would have to think out such tasks and such an order in tasks that we have al reason to expect that by working on them pupils are steered in the direction of some goal (e.g.: their recognition of some problem). 'Holding back' might in that context be given content as sort of opposite to 'seeking confirmation of our expectations' or 'pursuing our goals at all cost.' Whereas the latter two attitudes do not prepare the ground for a meaningful evaluation, holding back in the sense of trying to learn along with the pupils may bring to the fore both the need for adjustments concerning (the order in) tasks, expectations and/or goals, and suggestions for plausible such adjustments (cf section 7.4.3).

Use of visits to lessons

One aim of the preparatory period was to familiarize myself with the teacher's classroom behaviour, i.e., in the terminology of section 10.2, both with his methodological and his interpersonal teaching style. In this respect my regular visits to his lessons were of course useful. They were also of use for our meetings, however, as I now try to illustrate. Let me first of all repeat that in our meetings we mainly focused on the methodological aspect. The interpersonal aspect of classroom behaviour, and in particular the teacher's interpersonal teaching style hardly came up in our talks. In the first place I did (and do) not feel competent to discuss the latter aspect. Secondly, it seemed to me that in his case there was hardly any reason to discuss it (cf section 10.2). So concerning this aspect I limited myself to occasional remarks how well I thought he managed to create and maintain a pleasant and productive working atmosphere.

Especially during our first meetings, I tried to bring forward some features of his methodological teaching style that I had picked up from visiting his lessons. He e.g. hardly ever gave a direct answer to pupils' questions, but instead tried to challenge them to themselves find the answer, if necessary by giving some casual clues: 'I don't know, but might it be that...' He would then some time later come back to see how they were doing and, if necessary, help them yet another bit further. Out of examples such as these, and the teacher's comments on them, eventually grew didactical themes such as: explaining versus challenging pupils to find things out by themselves; asking pupils questions versus making pupils ask questions; holding back versus steering.

In the above I have already repeatedly mentioned this aspect of the use of my visits of lessons, i.e., to have available concrete examples that both of us witnessed. Those examples could then e.g. be used to make explicit each other's approach, to start a discussion about further or similar experiences, to bring up or illustrate other didactical themes, etc.

Another aspect of the use of my visits of lessons derives from the different approaches of the teacher and me. One of my aims of our discussion of some interviews in which it was tried to make pupils give particle explanations, for instance, was to explore why pupils failed to do so, and this aim reflects my more theoretical emphasis. The teacher's more practical and pragmatic approach, with an immediate link to his everyday teaching practice, is e.g. reflected by the fact that following our discussion he wanted to find out about *his* pupils' ability to give particle explanations. Moreover, and in this sense my visits, and particularly the ones at the beginning of the preparatory period, provided a stimulus for him to try things out in my presence, so that we could later talk about it. Later on, however, he no longer needed my actual presence in order to try things out. It was then rather his own enthusiasm that made him do it. Of course, he would then still report about his experiences in a subsequent meeting.

Some learning outcomes

In his review of the meetings, the teacher indicated what he had learned from them:

> Well, one of the things that have most struck me is that much more than before I wonder whether my way of teaching, treating the subject matter, observing and evaluating pupils... is done in the right way. Less than before I rely the old routine in which, as I have come to realize, I was somewhat getting stuck. So you could now describe it as greasing the whole thing in order to counter the getting stuck.

Also during the meetings themselves he had already made similar remarks, e.g.:

> ...you are confronted with what you are really doing the whole day, and self-evidently so.
>
> So you see, not just here I am wondering... but also during my lessons I am... it already is on my mind. Well, why am I doing this? I do not wonder whether I am doing it right, really, but could I do it differently, does it make sense that I tell it to them, what do they really pick up from it, what will they do with it?

So the teacher has experienced the meetings as useful, as refreshers of his teaching practice in general. This may also be illustrated by the enthusiasm with which he tried things out that were discussed in meetings.

More in particular, the teacher has also experienced the meetings as useful. Concerning the themes relating to content, for instance, he indicated to have become sensitive to the problems that pupils have with particles and to the question whether a treatment of the topic of radioactivity should be based on particle models. He in fact admitted to have been shocked by the poor understanding that pupils have of particle models. And his pupils too, as he found out when in one of his classes he challenged the pupils to explain why a roadway expands on a hot day and they came up with answers such as: the molecules expand, the air between the molecules expands, or the intermolecular spaces between the molecules expand. Here is one more example of the influence that in this respect the meetings have had on his teaching practice:

> Today, for instance. [...] Someone drops the word 'molecule.' Another one immediately says: the smallest particle of a substance with all its properties. Never ever would I have reacted to that. That is correct. Today we have talked about it for a quarter of an hour. Have talked about it for a quarter of an hour! Would it really be like that? [...] I don't know whether those pupils have gained anything from it. But at any rate it is the result of these meetings.

Concerning the didactical themes, the teacher wrote in his review that especially our recurring discussions about 'holding back and steering' had been very instructive. He also indicated to have gathered from the totality of our meetings that I am a proponent of "letting pupils themselves experience, describe and tentatively process, instead of the traditional model of learning, digesting and testing." In this respect too the teacher noted that the meetings have had their influence on his teaching practice, e.g.:

> ...I more often try to get into the skin of the pupils...
>
> It has already yielded fruit (still to be seen whether it is ripe) in my daily teaching practice. Holding back, listening to pupils, adjusting a little later. A changed attitude with regards to pupils' making notes of observations. Less direct 'explaining.'

The main thing I learned from the meetings was to further specify and illustrate what the consequences for the teacher's role are of my ideas about how pupils could meaningfully learn about the topic of radioactivity. For up to then those ideas mainly concerned pupils' learning process, e.g.: whether *for pupils* one thing (e.g. particle models) really is a meaningful preparation for another thing (radioactive phenomena). Of course I had some ideas about the teacher's role in pupils' learning process, but it was the teacher, with his pragmatic demand for immediate applicability to his practice, who continuously challenged me to do further develop those ideas and also contributed to that further development. For me too, our discussions about 'holding back and steering,' and particularly about how the notions 'holding back' and 'steering' could be given further content in relation to my developing ideas about a problem-posing approach, were most instructive.

Another thing I learned from the way the meetings themselves proceeded, was how useful it is to regularly and explicitly build in reflective activities. For it had been beneficial for our meetings that each of us regularly thought about, and that we then explicitly talked about, questions such as: what have we done, what have we achieved and where does that leave us? So it would also be useful, and moreover in line with a problem-posing approach, to build in such activities in the series of lessons we were going to devise.

Some of the minor, but still important, things I learned also relates to the construction of the series of lessons. The textbook that pupils are to work with should be carefully edited, and easily surveyable and readable. It should be clear to them that quite some time and effort has been put in it, in order to increase their willingness to seriously work with it. The latter point may be compared to a remark that the teacher made in his review, namely that it was also due to my careful preparation of the meetings that he was challenged to invest quite some time in the homework assignments.

I conclude that our preparatory period had met most of its aims. I had come to familiarize myself with his way of teaching. He had become sensitive to the problems with the existing structure to treat the topic of radioactivity, and had gathered some ideas about an alternative structure. We had developed a common way of talking about teaching and learning that promised to be useful for a productive future working relation with respect to writing, trying, etc new teaching materials. Particularly the theme 'holding back versus steering' seemed to be useful for both of us. For the teacher because it directly concerned his role; for me to further think through what, in terms of holding back and steering, the consequences for this role are in a problem-posing approach. I felt prepared for our future cooperation, and so did the teacher: "I'm one hundred per cent behind the experiment. I have confidence in it."

What had not become clear, as the teacher remarked in his review, is "what precisely the lines are along which and why your research takes place." I guess I myself also did not know that at the time.

10.4 Cooperation during the (re)construction and try-out of the didactical structure

Following the preparatory period, the teacher participated in my research for a period of two and a half years. In this period he worked with both versions of the didactical structure and was also involved in the construction and evaluation of them. In this section I describe some aspects of our cooperation in this period, and in particular how in this period our discussion about his own role in the classroom continued, with the eventual aim that he made himself so familiar with the essence of (especially the second version of) the didactical structure and his role in it that he would not deviate essentially from it.

10.4.1 Construction and try-out of the first version

For the construction of the first version of the didactical structure there was about three months available. In these three months I had to put flesh to my still vague ideas about another way to structure the treatment of the topic of radioactivity (e.g.: not begin with particles but rather end with them), by thinking of suitable tasks and a suitable order in the tasks. Choices had to be made (sometimes rather *ad hoc*) in order to meet some constraints: the total series should take about 10 lessons (of 50 minutes), applications of radioactivity should be treated, the examination syllabus had to be covered, etc. Furthermore, a textbook for pupils had to be written, edited and laid out in such a way that for them it would be challenging to work with, and easily readable and surveyable. At the end of the three months there was indeed a pupils' textbook but, as it had been produced under heavy time-pressure, I was not quite satisfied about it. I did have the feeling, however, that it was worth being tried in the sense that from the try-out we could learn a lot about possible improvements.

In those three months the teacher was one of the people who commented on my intermediate products, and what occupied him most was to see how the vague ideas about an alternative structure that we had talked about during the preparatory period gradually assumed a more definite and concrete form. There simply was no time left to discuss his role in relation to the material that was being written any further than whether he thought it feasible to do the activities in the time that was planned for them. Moreover, the teacher guide that was also being written, was more a justification of the new structure of the treatment of the topic of radioactivity than a practical guide. So also concerning the teacher's role I had the idea that a lot could be learned from the try-out. It was in the evaluation of the first version of the didactical structure that the main work had to be done, with respect to both the structure itself and the teacher's role in it.

The first version of the didactical structure was tried in two classes. The procedure of the class observations had been much the same as later in the try-out of the second version (cf section 9.2.1). In one of the classes the lessons were recorded on audiotape, in the other on videotape; on the basis of the experiences in the class in which a particular lesson was given first, some changes were sometimes made concerning the matching lesson in the other class, etc. But whereas the procedure of the observations was similar, the first impressions from the observations differed markedly. For, in line with the above mentioned expectations, the first impressions I gathered during the try-out of the first version the didactical structure were that it certainly was not yet 'good enough.' That is, too often the things the pupils did and said were too far out of line with what they were expected to say and do. Moreover, whereas in some cases rather cosmetic changes might suffice to improve matters (e.g. by avoiding unspecific terms in the formulations of the tasks, cf section 7.4.1), in others more structural improvements seemed necessary. In order that pupils perceive the coherence in successive tasks (cf section 7.4.2) or come to appreciate some problem in the right way (cf section 7.4.3), for instance, it seemed necessary to not just superficially change some tasks but also to change their function and aim, and the way in which they are to be put in a coherent structure.

After the try-out of the first version the teacher was asked to write down his first impressions. The following may give an idea of what they were.

> The last weeks before the start of the series of lessons were marked by a lot of pressure, concerning the normal work at school as well as the preparation of the start. [...] In addition to this the material still had not got its definite form and a remark of [one of the other people who commented on the material] about the amount of subject matter and the in his opinion too optimistic planning had made me doubt about the possibilities of the material. After in the end the material had got its definite and carefully edited

> form my concerns were somewhat taken away again.
> Once the lessons had begun I was glad to have the opportunity to always teach the lesson once again in the other class in order to then deal with problems that had been found in the first lesson. Because of that it turned out that after four lessons I myself got the feeling that the planning was feasible and my decreasing tension for the lessons of course made that the further lessons proceeded less tensely.

10.4.2 Evaluation of the first version and construction of the second version

The above may already indicate that at the beginning of the evaluation the teacher and I had a different attitude, which may again be characterized as the difference between a theoretical and a pragmatic attitude. For me the real work still had to begin, and I was sure that the evaluation would lead to suggestions for structural changes, for substantial changes in the didactical structure itself. For the teacher, however, things had worked out well, and by this he meant things like: we made it in time, the pupils learned something and they were involved.

In the first stages of the evaluation this difference was not properly taken into account, however. We had weekly sessions, for which we prepared by studying one lesson. The teacher studied the videotape of that lesson, i.e., the lesson in one of the classes. I studied the videotape too (together with Hans Créton and Wout Moerman), and also the audiotape of that lesson (i.e., the lesson in the other class) and pupils' notes. During the session we then exchanged our findings. At least, that was the plan. It turned out, however, that there was hardly any exchange, but rather a one-way transmission from me to the teacher, in which I pointed at numerous cases in which what the pupils did and said was (far) out of line with what we had expected, at cases in which the teacher's role could have been better, at possible suggestions for improvements in the didactical structure itself and the teacher's role in it. I was far from content about this one-way traffic. The teacher, on the other hand, felt sort of guilty for not having enough critical remarks. So the sessions were increasingly dissatisfying for both of us.

In order to escape this situation, we spend a session on the sessions themselves. Below are some fragments of what the teacher then brought forward, which also illustrate our different attitudes.

> I've looked quite differently at [the lessons]. I think: I have my material, I give my lessons, well, I think that my pupils have learned something of it, right. You've looked quite differently at it, because your starting point was: well, we'll see whether the pupils have learned something of it. Well, I don't look that way at lessons, I don't look months back. I think: well, the lessons are over, we have made it in time, so I was satisfied, right. So I thought that the lessons went well. If you're looking at it through such a magnifying-glass, well, then indeed you're going to say, and I really do admit that now too: what we had expected did not quite come out and it might have been done differently.
> [During the try-out] I myself didn't have the idea that we were going to discuss it that well, that accurate, that we'd go that deeply into it.
> So I really am content about the sessions, about the way we're working on it, but it is different from what I had imagined. Much more about small things, of which you say: here, see that, now? [...] I found it for instance nice... a nice example, that that second

> lesson I had watched, that I had hardly made any notes really and that I tell you those and that you then come with [..] no less than thirty remarks, well, five pages full. And if I read them over, then I think: and it is like that too. Well, and that you pull them out much more easily than I do. I obviously take notice of quite different things: whether the children are participating, or that they... I don't take notice of whether they... And I do think along with you whether it can be done differently, but I do not pick it out myself.

We concluded that it had been a kind of strange experience for the teacher to look through a magnifying-glass at the small things of something that was well over and that on the whole he was quite satisfied about. On the other hand, now that he got used to the idea he also appreciated that by looking this way it became clear that what we had expected did not always come out and that things might have been done differently. In fact, the teacher also indicated that through the evaluations he had become aware that during the try-out he had not grasped the point of some activities, which accordingly he had not carried out very well, and had also become aware of other cases in which his role had not been adequate. Furthermore, the teacher indicated that the many small things added up to suggestions for quite structural changes, which he appreciated as improvements: "It is a whole different approach, it is quite a different approach. I do think so. The new design appeals to me."

So the main source of the problem seemed to us that, although he did think along with me and appreciated the points I brought forward, the teacher himself did not pick out the things that I did and did not himself come up with suggestions for structural changes. It was not so much problematic that I picked out more things and that I came up with the suggestions for improvements. After all, I had given the didactical structure a lot more thought than the teacher had. Moreover, it was precisely in this period that things began to fall in place for me, that I began to arrive at the global outline for a didactical structure as outlined in chapter 6. So it was quite naturally that I took the lead concerning the structural aspects. What was problematic, however, was that in the sessions up to then this inequality had not been properly taken into account. For the teacher had the same general assignment that I had: study a lesson and comment on it.

As a solution to the problem we suggested that each of us would study the lessons with a special assignment. I would especially focus on the *structural* aspects, e.g.: whether the things pupils do and say is in line with what they were expected to say and do; whether by changes in formulation, aim, function, order, etc pupils might come to perceive the coherence in successive tasks or come to appreciate some problem in the right way, etc. The teacher, on the other hand, would especially focus on, what we called, the *procedural* aspects, e.g.: whether the way in which an activity was carried out has contributed to reaching the aim of the activity; whether by changes in instructional technique or teacher participation (more) pupils might come to (better) appreciate some problem in the right way, etc. Of course the structural and procedural aspects hang closely together. So the teacher had to keep on thinking along with me with respect to the structural aspects, though he was no longer expected to make substantial contributions concerning them. And of course I had to discuss the procedural aspects with him, and in particular their relation to the structural aspects.

It turned out that by the above division of tasks the problem was indeed solved. Firstly, it made more clear that both concerning the structural and the procedural aspects the series of lessons needed to be considerably improved, and also which were the structural and which the procedural improvements. Secondly, the teacher's new task was directly related to what most concerned him: his own role, and he was willing, and able, to work on his new task. Thirdly, the new task was a good preparation for his task during the writing stage of the second version of the didactical structure, namely to write his own guide. His new task, finally, enabled us to continue our discussion about his own role in the classroom, which in the preparatory period we had already begun, and this time more concretely in close relation to the didactical structure.

So the teacher began to study the tapes again, this time especially focusing on the procedural aspects. In the terms of our theme 'holding back versus steering,' he noticed that there were many cases in which his participation had been far too steering. There were cases in which he virtually took over an experiment that pupils were performing, put words in their mouths, heard and saw much more in what pupils said and did than what they actually intended to say and do (cf section 7.4.3), was too focused on pulling out the desired answer (as in: "I've already heard the right answer"), he tended to address himself to especially the 'better' pupils, etc.

Obviously we did not discuss such cases in a blame-context, but acknowledged that a lot of them derived from the fact that the whole thing had been new and stressing for the teacher. He had been nervous, especially during the first lessons (cf his review of the try-out). He had felt the responsibility to make it happen as expected, and therefore was very much focused on the desired answers, apt to hear and see more than there was to see and hear, etc. He also had his initial doubts about the possibilities of the material, whether the pupils are indeed able to find things out for themselves or in the time planned for it, and therefore he had sometimes tried to speed things up by putting the words in pupils' mouths, taking over experiments, addressing himself especially to the better pupils, etc. Furthermore, sometimes our expectations had simply been too high, so that on the spot the teacher had to deal with unexpected situations. I also think that keeping a tight control with respect to content was an ingredient of his way of keeping order.

In our discussions I rather tried to make the teacher take two steps. First, to gain confidence both in the material and in the pupils. That is, the tasks, certainly when the suggestions for structural improvements are taken into account, are such that the pupils are indeed able to take control over their progress with respect to content, that also without a tight control of him in that respect they are willing and able to themselves think of experiments, carry those out, draw conclusions, formulate questions, etc. So with respect to content the steering part of the process should be initiated by the material and further driven by the pupils as they work with the material. The second step relates to the procedural aspects: to find ways to so guide the process that, on the one hand, all pupils are involved, make contributions, listen to each other, etc while, on the other, the process still proceeds orderly and structured.

In the first step we discussed cases in which, as the teacher himself had already noticed, his participation had been far too steering, and compared those to cases in which he had appropriately held back. Sometimes it was even possible to make this comparison with respect to the way that one particular activity was carried out in the two classes. This was the case, for instance, concerning the task whether or not the cleaners of an X-ray department need lead aprons.[14)] In the one class pupils were divided over the matter. The teacher subsequently gave both sides the opportunity to convince each other, an activity that he ingeniously managed by imposing the rules that the two sides have to take turns in bringing forward a point, that someone who wants to bring forward a point for his or her side has to stand up and that only someone who is standing up is allowed to speak, and that pupils are allowed to switch sides each time one side has made a point. Since neither of the sides turned out to be able to make a convincing case, the pupils were then asked to think of an experiment that could be done with the material present in the classroom and that might decide the issue. The pupils proposed to put the X-ray machine on for a while and then measure whether its walls had become radioactive. The final conclusion, on which everybody agreed, was that lead aprons are not necessary. In the other class, however, things went rather differently. There all of the pupils initially agreed that lead aprons are needed. This unexpected result (he had expected that, as in the other class, the pupils would be divided over the matter) so unnerved the teacher, that he completely took over from then. He forgot to let the pupils think of an experiment that would prove them right. Instead he called a pupil forward, told him to put the X-ray machine on for a while, to then measure the walls with a Geiger counter, and concluded that lead aprons are not necessary. This conclusion lead to quite some protests from the pupils, probably because they did not have the faintest idea why the experiment had been carried out. They certainly had not decided for themselves that it is an experiment by means of which it can be decided whether or not lead aprons are needed. Consequently, the experiment played no role in their further reasoning. What had become clear to the pupils, however, is that the teacher had launched an offensive at their communally held opinion that lead aprons are not needed, and they began to passionately defend that opinion, e.g.: dust particles or the air in the X-ray department have been irradiated and therefore are radioactive. The experiment also played no role in the teacher's further reasoning. Instead he tried to explain why e.g. dust particles cannot have become radioactive, pretty soon got stuck in the explanation when he noticed that in it he would have to use the not yet settled concepts of irradiation and contamination, and ultimately saw no other possibility than to force the matter: as you will learn in the next chapter, irradiated dust particles are not radioactive. At that stage it had of course become clear to the pupils that the teacher very much wanted them to say that lead aprons are not necessary. So in the end they decided to meet the teacher, at least part of the way: okay, the cleaners do not need lead aprons, but they do need something else. So here we had a case where the teacher's very steering role had rather been detrimental to pupils' learning process. If the teacher had given the pupils the opportunity to themselves steer their learning process (by letting them, as the pupils in the other class, think of an appropriate experiment), then they would have been

4. In the second version of the didactical structure this task returned (cf section 8.4.2), but, due to some structural changes, at a different place.

confronted with experimental facts that, for good reasons, they themselves had brought forward. The further discussion could then have been based on facts (on what is seen and heard) instead of vague speculations and not yet justified conclusions, and would then not have proceeded in an undesirable attack-and-defence context.

In the second step, the teacher thought of ways to so structure the classroom process that as much pupils as possible are given ample chance to take control over their progress with respect to content: in which cases group work is most appropriate and how it could best be organized; in which cases a class discussion is most appropriate and how it could best be initiated, guided, rounded off, etc. It was of course clear to the teacher that giving the pupils control over their learning process does not imply his withdrawal, especially not if the process is still to proceed orderly and structured. On the contrary, it requires him to draw on a whole repertory of management techniques. So the teacher studied which such techniques he had already spontaneously used (in the above I have given an example), how they had worked out, where else they could be applied, and he explicitly thought of other techniques. As it was part of his way of keeping order, for instance, to be very much present and in particular to be speaking quite a lot, we thought of a way to combine this with not taking over with respect to content, e.g.: when pupils were carrying out an experiment he could physically withdraw, but verbally be very present as a kind of commentator.

As my evaluation of the first version, via ever more concrete suggestions for structural improvements, gradually transformed into the construction of the second version, so the teacher's second step gradually transformed into writing his own guide for the second version, i.e., into a detailed specification of the instructional techniques and his role in the activities that were planned in the second version. This guide was indeed very much geared to the teacher himself, and contained all sorts of reminders that especially concerned him, e.g.: do not yet go into it; aim at mutual agreement; do not take over!; try to involve especially the 'lesser' pupils in the discussion; do not run ahead of things; take stock of all suggestions and solutions. Writing his guide was at the same time the teacher's preparation for the try-out of the second version.

10.4.3 Try-out and evaluation of the second version

At the start of the try-out of the second version of the didactical structure, both the teacher and I had quite some confidence in it, i.e., we both expected that it would come out as 'good enough.' Both of us also expected that the teacher had made himself so familiar with the essence and details of it and had so well prepared his role in it, that he could carry it out as intended. In chapter 9 I have already tried to show that both expectations came true, although some structural as well as procedural modifications were still necessary (see e.g. section 9.4.1). I also refer to chapter 9 for a description of the cooperation between the teacher and me during the try-out and evaluation of the second version.

After the evaluation, the teacher has written a draft teacher guide that is no longer meant to be especially geared to him. It can be characterized as a shortened and more easily readable merger of (parts of) chapters 8 and 9 of this thesis, i.e., a justification of the main tasks, augmented by pupils' reactions to them and some practical clues for teachers. Out of this draft teacher guide I now quote some fragments of the closing section in which the teacher himself gives a general evaluation of the material.

> Once I described the material as 'the engine,' the 'fuel' for which is represented by pupils' contributions. Now that I've worked for several years with this material, I've discovered that this metaphor is not that badly chosen at all. The pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions. And even to the extent that the engine always got that well run in that almost as a matter of course it made its way through the topic of radioactivity. [...]
>
> Apart from that all, I in fairness have to tell that teaching in this way, with 'holding back' and 'listening,' does require quite an effort. After these lessons I generally was more tired than after lessons taught in my old way. The question then presents itself whether that additional effort balances the achieved result. I do give this question a cautious 'yes,' though. The design of the material (its structure, emphases and basic assumptions) has more appeal to me than the traditional treatment of the topic of radioactivity. Furthermore it is my experience that practically throughout the series of lessons the pupils enthusiastically continue to take part. In evaluations of the unit the pupils themselves too indicate that they have experienced 'learning from each other' and 'having come to solutions oneself' as positive [cf section 9.6, KK]. [...]
>
> I have confidence in the strategy described in this guide. You too will have to get confidence in it. All I can say is that in my series of lessons on the basis of this material [...], the necessary fuel for the engine has always been sufficiently supplied by the pupils. To put it differently: I've never been afraid that we would come to run dry; we've never even driven on the reserve tank.

10.5 Some general remarks on the role of a teacher

In this section I try to go beyond the educational experiment that this thesis reports on, i.e., beyond this particular teacher that has worked with this particular material in this particular research. In doing so I also go beyond a firm ground of experiences to base my opinions on and, to some extent, beyond my competence. So this section is of a speculative nature and should accordingly be read as a representation of some of my personal ideas. Let me begin with going beyond this particular topic. This is what the teacher has to say about it (in his draft teacher guide).

> My most important finding, though, is that you will not be able to work with this material if you haven't at least come to believe in its basic assumptions, e.g., confidence in the importance of 'postponing questions' and 'holding back' of you as teacher. Are these basic assumptions and strategy also applicable to other topics from the physics curriculum? I do think so: postponing questions will be going to function as something normal for the pupils. Especially if more often they notice that the answers are found (and often by themselves) as a matter of course. [...] Thinking of experiments oneself and drawing conclusions from those is, according to me, also of use for more topics. Does all this mean that in your physics classes you will tomorrow be able to begin with 'holding back,' postponing questions, letting pupils themselves think of experiments, carry those out and note down conclusions? The answer to this question is a very distinct: no! Material that makes possible such an approach for other topics simply isn't

> available. But if such material is to come, and it isn't up to me to take care of that, I will surely use it.

Like the teacher, I believe that the basic assumptions and strategy are applicable to other topics as well. In fact, in chapter 6 I have already quite generally presented a global outline of a didactical structure. I also think that the teacher will be able to work with material that, for some other topic, makes possible a similar approach, i.e., with a 'good enough' didactical structure of some other topic. I also think that it would not take him that much preparation time as his learning to work with the didactical structure of the topic of radioactivity has taken him. After all, he does already believe in the basic assumptions and strategy, so his preparation would simply be a matter of finding out how the basic assumptions have been detailed and how the strategy could be detailed for the case at hand. In all this, he would of course draw on his experience with (working with) the didactical structure of the topic of radioactivity. I also think that the teacher himself would not be able to construct, for some other topic, material that makes a similar approach possible. This, of course, is no disgrace. I myself, for instance, think that I am able to construct didactical structures for other topics, and that those (re)constructions will much quicker converge to 'good enough' didactical structures than has been the case for the topic of radioactivity, but I do not think of myself as good enough a teacher to be able to work with such didactical structures without any further training. But, as I have already noted, all this is speculation.

Let me speculate a bit further and ask whether other teachers than the one who participated in my research are able to work with the 'good enough' didactical structure of the topic of radioactivity (or some other 'good enough' didactical structure), and what it takes to make them able to do so. One thing that it takes, as the teacher who participated has repeatedly emphasized, is confidence in its basic assumptions and strategy on the one hand, and in the pupils on the other. In order that other teachers gain such confidence, I do not think it is necessary that they go through the whole process that the teacher who participated has gone through (and that has been the main topic of this chapter). Neither do I think that it will be necessary that they study the theoretical background, i.e., something like chapter 4 of this thesis. What I think might be useful is that they actually *have* lessons that are based on the 'good enough' didactical structure at hand and that they watch videos of (fragments of) lessons in an actual classroom. As a pupil and an observer they will thus, as it were in play, get acquainted with why and how the didactical structure is as it is. What they will have to gain confidence from, I guess, is that they see it working, that they also are impressed by the fact that "[t]he pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions." I do not know whether this kind of in-service training will work. We have not (yet) got any experience with it. The teacher and I have run a couple of workshops at a teacher conference, however, in which we, be it in a time span of just one and a half hours, tried to do the sort of things just mentioned. And the fact that most teachers present at our workshops were quite enthusiastic about it, is an argument in favour of attempting an in-service training along the sketched lines.

However, having gained confidence in its basic assumptions and strategy is one thing, being able to work with a 'good enough' didactical structure quite another. It requires, for instance, that one can rather flexibly draw on a quite extensive repertory of management techniques. In the terms of Brekelmans (cf section 10.2), I would without any reservations advise only teachers with an 'authoritative' or 'tolerant and authoritative' communication style to work with a 'good enough' didactical structure. They seem to be the best teachers anyhow, no matter what instructional methods they use. Whether, and how, someone (e.g. a student teacher) can acquire the sort of desired management techniques or communication style is beyond my competence. I do think, however, that such an acquisition will involve the abandonment of some of the common ways in which (student) teachers (learn to) structure lessons, often as a means to keep order. This was once more brought to my attention by Marjolein Vollebregt, a PhD-student who, concerning her first attempts to write a didactical structure (for the introduction of particles, see e.g. 1994), had written in the diary she keeps: "I still don't succeed in writing a scenario that starts from the pupils. Too strongly I hold on to the activities and aims with respect to content in order to maintain with those the *common* control of the teacher."[15)] In a verbal explanation she said that as a student teacher she had learned to structure her lessons as follows: set your goals, i.e., what pupils should be able to do at the end of the lesson; think of activities that are needed to achieve that; think of ways to control that the activities are indeed carried out as desired. So she had learned to think about the appropriateness of activities from the point of view of the teacher's aims and not from the point of view of pupils' motives. And she had learned to keep a tight control with respect to content, especially as a means to keep order, i.e., as a means to survive in the classroom. Now, of course, I also want student teachers to survive, but I wonder whether for that purpose it is necessary that they learn to structure their lessons and to keep order as indicated above. Are there no other ways that are still within the reach of student teachers? It seems to me that such questions concerning the interconnection between the methodological and the interpersonal aspects of teacher behaviour deserve a thorough investigation.

10 The teacher's role

10.1 Introduction

In the preceding I have repeatedly pointed at (the importance of) the role of the teacher. In chapter 8 I have noted that the teacher's role in working with a didactical structure as the one outlined there is different from the teacher's role in more traditional approaches. For example, giving pupils more control over, and thus more responsibility for, their

5. Quoted with approval.

progress with respect to content implies a shift in the teacher's control and responsibility: a shift towards procedural control and responsibility for managing the process. In section 7.4.3 I have noted that it also involves a shift from wanting to make pupils say and do particular things (with the associated danger of 'hearing and seeing much more' in what the pupils say and do), towards the teacher's being more prepared to find out what the pupils actually do say, believe, want, etc and to (re)determine his or her goals on the basis of what they actually say, believe, want, etc. In section 7.3 I have noted that even if a didactical structure as such can be judged as 'good enough,' which is the maximum attainable, it still needs the creativity of a good teacher for it to lead to successful education.

In section 7.3 I have also noted that at least the evaluation of a didactical structure should take place in cooperation with the teacher that has worked with it. In section 9.2.1 I have mentioned that I cooperated quite closely and intensively with one teacher. He not only worked with the second version of the didactical structure outlined in chapter 8, but had also worked with the first version, and was involved in the construction and evaluation of both versions. By this cooperation it was tried to secure as well as possible that the teacher had made himself so familiar with the essence of the didactical structure and his role in it that he would not deviate essentially from it.

In this chapter I somewhat elaborate the above themes. But I now first briefly report on some experiences during the first year of my research, which have made me realize that a cooperation with a teacher should be very carefully set up and that it should be set up with a teacher that has good managing qualities.

In the first year of my research I observed two series of lessons in middle ability classes that used the unit *Radiation, you cannot evade it...* (Knoester & Lancel, 1988; cf section 3.3 for some findings of the observations). One of these series was taught by a teacher that possibly was to further participate in my research, and the main aim of my observation of the series of lessons taught by her was to find out whether there was a basis for further cooperation. Before the series of lessons I told her my at that time still very vague ideas about the aim and nature of my research: I wanted the pupils to meaningfully learn about the topic of radioactivity, and for that purpose one should somehow start from pupils' existing knowledge; I later was going to write a series of lessons on the topic myself, and to get some ideas for that I would like her to try out some additional activities while teaching the unit *Radiation, you cannot evade it...*. The teacher then indicated that she was somewhat sceptical about my aim. Her scepticism did not so much consist in a denial that pupils have ideas of their own, but rather in her experience that the gap between their own ideas and those of physics was rather large and hard to bridge. In fact, she indicated that in her worst moments she sometimes sighed that all that can be achieved is that pupils learn to solve standard exercises for examinations. Nevertheless, she said that she herself constantly tried to bridge the gap and so she was quite prepared to participate and to try my proposals. In fact, she already saw the unit *Radiation, you cannot evade it...*, of which she was one of the authors, as making a serious attempt to bridge the gap.[16)]

During the series of lessons her scepticism was not noticeable at all (at least not by me). She was enthusiastic, put quite a lot of time in it, tried to carry out my proposals for additional activities as well as possible, and regularly indicated to enjoy it all. I too was satisfied about the series of lessons in the sense that I was confirmed in my suspicion that the structure of the unit I was going to write myself had to be quite different from the structure of the unit *Radiation, you cannot evade it...*. Moreover, from how the tried out additional activities worked out I got some ideas about activities that might be useful for the unit I myself was going to write.[17)] There was also a source of trouble, however, relating to the teacher's order-keeping abilities. The situation in her classroom could most of the time best be described as a 'non-aggressive disorder' (cf Créton & Wubbels, 1984). She did not show much leadership, and quite often the lessons were poorly structured. She generally tolerated quite some disorder, and the pupils very often were not task-oriented. Although she was quite concerned about the class and willing to explain things over and over to pupils who had not been listening, the whole situation was usually so unstructured that only the pupils in her direct neighbourhood were attentive, while the others would do other things such as talk with each other or make some homework. They were not provocative, however, i.e., their other activities were not directed against her, and she usually ignored them while talking loudly to the pupils near her. Her few efforts to also involve the other pupils were usually delivered without emphasis and mostly had little or just a short-term effect. Though most of the pupils seemed to like her and she certainly liked most of the pupils and took a great deal of interest in them, the interaction between her and the pupils very often resulted in a non-productive equilibrium in which all of them sort of seemed to go their own way. The teacher's limitations especially came forward during the additional activities, most of which were of the 'class discussion'-type. For even though the teacher really attempted to involve all pupils, she mostly did not succeed. The result was that the discussion was also hard to follow for the few pupils that were attentive, because of the many times that it was interrupted by the teacher's (vain) attempts to call the other pupils to order. The teacher was well aware of all this, and although she herself also did not find her teaching style particularly good, she also maintained that, at least for the time being, it reflected her best way of surviving in the classroom. So if there was to be a further cooperation with this teacher, it would have to be accompanied by an in-service training in managing order problems.

However, and at the time quite unexpectedly for me, the teacher herself decided that there was not going to be a further cooperation. The results of the test that followed the series of lessons had reawoken her old scepticism. The test consisted for about two-third of rather standard tasks (about half-life, the different penetrating power of the different kinds of radiation, the number of protons neutrons and electrons that a given isotope consists of, etc, i.e., exercises of the type that could come up in the examination), and for

1. Because the unit is based on micro-level explanations (cf section 3.2), I myself could not see it that way.
2. Some of the tried out additional activities are indeed precursors of activities that figure in the first and/or second version of the didactical structure.

about one-third of tasks that demanded some insight (in e.g. the point of distinguishing between contamination and irradiation). It turned out that generally the pupils answered the standard tasks sufficiently well, though not overwhelmingly so, but the insight-tasks rather poorly. I did not make much of those test results, or at any rate I found them quite understandable. For, as I have already noted, the additional activities, which explicitly aimed at insight, went past most pupils. Furthermore, the additional activities were not backed up by worksheets and also did not fit nicely into the unit *Radiation, you cannot evade it...*. For me, all this meant that adding just a few activities was not sufficient. Although some of them might be useful, they had to integrated in a structure that was quite different from the structure of the unit *Radiation, you cannot evade it...*, and had to backed up by written material that would serve as a hold for pupils. In short, I would have to write my own series of lessens and that was precisely what I was going to do. For the teacher, however, the results of the tests confirmed her earlier scepticism. Below I give some fragments of her verbal explanation of her decision to quit.

> If I look at the enormous amount of time I have spent on it and that the part that does later come up for examination, that already that part is not really right, and that this [the part relating to insight, KK] apparently also has not got across, then I say... well, this is wrong, this is a waste of my time, period.
>
> These pupils [middle ability pupils, KK] have been taught tricks and memory aids from primary school on, otherwise they do not make it through that school. And then you cannot in six weeks all at once aim at insight... and forget that there is something like an examination waiting for them that they will have to do. So I think that in this context it is indeed unfeasible [to aim at insight, KK].
>
> I have followed your road all along, and if I now look at what it has yielded then I think... well, if I had done it my way it would have taken me, a, less time and the test would have been made better. [...] Not the second part [the insight-tasks, KK], the multiple choice [the standard tasks, KK]. Then I would have shifted the emphasis. And then I think, simply from the point of view of my pupils, that is what they have to know. And then I will do my best to also bring in those other things, but already beforehand I accept that that will largely be a wasted effort. I told you so at the beginning: you can try it, but I don't think that it will work. And then I am working on it and then I am really enthusiastic and then... and I did terribly enjoy doing it, I would like to always work like this, but... well, I just notice that it has had little or no effect up to now.
>
> I think we have done all that we could have done in this context [she later specifies this to: with these pupils, in these times, with this previous education; KK]. I would not know what else you should have done.

Whereas for me the whole thing still had to begin, for the teacher it was all over; whereas I thought the time was ripe to lay my own road, she thought she had already followed my road all along, and with little or no effect.

In order to find a new teacher some heads of physics were approached with the question whether they knew a good and experienced teacher that might be willing to participate in an educational experiment. In this process the teacher that I worked with for the rest of my research came forward. In section 10.2, this teacher is characterized. In order to carefully prepare a productive working relation, the teacher and I took quite some time to get acquainted. In section 10.3, I report on this preparatory period. In section 10.4, I go into some aspects of our cooperation during the (re)construction of the didactical structure. In section 10.5, finally, I try to go beyond this one teacher and more generally address the question what it means for a teacher to work with a didactical structure that is 'good enough.'

10.2 Characterization of the teacher

The teacher I worked with was born in 1945. He graduated from a college of education in 1967, but only taught for about two months at a primary school. By means of some refresher courses he in 1969 acquired a qualification to teach physics and chemistry at the LBO and MAVO types of education and at the first three years of the HAVO and VWO types of education (cf section 9.2.1). From 1969 to 1984 he taught physics and chemistry at a school which consisted only of a MAVO-stream. In 1984 this school merged with another school to form a school for MAVO, HAVO and VWO. It is at this school that up to this day he has taught physics and chemistry at the levels he is qualified for. It is thus also the school at which he has worked with the various versions of the didactical structure. The above may suffice to illustrate that he is a very experienced teacher.

The head of physics that recommended him also assured us that he is a good teacher, i.e., a teacher of whom pupils say that he is a good teacher. I also got this impression by observing some of his lessons in the preparatory period (cf section 10.3). There was a pleasant and productive working atmosphere in his lessons, there were hardly any order problems and if some cropped up the teacher usually managed to immediately and effectively deal with them. I would have characterized him as 'strict, but nice' or 'nice, but strict.' In order to somewhat further substantiate these claims, the so called Questionnaire on Teacher Interaction (QTI) was administered to the teacher and several of his classes. The QTI, which was developed in the early eighties by Créton & Wubbels (1984), is an instrument to characterize the affective climate of the learning environment, as perceived by the participants (pupils and teacher). If we roughly discern two aspects of teacher behaviour, a methodological one that relates to content presentation and instructional methods and an interpersonal one that has to do with the teacher's interpersonal actions that create and maintain a positive classroom atmosphere, the QTI can be said to capture the latter aspect of teacher behaviour. By discerning these two aspects I do not mean to deny, of course, that they are interconnected. Wubbels & Levy (1993b) note in this respect that "[i]f the quality of the classroom environment does not meet certain basic conditions the methodological aspect loses its significance." In fact, concerning the teacher whose lessons I observed during the first year of my research I have made a similar remark (cf section 10.1).

The QTI leads to a characterization of interpersonal teacher behaviour in terms of eight different types of interpersonal behaviour, which can be represented in a two-dimensional plane (cf figure 10.1).

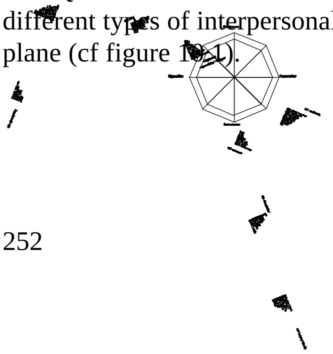

Figure 10.1 The model for interpersonal teacher behaviour. (Figure 2.2 in Wubbels & Levy, 1993a.)

The two dimensions of the plane have been labelled 'proximity' and 'influence.' The 'proximity-dimension' indicates the teacher's degree of cooperation with or closeness to pupils, on a scale between Opposition (O) and Cooperation (C). The 'influence-dimension' indicates the extent to which the teacher directs or controls the interaction with pupils, on a scale between Submission (S) and Dominance (D). In figure 10.1 the eight different types of behaviour are represented by the eight sectors DC, CD, etc, "according to their position in the coordinate system (much like the directions on a compass). For example, the two sectors DC and CD are both characterized by Dominance and Cooperation. In the DC sector, however, the Dominance aspect prevails over the Cooperation aspect" (Wubbels, Créton, Levy & Hooymayers, 1993). In figure 10.1, each of the eight sectors is also characterized in words, both briefly (DC by 'leadership,' CD by 'helping friendly,' etc) and somewhat more elaborately in terms of characteristic teacher behaviour.

The questionnaire itself, the QTI, of which there is a Dutch and an American version, "is divided into eight scales which conform to the eight sectors of the model. In the Dutch version each sector scale consists of about ten items (seventy-seven in total) which are answered on a five-point Likert scale. The American version has sixty-four items and a similar response scale" (*ibid*). For a discussion of the reliability and validity of the QTI, I refer to Brekelmans *et al* (1990).

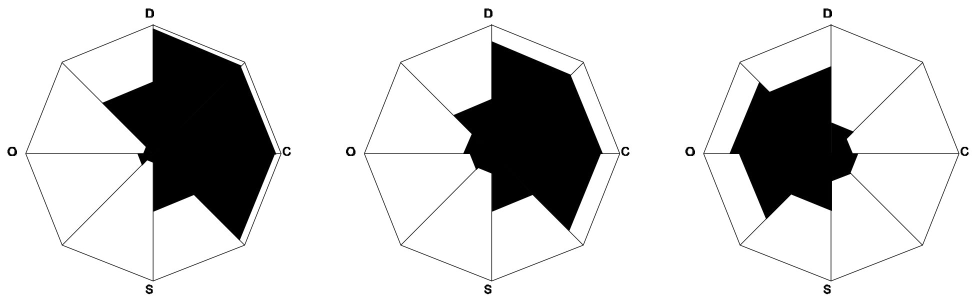

Figure 10.2 Average teachers' perceptions of ideal teacher behaviour and average students' perceptions of best and worst teachers in the United States. (Figure 3.7 in Wubbels & Levy, 1993a.)

"Each completed questionnaire yields a set of eight scale scores which are then combined into a profile ... Scale scores equal the sum of all item scores and are reported in a range between zero and one. A scale score of 'one' indicates that all behaviours in a scale are always (or very much) displayed. A 'zero' is the opposite: the absence of scale behaviours. The profile represents the teacher's communication style as perceived by the teacher or his or her students. It is usually depicted in a graph with scale scores represented by shading in each sector" (Wubbels, Créton, Levy & Hooymayers, 1993). Figure 10.2 contains three examples of such graphically represented profiles. They derive from three different types of data. "Students in The Netherlands, the United States and Australia were asked to rate their best teachers on the QTI. Also, teachers in the three countries provided self-perceptions about their ideal behaviour. Finally, a smaller group of Dutch students completed the QTI for a teacher they thought of as their worst. Figure [10.2] shows the average scores for these three groups in the United States. The results are similar for the other countries" (Levy *et al*, 1993). Figure 10.3 may be another profile of interest. It "shows the average of 463 students' perceptions for a random sample of 118 Dutch teachers." (*ibid*). So in a sense it represents the communication style of the mean Dutch teacher, as perceived by students.

Figure 10.3 Average students' perceptions of random sample of Dutch teachers. (Figure 3.2 in Wubbels & Levy, 1993a.)

By using a variety of clustering procedures and similarity measures, Brekelmans (1989) has established a reliable and stable typology of eight types of communication style, such that each profile out of a large number of profiles of Dutch, American and Australian teachers belongs to one of these eight types. By combining QTI data with descriptive data of classroom atmosphere, Brekelmans has also given a description of each of the eight communication styles in terms of teacher/student behaviours and learning environment characteristics. Brekelmans *et al* (1993) contains, for each of the eight communication styles, both the mean profile corresponding to it and its description in terms of learning environment characteristics.

I hope the above gives sufficient information on the QTI. As I have already noted, the QTI has also been administered to the teacher and to several of his classes that worked with a version of the didactical structure.

Figure 10.4 The teacher's perception of ideal teacher behaviour (a); the teacher's perception of his interpersonal behaviour in one of his classes (b); that class' perception of the teacher's interpersonal behaviour (c).

The profile in figure 10.4a is the result of the teacher's completion of the QTI in terms of his ideal behaviour; figure 10.4b is the resulting profile of the teacher's completion of the QTI for his behaviour in one particular class (in fact, one of the classes in which the first version of the didactical structure was tried); figure 10.4c represents the teacher's communication style as perceived by the pupils in that particular class (it corresponds to the class means of their completion of the QTI). The profiles corresponding to the teacher's perception and the pupils' perception of the teacher's communication style in other classes are similar to figures 10.4b and 10.4c respectively. In fact, in terms of Brekelmans' typology all those profiles are of the type that she has labelled 'Authoritative.' In Brekelmans *et al* (1993) it is characterized as follows.

> The Authoritative atmosphere is well-structured, pleasant and task-oriented. Rules and procedures are clear and students don't need reminders. They are attentive, and generally produce better work than their peers in the Directive [another category in the typology, KK] teacher's classes. The Authoritative teacher is enthusiastic and open to students' needs. He or she takes a personal interest in them, and this comes through in the lessons. While his or her favourite method is the lecture, the Authoritative teacher frequently uses other techniques. The lessons are well planned and logically structured. He or she is considered to be a good teacher by students.

The teacher's ideal communication style (i.e. the one that corresponds to the profile of figure 10.4a) is of the type that Brekelmans has labelled 'Tolerant and Authoritative.'[18)] In Brekelmans *et al* (1993) it is characterized as follows.

> Tolerant/Authoritative teachers maintain a structure which supports student responsibility and freedom. They use a variety of methods, to which students respond well. They frequently organize their lessons around small group work. While the class environment resembles Type 2 [the above 'Authoritative' type, KK], the Tolerant/Authoritative teacher develops closer relationships with students. They enjoy the class and are highly involved in most lessons. Both students and teacher can occasionally be seen laughing, and there is very little need to enforce the rules. The teacher ignores minor disruptions, choosing instead to concentrate on the lesson. Students work to reach their own and the teacher's instructional goals with little or no complaints.

Hereby I hope to have sufficiently characterized the interpersonal aspect of the teacher's classroom behaviour. Let me close this section by noting that the quality of the classroom environment that he manages to create is such that the methodological aspect, on which my research mainly focuses, could indeed be given full consideration. In devising the

3. I want to thank Rob Houwen for the analyses of the QTI data: for producing the profiles like those in figure 10.4, and for determining the type of communication style to which each of them belongs.

didactical structure we have been in the luxurious position that whatever technique or instructional method we proposed (be it group work, class discussion, experimental work, or complex combinations of these), we could always count on the teacher's ability to satisfactorily handle them.

10.3 A preparatory period

Before the teacher and I decided to cooperate on an educational experiment, we had an exploratory talk in which I told something about my ideas concerning the experiment and the teacher about his attitude towards it. I told him that I wanted pupils to meaningfully learn about the topic of radioactivity, that recent research had shown that this aim was very often not reached (not just for the topic of radioactivity, but for almost any topic), and that part of this failure might be due to the fact that most approaches do not start from where pupils are. It almost seems as though for pupils the scientific knowledge they 'learn' is something alien that only has application in the science classroom. I also told him about the cause of our having this exploratory talk: another teacher's decision to quit, and why that other teacher had decided so (cf section 10.1). Of course, I would like to prevent a repetition of that situation. In order to do so I told him I had first of all planned a quite extensive period to carefully prepare a productive working relation. So taking an active part in this preparatory period would be one thing I expected him to do, if he decided to cooperate. Other things would be that he helped in writing new teaching materials (in the first instance in a commenting role), worked with these new materials (while the relevant lessons were being videotaped), etc. What he would get in return were two non-teaching periods and a piece of in-service training that, hopefully, was going to be useful for him.

Of course I also wanted to know how he felt about the aim of my research, however vague it was. In particular I wanted to know, in the context of preventing a repetition of the situation with the previous teacher, whether or not he shared her sceptical attitude. The teacher said to recognize that knowledge does not always function, in the sense that pupils cannot apply it. He told that he thinks that is a problem: it frustrates. So he suspected that he somehow worked on that problem, although it was not a conscious element of his teaching practice. At any rate, from what I had told him he said to have gathered that participating in my research would give him the opportunity to explicitly think and learn about an attempt to tackle that problem, and he certainly did not already beforehand consider such an attempt to be a lost cause. In fact, he said to see no reason why insight would be impossible for middle ability pupils. Finally, the teacher said to hope that by participating in my research he could learn something that might also be of use for other topics than the topic of radioactivity. From this I gathered that at least he had a non-negative attitude towards (the aim of) my research.

On the basis of this exploratory talk the teacher and I decided to cooperate. In this section

I report on the first stage of our cooperation: the preparatory period. In section 10.3.1, I sketch the aims, procedure and outline of this preparatory period; in section 10.3.2, I sketch the way it developed and mention some of its main outcomes.

10.3.1 Aims, procedure and outline

The main aim of the preparatory period was to prepare a productive future working relation with respect to writing, trying, etc new teaching materials. In a process in which he came to familiarize himself with (the aim of) my research and I came to familiarize myself with his way of teaching we would have to develop a common way of talking about teaching and learning in general, and about teaching and learning the topic of radioactivity in particular.

The preparatory period took place during the fall of 1989. In that period I visited about one lesson per week, mostly in one of the classes in which later in the school year the first version of the didactical structure was going to be tried. Furthermore, the teacher and I had eleven meetings of about two hours each. The teacher's preparation of a meeting consisted in his doing some homework (of about two hours per meeting). Mostly the homework tasks were given by me, e.g.: study the similarities and dissimilarities between two units on the topic of radioactivity; study some transcripts of interviews with pupils about molecules or radioactivity and relate these to your own teaching about those topics; study some transcripts of fragments of lessons on the atomic model (what are pupils' difficulties and do you recognize these difficulties from your own experience?); study a description of pupils' existing knowledge about radioactivity (along the lines of section 2.5 of this thesis) and comment on it. Occasionally the teacher also set his own homework task, e.g.: carry out a small scale questionnaire study in one class at his school and analyze the results. My preparation usually took me about one working day. It consisted of things like: selecting useful homework tasks for the teacher; anticipating his reactions to it and thinking of ways to build on that in order to clarify some of my ideas about teaching and learning (the topic of radioactivity); studying the conversation we had during a previous meeting (the meetings were recorded on audiotape), and making a reflective report of it in order to identify themes that deserved a further treatment in later meetings; thinking of ways to integrate what I had noticed during visits of lessons in our meetings.

Some of the themes that came up during the meetings were: the aim of the preparatory period and an outline of it; the tendency to base units on the topic of radioactivity on particle models (cf section 3.2); the way such 'models' are often understood by pupils and its consequences for their learning about radioactivity (cf section 3.3); parallels between the teacher's and my learning process during the meetings on the one hand, and pupils' learning on the other; the teacher's role with respect to content: holding back versus steering; the knowledge that seems to be required for an adequate understanding of (the possible dangers of) daily life situations having to do with radioactivity; the usefulness of the meetings.

The teacher's homework for the final meeting of the preparatory period was to write a review of it: on what he had learned from it, on whether through it he felt prepared for a further cooperation, etc. In the final meeting we discussed his review. The totality of my reflective reports of each meeting can be seen as my review of the preparatory period. Section 10.3.2 is based on it.

10.3.2 Development and outcomes

At the beginning of the preparatory period I had some ideas about themes that I wanted to bring up for discussion (cf the previous section), but I did not really have much ideas about how to structure each of the meetings, about a suitable order in the themes I wanted to bring up for discussion, about useful homework tasks for the teacher, etc. In fact, the latter ideas gradually developed during the meetings and also as a result of my making reflective reports of each of the meetings. Below I sketch and exemplify these developments, the use of my regular visits to lessons given by the teacher, and some of the main things the teacher and I have learned from the meetings.

The structure that the meetings gradually assumed

After a while the structure of the meetings between the teacher and me was based on our awareness that we approached educational matters differently and with different experiences, and took the form of trying to make explicit each other's approach and experiences while discussing concrete material (transcripts of lessons and interviews with pupils, results of questionnaires, textbooks, things that happened in a lesson I visited, etc). Below I exemplify how an analysis of the earlier meetings gave rise to this structure and how this structure was made explicit.

The first meeting was a brief one and concerned the procedural aspects of future meetings (how often, how long, how much preparation, etc). The second meeting was the first one in which we discussed issues. The theme I wanted to bring up then was the obviousness of the tendency to base a unit on the topic of radioactivity on particle models. In order to first of all make clear this tendency, I selected two such units (the unit in the textbook the teacher normally used and the unit *Radiation, you cannot evade it...*), which, although they are quite different with respect to e.g. content presentation, essentially have the same structure. So the homework task I gave to the teacher was to study those two units and capture the main lines of the way each of them is build up. I expected that thus he would also find that the two units are essentially the same and, in particular, both begin with the presentation of a nuclear 'model.' (This would then allow me to ask whether it is obvious to begin in that way.) More or less for the sake of completeness I added to the homework assignment the question what the differences between the units are. It turned out that the teacher had indeed noticed the similarity in structure, which he framed as 'what atoms are; what radiation is; how radiation emerges; what the effects of radiation are,' but that he was most struck by the differences between the two units. He found the unit *Radiation, you cannot evade it...* much more pupil-friendly, especially for middle ability pupils: better geared to them and more surveyable for them. For it consists of relatively short and easily readable pieces of information, each of which is followed by some questions that directly refer to it, it contains regular and short summaries, etc. The other unit, in contrast, contains many long stretches of text with too high a level of difficulty, which, as was the teacher's experience, a middle ability pupil simply cannot get through.

Our different approach can in this case be characterized as our laying a different emphasis. Although I noticed the difference in content presentation (and had, in fact, selected the two units because of this difference), I emphasized the similarity with respect to structure. And although the teacher noticed this similarity, he emphasized the difference in content presentation. The teacher's emphasis can be said to reflect his practical and pragmatic approach, with an immediate link to his everyday teaching experience. One of the first things he asked me when discussing the two units was: what do you have in mind, something like this unit or something like that one? My own emphasis can be said to reflect my more theoretical approach, which is also related to existing teaching practice but more in the sense of looking at it from some distance and bringing it up for discussion -in this case, the obviousness of the existing tendency to base a unit on the topic of radioactivity on particle models.

What enabled the teacher to also bring in his points was the part of the homework assignment that asked for dissimilarities between the two units. I have already mentioned that at the time I more or less accidentally included that question in the homework assignment, or had at any rate not included it in order to allow the teacher to bring forward his points. If only for the reason that in a period of getting acquainted the teacher should also be given the opportunity to bring forward his own points, for future meetings I very consciously tried to devise such homework tasks, that the teacher, with his more pragmatic approach, and I, with my more theoretical approach, could each bring forward our own points, thus make explicit each other's approach and experiences, and thus also learn from each other. Indeed, it was not just out of politeness that the teacher was given the opportunity to bring forward his own points, and the fact that in the meetings I naturally had to take the initiative did not imply that only the teacher was supposed to learn something. I also learned from the teacher. The teacher's comparison of the two units, for instance, made me realize that in the later writing of new teaching materials I would have to seriously deviate from my normal writing style. Instead I would have to write relatively short and simply constructed sentences that would have to be organized in a whole that is easily surveyable for middle ability pupils. At least in that respect, so I learned from the teacher, I should take the unit *Radiation, you cannot evade it...* as an example.

In later meetings I also tried to make this structure of our meetings explicit: by illustrating it at examples like the one above; by explicitly telling one another what each learned from the other and how that relates to the other's approach; by drawing parallels between our learning from each other and pupils' learning from their teacher (or teacher's learning from his or her pupils). In the fifth meeting, in which among other things we looked back on the previous meetings, the teacher also recognized the structure that the meetings had assumed:

> I do also sense it like that. That we are feeling out, catching up from each other. I hear new things, you learn new things. Obviously you take the initiative. Well, that's how I

> see it: you are... I'm here for you. I think you have to take the initiative. I think I get all room. If I dwell on something, then there simply is time for that, then we simply keep on talking about that subject. I... up to now... I actually think it's getting easier and easier for me. The first time I thought: Jesus, it looks like an examination or it looks like... I have the feeling that I'm being interrogated about what I do and do not know. And now I don't have that at all. We're simply feeling out: how do we think about some things?

Later on the teacher told me that his initial feeling also derived from his not feeling very safe at the time. He, the dumb teacher, had to go to a place where he did not really belong: The University.

Of course the teacher and I gradually grew closer to each other. When in later meetings we e.g. discussed some transcripts of lessons, the teacher would bring forward points that I also found relevant, and for very much the same reasons. The main difference between us then was that I usually brought forward more similar such points, which the teacher, after I brought them forward, mostly also recognized as similar. At first this difference in quantity gave the teacher the impression that he had not done his homework well enough and, in fact, made him feel sort of guilty. Of course, I then told him that there was no need for such impressions and feelings. On the contrary, the fact that he focused on very much the same points as I did was evidence for the fact that our approaches converged with respect to some themes. The difference between us then no longer was a matter of different approaches, but rather of different amounts of time spent on homework assignments.

Shifts in theme: from content to didactics

There usually also was a shift in theme in each meeting, which at first again occurred rather accidentally but, after I had noticed it in earlier meetings, was planned more consciously in later meetings. I would characterize the shift as one from content to didactics. Let me again try to illustrate this at the meeting in which the two units were compared. The question concerning the similarity between the two units can be said to deal with content, in the sense that its answer is that with respect to content the two units are essentially the same. On the basis of that answer, which as already noted the teacher had also given, our discussion gradually developed in a didactical direction in the sense that the structure of the content presentation was related to teaching and learning. To my question why the units begin with atomic models, the teacher's initial response was as follows.

> This book simply assumes that... I later have to tell about those isotopes with which something special is up, so I first have to tell what isotopes are. [...] In order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you can't explain it. But you think it can be done differently?

The teacher's argument is of course valid within the existing structure of the units. But it was this structure that I wanted to bring up for discussion. I tried to do so by noting that beginning with atomic models is like beginning on the most advanced level. Is it not possible to already say something about radioactive phenomena without using particles, without immediately going deeply into the theory behind them? This at least made the teacher understand that I wanted something that differed from the existing structure.

> You don't want to begin with... straight to the smallest particle and everything is connected to those smallest particles. You want to begin with... what does happen, how could that be, search... arouse interest... and first spend some time on that before we go more deeply into it, right?

I then tried to link up with his 'to arouse interest' in the sense of 'to induce a need for a deeper explanation,' an explanation at any rate of something they already know at a phenomenological level. The teacher put this in his own words as follows:

> Would they be more inquisitive, that really is... more eager to learn about the particle model if they are going to hear about it later? First, what is it and what do we notice of it and effects, slowly settling in, and only then the explanations.

This 'to make pupils eager to learn about something,' which fitted into my developing ideas about a problem-posing approach, is a didactical theme that often recurred in our subsequent meetings.

Another more didactical theme that the teacher had picked up from this meeting is the following: is one thing really needed as a preparation for something else? This turned out when several meetings later he came back on his earlier statement that "in order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you cannot explain it," and concluded that it is possible to talk about isotopes without first having to talk about atomic models, which was in fact *his* first step in loosening himself from the existing structure. His reasoning was that all that is really needed to understand the concept of isotopes is the idea of slightly different things. He used the example of a bag of a hundred white marbles, of which on closer observation it turns out that one has a little crack and one a little black spot. By calling the three possibilities (perfect white marble, marble with little crack, marble with little black spot) three isotopes of white marbles, pupils could thus get the idea of what an isotope is without having to know anything about atomic models. He went on by noting that also in a subsequent treatment of atomic isotopes, there really would be no need to talk about protons, electrons or differing numbers of neutrons. All that needs to be said is that some atomic isotopes are different in the sense that something special can happen to them. I then elaborated on the theme the teacher brought forward, for I believed that he was very close to noticing that it is possible to talk about 'the something special that can happen to them' in other terms than changes in microscopic structure. I tried to do so by admitting his conclusion that it is possible to talk about isotopes without having to talk about atomic models, and by going one step further: is it also possible to talk about radioactivity without having to talk about isotopes? The teacher thus came to the insight that it is possible by simply calling something radioactive if a Geiger counter starts ticking in its vicinity. I could then also inform the teacher that I had this possibility in mind as a means to start up the series of lessons we were going to devise.

The didactical theme brought up here by the teacher also came back in later meetings. When later on we e.g. discussed the general constraints on the series of lessons we were going to devise, it returned in the following form: an activity should be meaningfully prepared by preceding ones and meaningfully prepare following ones.

When thinking about a suitable order in the themes I wanted to bring up for discussion, I also tried to make use of the idea 'making someone eager to learn about something.' That is, I tried to arouse the teacher's interest in a new theme on the basis of previous themes. In some cases I succeeded in this. The teacher for example understood why on the basis of the meeting in which the two units were discussed, I gave him the homework assignment to study some interviews in which pupils were prompted to give particle explanations.

> You want to get rid of that particle model in your new planning. [...] We teach them that all right, those particles and how all of that... but can they themselves handle that too? For, of course, if you find out, they cannot handle that at all and haven't formed any idea at all of.., then you will be on strong ground in saying we have to try it in a different way.

When shifting to a didactical theme I often used such concrete examples from our own meetings as a means to bring it up for discussion. If possible I would, for the same purpose, also use concrete examples from the lessons I visited.

Apart from shifts from content to didactics within one meeting, in retrospect I notice a similar shift in the course of the meetings as well. In later meetings we more often and more directly discussed didactical themes, e.g.: pupils enter the classroom as empty vessels versus pupils have a background and this background influences their participation; explaining versus challenging pupils to find things out by themselves (as a form of making them eager to learn about something); asking pupils questions versus making pupils ask questions (as a form of making them eager to learn about something).

In discussing such themes, the teacher was of course especially interested in the consequences for his own role in the classroom. In fact, our discussion about his role was one an ongoing one. It continued during the following construction, try-out, reconstruction, etc of the didactical structure (cf section 10.4). In the preparatory period we often talked about the teacher's role in relation to yet another didactical theme: holding back versus steering. We tried to sort of take stock of the various ways in which these terms might be given content, if possible by using concrete examples. Steering or helping pupils, for instance, need not only consist in explaining. Pupils might e.g. also be helped in their learning process by making them arrive at some problem that they themselves come to see as worthwhile to work on. 'Holding back,' on the other hand, is not meant as 'withdrawing' or 'laisser faire.' It might e.g. be given content in the form of 'getting into the skin of the pupils' and 'trying to learn along with the pupils.' Since the preparatory period was also meant as a preparation for the coming construction of a series of lessons, in the later meetings we more and more began to talk about that as well (as part of our shift towards more didactical themes). In that context it was concluded that a substantial steering role should also emanate from the design of the series of lessons. In the construction of the series of lessons, we would have to think out such tasks and such an order in tasks that we have al reason to expect that by working on them pupils are steered in the direction of some goal (e.g.: their recognition of some problem). 'Holding back' might in that context be given content as sort of opposite to 'seeking confirmation of our expectations' or 'pursuing our goals at all cost.' Whereas the latter two attitudes do not prepare the ground for a meaningful evaluation, holding back in the sense of trying to learn along with the pupils may bring to the fore both the need for adjustments concerning (the order in) tasks, expectations and/or goals, and suggestions for plausible such adjustments (cf section 7.4.3).

Use of visits to lessons
One aim of the preparatory period was to familiarize myself with the teacher's classroom behaviour, i.e., in the terminology of section 10.2, both with his methodological and his interpersonal teaching style. In this respect my regular visits to his lessons were of course useful. They were also of use for our meetings, however, as I now try to illustrate. Let me first of all repeat that in our meetings we mainly focused on the methodological aspect. The interpersonal aspect of classroom behaviour, and in particular the teacher's interpersonal teaching style hardly came up in our talks. In the first place I did (and do) not feel competent to discuss the latter aspect. Secondly, it seemed to me that in his case there was hardly any reason to discuss it (cf section 10.2). So concerning this aspect I limited myself to occasional remarks how well I thought he managed to create and maintain a pleasant and productive working atmosphere.

Especially during our first meetings, I tried to bring forward some features of his methodological teaching style that I had picked up from visiting his lessons. He e.g. hardly ever gave a direct answer to pupils' questions, but instead tried to challenge them to themselves find the answer, if necessary by giving some casual clues: 'I don't know, but might it be that...' He would then some time later come back to see how they were doing and, if necessary, help them yet another bit further. Out of examples such as these, and the teacher's comments on them, eventually grew didactical themes such as: explaining versus challenging pupils to find things out by themselves; asking pupils questions versus making pupils ask questions; holding back versus steering.

In the above I have already repeatedly mentioned this aspect of the use of my visits of lessons, i.e., to have available concrete examples that both of us witnessed. Those examples could then e.g. be used to make explicit each other's approach, to start a discussion about further or similar experiences, to bring up or illustrate other didactical themes, etc.

Another aspect of the use of my visits of lessons derives from the different approaches of the teacher and me. One of my aims of our discussion of some interviews in which it was tried to make pupils give particle explanations, for instance, was to explore why pupils failed to do so, and this aim reflects my more theoretical emphasis. The teacher's more practical and pragmatic approach, with an immediate link to his everyday teaching practice, is e.g. reflected by the fact that following our discussion he wanted to find out about *his* pupils' ability to give particle explanations. Moreover, and in this sense my visits, and particularly the ones at the beginning of the preparatory period, provided a stimulus for him to try things out in my presence, so that we could later talk about it. Later on, however, he no longer needed my actual presence in order to try things out. It was then rather his own enthusiasm that made him do it. Of course, he would then still report about his experiences in a subsequent meeting.

Some learning outcomes

In his review of the meetings, the teacher indicated what he had learned from them:

> Well, one of the things that have most struck me is that much more than before I wonder whether my way of teaching, treating the subject matter, observing and evaluating pupils... is done in the right way. Less than before I rely the old routine in which, as I have come to realize, I was somewhat getting stuck. So you could now describe it as greasing the whole thing in order to counter the getting stuck.

Also during the meetings themselves he had already made similar remarks, e.g.:

> ...you are confronted with what you are really doing the whole day, and self-evidently so.
>
> So you see, not just here I am wondering... but also during my lessons I am... it already is on my mind. Well, why am I doing this? I do not wonder whether I am doing it right, really, but could I do it differently, does it make sense that I tell it to them, what do they really pick up from it, what will they do with it?

So the teacher has experienced the meetings as useful, as refreshers of his teaching practice in general. This may also be illustrated by the enthusiasm with which he tried things out that were discussed in meetings.

More in particular, the teacher has also experienced the meetings as useful. Concerning the themes relating to content, for instance, he indicated to have become sensitive to the problems that pupils have with particles and to the question whether a treatment of the topic of radioactivity should be based on particle models. He in fact admitted to have been shocked by the poor understanding that pupils have of particle models. And his pupils too, as he found out when in one of his classes he challenged the pupils to explain why a roadway expands on a hot day and they came up with answers such as: the molecules expand, the air between the molecules expands, or the intermolecular spaces between the molecules expand. Here is one more example of the influence that in this respect the meetings have had on his teaching practice:

> Today, for instance. [...] Someone drops the word 'molecule.' Another one immediately says: the smallest particle of a substance with all its properties. Never ever would I have reacted to that. That is correct. Today we have talked about it for a quarter of an hour. Have talked about it for a quarter of an hour! Would it really be like that? [...] I don't know whether those pupils have gained anything from it. But at any rate it is the result of these meetings.

Concerning the didactical themes, the teacher wrote in his review that especially our recurring discussions about 'holding back and steering' had been very instructive. He also indicated to have gathered from the totality of our meetings that I am a proponent of "letting pupils themselves experience, describe and tentatively process, instead of the traditional model of learning, digesting and testing." In this respect too the teacher noted that the meetings have had their influence on his teaching practice, e.g.:

> ...I more often try to get into the skin of the pupils...
>
> It has already yielded fruit (still to be seen whether it is ripe) in my daily teaching practice. Holding back, listening to pupils, adjusting a little later. A changed attitude with regards to pupils' making notes of observations. Less direct 'explaining.'

The main thing I learned from the meetings was to further specify and illustrate what the consequences for the teacher's role are of my ideas about how pupils could meaningfully learn about the topic of radioactivity. For up to then those ideas mainly concerned pupils' learning process, e.g.: whether *for pupils* one thing (e.g. particle models) really is a meaningful preparation for another thing (radioactive phenomena). Of course I had some ideas about the teacher's role in pupils' learning process, but it was the teacher, with his pragmatic demand for immediate applicability to his practice, who continuously challenged me to do further develop those ideas and also contributed to that further development. For me too, our discussions about 'holding back and steering,' and particularly about how the notions 'holding back' and 'steering' could be given further content in relation to my developing ideas about a problem-posing approach, were most instructive.

Another thing I learned from the way the meetings themselves proceeded, was how useful it is to regularly and explicitly build in reflective activities. For it had been beneficial for our meetings that each of us regularly thought about, and that we then explicitly talked about, questions such as: what have we done, what have we achieved and where does that leave us? So it would also be useful, and moreover in line with a problem-posing approach, to build in such activities in the series of lessons we were going to devise.

Some of the minor, but still important, things I learned also relates to the construction of the series of lessons. The textbook that pupils are to work with should be carefully edited, and easily surveyable and readable. It should be clear to them that quite some time and effort has been put in it, in order to increase their willingness to seriously work with it. The latter point may be compared to a remark that the teacher made in his review, namely that it was also due to my careful preparation of the meetings that he was challenged to invest quite some time in the homework assignments.

I conclude that our preparatory period had met most of its aims. I had come to familiarize myself with his way of teaching. He had become sensitive to the problems with the existing structure to treat the topic of radioactivity, and had gathered some ideas about an alternative structure. We had developed a common way of talking about teaching and learning that promised to be useful for a productive future working relation with respect to writing, trying, etc new teaching materials. Particularly the theme 'holding back versus steering' seemed to be useful for both of us. For the teacher because it directly concerned his role; for me to further think through what, in terms of holding back and steering, the consequences for this role are in a problem-posing approach. I felt prepared for our future cooperation, and so did the teacher: "I'm one hundred per cent behind the experiment. I have confidence in it."

What had not become clear, as the teacher remarked in his review, is "what precisely the lines are along which and why your research takes place." I guess I myself also did not know that at the time.

10.4 Cooperation during the (re)construction and try-out of the

didactical structure

Following the preparatory period, the teacher participated in my research for a period of two and a half years. In this period he worked with both versions of the didactical structure and was also involved in the construction and evaluation of them. In this section I describe some aspects of our cooperation in this period, and in particular how in this period our discussion about his own role in the classroom continued, with the eventual aim that he made himself so familiar with the essence of (especially the second version of) the didactical structure and his role in it that he would not deviate essentially from it.

10.4.1 Construction and try-out of the first version

For the construction of the first version of the didactical structure there was about three months available. In these three months I had to put flesh to my still vague ideas about another way to structure the treatment of the topic of radioactivity (e.g.: not begin with particles but rather end with them), by thinking of suitable tasks and a suitable order in the tasks. Choices had to be made (sometimes rather *ad hoc*) in order to meet some constraints: the total series should take about 10 lessons (of 50 minutes), applications of radioactivity should be treated, the examination syllabus had to be covered, etc. Furthermore, a textbook for pupils had to be written, edited and laid out in such a way that for them it would be challenging to work with, and easily readable and surveyable. At the end of the three months there was indeed a pupils' textbook but, as it had been produced under heavy time-pressure, I was not quite satisfied about it. I did have the feeling, however, that it was worth being tried in the sense that from the try-out we could learn a lot about possible improvements.

In those three months the teacher was one of the people who commented on my intermediate products, and what occupied him most was to see how the vague ideas about an alternative structure that we had talked about during the preparatory period gradually assumed a more definite and concrete form. There simply was no time left to discuss his role in relation to the material that was being written any further than whether he thought it feasible to do the activities in the time that was planned for them. Moreover, the teacher guide that was also being written, was more a justification of the new structure of the treatment of the topic of radioactivity than a practical guide. So also concerning the teacher's role I had the idea that a lot could be learned from the try-out. It was in the evaluation of the first version of the didactical structure that the main work had to be done, with respect to both the structure itself and the teacher's role in it.

The first version of the didactical structure was tried in two classes. The procedure of the class observations had been much the same as later in the try-out of the second version (cf section 9.2.1). In one of the classes the lessons were recorded on audiotape, in the other on videotape; on the basis of the experiences in the class in which a particular lesson was given first, some changes were sometimes made concerning the matching lesson in the other class, etc. But whereas the procedure of the observations was similar, the first impressions from the observations differed markedly. For, in line with the above mentioned expectations, the first impressions I gathered during the try-out of the first version the didactical structure were that it certainly was not yet 'good enough.' That is, too often the things the pupils did and said were too far out of line with what they were expected to say and do. Moreover, whereas in some cases rather cosmetic changes might suffice to improve matters (e.g. by avoiding unspecific terms in the formulations of the tasks, cf section 7.4.1), in others more structural improvements seemed necessary. In order that pupils perceive the coherence in successive tasks (cf section 7.4.2) or come to appreciate some problem in the right way (cf section 7.4.3), for instance, it seemed necessary to not just superficially change some tasks but also to change their function and aim, and the way in which they are to be put in a coherent structure.

After the try-out of the first version the teacher was asked to write down his first impressions. The following may give an idea of what they were.

> The last weeks before the start of the series of lessons were marked by a lot of pressure, concerning the normal work at school as well as the preparation of the start. [...] In addition to this the material still had not got its definite form and a remark of [one of the other people who commented on the material] about the amount of subject matter and the in his opinion too optimistic planning had made me doubt about the possibilities of the material. After in the end the material had got its definite and carefully edited form my concerns were somewhat taken away again.
> Once the lessons had begun I was glad to have the opportunity to always teach the lesson once again in the other class in order to then deal with problems that had been found in the first lesson. Because of that it turned out that after four lessons I myself got the feeling that the planning was feasible and my decreasing tension for the lessons of course made that the further lessons proceeded less tensely.

10.4.2 Evaluation of the first version and construction of the second version

The above may already indicate that at the beginning of the evaluation the teacher and I had a different attitude, which may again be characterized as the difference between a theoretical and a pragmatic attitude. For me the real work still had to begin, and I was sure that the evaluation would lead to suggestions for structural changes, for substantial changes in the didactical structure itself. For the teacher, however, things had worked out well, and by this he meant things like: we made it in time, the pupils learned something and they were involved.

In the first stages of the evaluation this difference was not properly taken into account, however. We had weekly sessions, for which we prepared by studying one lesson. The teacher studied the videotape of that lesson, i.e., the lesson in one of the classes. I studied the videotape too (together with Hans Créton and Wout Moerman), and also the audiotape of that lesson (i.e., the lesson in the other class) and pupils' notes. During the session we then exchanged our findings. At least, that was the plan. It turned out, however, that there was hardly any exchange, but rather a one-way transmission from me to the teacher, in which I pointed at numerous cases in which what the pupils did and said was (far) out of line with what we had expected, at cases in which the teacher's role could have been better, at possible suggestions for improvements in the didactical structure itself and the teacher's role in it. I was far from content about this one-way traffic. The teacher, on the other hand, felt sort of guilty for not having enough critical remarks. So the sessions were increasingly dissatisfying for both of us.

In order to escape this situation, we spend a session on the sessions themselves. Below are some fragments of what the teacher then brought forward, which also illustrate our different attitudes.

> I've looked quite differently at [the lessons]. I think: I have my material, I give my lessons, well, I think that my pupils have learned something of it, right. You've looked quite differently at it, because your starting point was: well, we'll see whether the pupils have learned something of it. Well, I don't look that way at lessons, I don't look months back. I think: well, the lessons are over, we have made it in time, so I was satisfied, right. So I thought that the lessons went well. If you're looking at it through such a magnifying-glass, well, then indeed you're going to say, and I really do admit that now too: what we had expected did not quite come out and it might have been done differently.
>
> [During the try-out] I myself didn't have the idea that we were going to discuss it that well, that accurate, that we'd go that deeply into it.
>
> So I really am content about the sessions, about the way we're working on it, but it is different from what I had imagined. Much more about small things, of which you say: here, see that, now? [...] I found it for instance nice... a nice example, that that second lesson I had watched, that I had hardly made any notes really and that I tell you those and that you then come with [..] no less than thirty remarks, well, five pages full. And if I read them over, then I think: and it is like that too. Well, and that you pull them out much more easily than I do. I obviously take notice of quite different things: whether the children are participating, or that they... I don't take notice of whether they... And I do think along with you whether it can be done differently, but I do not pick it out myself.

We concluded that it had been a kind of strange experience for the teacher to look through a magnifying-glass at the small things of something that was well over and that on the whole he was quite satisfied about. On the other hand, now that he got used to the idea he also appreciated that by looking this way it became clear that what we had expected did not always come out and that things might have been done differently. In fact, the teacher also indicated that through the evaluations he had become aware that during the try-out he had not grasped the point of some activities, which accordingly he had not carried out very well, and had also become aware of other cases in which his role had not been adequate. Furthermore, the teacher indicated that the many small things added up to suggestions for quite structural changes, which he appreciated as improvements: "It is a whole different approach, it is quite a different approach. I do think so. The new design appeals to me."

So the main source of the problem seemed to us that, although he did think along with me and appreciated the points I brought forward, the teacher himself did not pick out the things that I did and did not himself come up with suggestions for structural changes. It was not so much problematic that I picked out more things and that I came up with the suggestions for improvements. After all, I had given the didactical structure a lot more thought than the teacher had. Moreover, it was precisely in this period that things began to fall in place for me, that I began to arrive at the global outline for a didactical structure as outlined in chapter 6. So it was quite naturally that I took the lead concerning the structural aspects. What was problematic, however, was that in the sessions up to then this inequality had not been properly taken into account. For the teacher had the same general assignment that I had: study a lesson and comment on it.

As a solution to the problem we suggested that each of us would study the lessons with a special assignment. I would especially focus on the *structural* aspects, e.g.: whether the things pupils do and say is in line with what they were expected to say and do; whether by changes in formulation, aim, function, order, etc pupils might come to perceive the coherence in successive tasks or come to appreciate some problem in the right way, etc. The teacher, on the other hand, would especially focus on, what we called, the *procedural* aspects, e.g.: whether the way in which an activity was carried out has contributed to reaching the aim of the activity; whether by changes in instructional technique or teacher participation (more) pupils might come to (better) appreciate some problem in the right way, etc. Of course the structural and procedural aspects hang closely together. So the teacher had to keep on thinking along with me with respect to the structural aspects, though he was no longer expected to make substantial contributions concerning them. And of course I had to discuss the procedural aspects with him, and in particular their relation to the structural aspects.

It turned out that by the above division of tasks the problem was indeed solved. Firstly, it made more clear that both concerning the structural and the procedural aspects the series of lessons needed to be considerably improved, and also which were the structural and which the procedural improvements. Secondly, the teacher's new task was directly related to what most concerned him: his own role, and he was willing, and able, to work on his new task. Thirdly, the new task was a good preparation for his task during the writing stage of the second version of the didactical structure, namely to write his own guide. His new task, finally, enabled us to continue our discussion about his own role in the classroom, which in the preparatory period we had already begun, and this time more concretely in close relation to the didactical structure.

So the teacher began to study the tapes again, this time especially focusing on the procedural aspects. In the terms of our theme 'holding back versus steering,' he noticed that there were many cases in which his participation had been far too steering. There were cases in which he virtually took over an experiment that pupils were performing, put words in their mouths, heard and saw much more in what pupils said and did than what they actually intended to say and do (cf section 7.4.3), was too focused on pulling out the desired answer (as in: "I've already heard the right answer"), he tended to address himself to especially the 'better' pupils, etc.

Obviously we did not discuss such cases in a blame-context, but acknowledged that a lot of them derived from the fact that the whole thing had been new and stressing for the teacher. He had been nervous, especially during the first lessons (cf his review of the try-out). He had felt the responsibility to make it happen as expected, and therefore was very much focused on the desired answers, apt to hear and see more than there was to see and hear, etc. He also had his initial doubts about the possibilities of the material, whether the pupils are indeed able to find things out for themselves or in the time planned for it, and therefore he had sometimes tried to speed things up by putting the words in pupils' mouths, taking over experiments, addressing himself especially to the better pupils, etc. Furthermore, sometimes our expectations had simply been too high, so that on the spot the teacher had to deal with unexpected situations. I also think that keeping a tight control with respect to content was an ingredient of his way of keeping order.

In our discussions I rather tried to make the teacher take two steps. First, to gain confidence both in the material and in the pupils. That is, the tasks, certainly when the suggestions for structural improvements are taken into account, are such that the pupils are indeed able to take control over their progress with respect to content, that also without a tight control of him in that respect they are willing and able to themselves think of experiments, carry those out, draw conclusions, formulate questions, etc. So with respect to content the steering part of the process should be initiated by the material and further driven by the pupils as they work with the material. The second step relates to the procedural aspects: to find ways to so guide the process that, on the one hand, all pupils are involved, make contributions, listen to each other, etc while, on the other, the process still proceeds orderly and structured.

In the first step we discussed cases in which, as the teacher himself had already noticed, his participation had been far too steering, and compared those to cases in which he had appropriately held back. Sometimes it was even possible to make this comparison with respect to the way that one particular activity was carried out in the two classes. This was the case, for instance, concerning the task whether or not the cleaners of an X-ray department need lead aprons.[19)] In the one class pupils were divided over the matter. The teacher subsequently gave both sides the opportunity to convince each other, an activity that he ingeniously managed by imposing the rules that the two sides have to take turns in bringing forward a point, that someone who wants to bring forward a point for his or her side has to stand up and that only someone who is standing up is allowed to speak, and that pupils are allowed to switch sides each time one side has made a point. Since neither of the sides turned out to be able to make a convincing case, the pupils were then asked to think of an experiment that could be done with the material present in the classroom and that might decide the issue. The pupils proposed to put the X-ray machine on for a while and then measure whether its walls had become radioactive. The final conclusion, on which everybody agreed, was that lead aprons are not necessary. In the other class, however, things went rather differently. There all of the pupils initially agreed that lead aprons are needed. This unexpected result (he had expected that, as in the other class, the pupils would be divided over the matter) so unnerved the teacher, that he completely took over from then. He forgot to let the pupils think of an experiment that would prove them right. Instead he called a pupil forward, told him to put the X-ray machine on for a while, to then measure the walls with a Geiger counter, and concluded that lead aprons are not necessary. This conclusion lead to quite some protests from the pupils, probably because they did not have the faintest idea why the experiment had been carried out. They

4. In the second version of the didactical structure this task returned (cf section 8.4.2), but, due to some structural changes, at a different place.

certainly had not decided for themselves that it is an experiment by means of which it can be decided whether or not lead aprons are needed. Consequently, the experiment played no role in their further reasoning. What had become clear to the pupils, however, is that the teacher had launched an offensive at their communally held opinion that lead aprons are not needed, and they began to passionately defend that opinion, e.g.: dust particles or the air in the X-ray department have been irradiated and therefore are radioactive. The experiment also played no role in the teacher's further reasoning. Instead he tried to explain why e.g. dust particles cannot have become radioactive, pretty soon got stuck in the explanation when he noticed that in it he would have to use the not yet settled concepts of irradiation and contamination, and ultimately saw no other possibility than to force the matter: as you will learn in the next chapter, irradiated dust particles are not radioactive. At that stage it had of course become clear to the pupils that the teacher very much wanted them to say that lead aprons are not necessary. So in the end they decided to meet the teacher, at least part of the way: okay, the cleaners do not need lead aprons, but they do need something else. So here we had a case where the teacher's very steering role had rather been detrimental to pupils' learning process. If the teacher had given the pupils the opportunity to themselves steer their learning process (by letting them, as the pupils in the other class, think of an appropriate experiment), then they would have been confronted with experimental facts that, for good reasons, they themselves had brought forward. The further discussion could then have been based on facts (on what is seen and heard) instead of vague speculations and not yet justified conclusions, and would then not have proceeded in an undesirable attack-and-defence context.

In the second step, the teacher thought of ways to so structure the classroom process that as much pupils as possible are given ample chance to take control over their progress with respect to content: in which cases group work is most appropriate and how it could best be organized; in which cases a class discussion is most appropriate and how it could best be initiated, guided, rounded off, etc. It was of course clear to the teacher that giving the pupils control over their learning process does not imply his withdrawal, especially not if the process is still to proceed orderly and structured. On the contrary, it requires him to draw on a whole repertory of management techniques. So the teacher studied which such techniques he had already spontaneously used (in the above I have given an example), how they had worked out, where else they could be applied, and he explicitly thought of other techniques. As it was part of his way of keeping order, for instance, to be very much present and in particular to be speaking quite a lot, we thought of a way to combine this with not taking over with respect to content, e.g.: when pupils were carrying out an experiment he could physically withdraw, but verbally be very present as a kind of commentator.

As my evaluation of the first version, via ever more concrete suggestions for structural improvements, gradually transformed into the construction of the second version, so the teacher's second step gradually transformed into writing his own guide for the second version, i.e., into a detailed specification of the instructional techniques and his role in the activities that were planned in the second version. This guide was indeed very much geared to the teacher himself, and contained all sorts of reminders that especially concerned him, e.g.: do not yet go into it; aim at mutual agreement; do not take over!; try to involve especially the 'lesser' pupils in the discussion; do not run ahead of things; take stock of all suggestions and solutions. Writing his guide was at the same time the teacher's preparation for the try-out of the second version.

10.4.3 Try-out and evaluation of the second version

At the start of the try-out of the second version of the didactical structure, both the teacher and I had quite some confidence in it, i.e., we both expected that it would come out as 'good enough.' Both of us also expected that the teacher had made himself so familiar with the essence and details of it and had so well prepared his role in it, that he could carry it out as intended. In chapter 9 I have already tried to show that both expectations came true, although some structural as well as procedural modifications were still necessary (see e.g. section 9.4.1). I also refer to chapter 9 for a description of the cooperation between the teacher and me during the try-out and evaluation of the second version.

After the evaluation, the teacher has written a draft teacher guide that is no longer meant to be especially geared to him. It can be characterized as a shortened and more easily readable merger of (parts of) chapters 8 and 9 of this thesis, i.e., a justification of the main tasks, augmented by pupils' reactions to them and some practical clues for teachers. Out of this draft teacher guide I now quote some fragments of the closing section in which the teacher himself gives a general evaluation of the material.

> Once I described the material as 'the engine,' the 'fuel' for which is represented by pupils' contributions. Now that I've worked for several years with this material, I've discovered that this metaphor is not that badly chosen at all. The pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions. And even to the extent that the engine always got that well run in that almost as a matter of course it made its way through the topic of radioactivity. [...]
>
> Apart from that all, I in fairness have to tell that teaching in this way, with 'holding back' and 'listening,' does require quite an effort. After these lessons I generally was more tired than after lessons taught in my old way. The question then presents itself whether that additional effort balances the achieved result. I do give this question a cautious 'yes,' though. The design of the material (its structure, emphases and basic assumptions) has more appeal to me than the traditional treatment of the topic of radioactivity. Furthermore it is my experience that practically throughout the series of lessons the pupils enthusiastically continue to take part. In evaluations of the unit the pupils themselves too indicate that they have experienced 'learning from each other' and 'having come to solutions oneself' as positive [cf section 9.6, KK]. [...]
>
> I have confidence in the strategy described in this guide. You too will have to get confidence in it. All I can say is that in my series of lessons on the basis of this material [...], the necessary fuel for the engine has always been sufficiently supplied by the pupils. To put it differently: I've never been afraid that we would come to run dry; we've never even driven on the reserve tank.

10.5 Some general remarks on the role of a teacher

In this section I try to go beyond the educational experiment that this thesis reports on, i.e., beyond this particular teacher that has worked with this particular material in this particular research. In doing so I also go beyond a firm ground of experiences to base my opinions on and, to some extent, beyond my competence. So this section is of a speculative nature and should accordingly be read as a representation of some of my personal ideas. Let me begin with going beyond this particular topic. This is what the teacher has to say about it (in his draft teacher guide).

> My most important finding, though, is that you will not be able to work with this material if you haven't at least come to believe in its basic assumptions, e.g., confidence in the importance of 'postponing questions' and 'holding back' of you as teacher. Are these basic assumptions and strategy also applicable to other topics from the physics curriculum? I do think so: postponing questions will be going to function as something normal for the pupils. Especially if more often they notice that the answers are found (and often by themselves) as a matter of course. [...] Thinking of experiments oneself and drawing conclusions from those is, according to me, also of use for more topics. Does all this mean that in your physics classes you will tomorrow be able to begin with 'holding back,' postponing questions, letting pupils themselves think of experiments, carry those out and note down conclusions? The answer to this question is a very distinct: no! Material that makes possible such an approach for other topics simply isn't available. But if such material is to come, and it isn't up to me to take care of that, I will surely use it.

Like the teacher, I believe that the basic assumptions and strategy are applicable to other topics as well. In fact, in chapter 6 I have already quite generally presented a global outline of a didactical structure. I also think that the teacher will be able to work with material that, for some other topic, makes possible a similar approach, i.e., with a 'good enough' didactical structure of some other topic. I also think that it would not take him that much preparation time as his learning to work with the didactical structure of the topic of radioactivity has taken him. After all, he does already believe in the basic assumptions and strategy, so his preparation would simply be a matter of finding out how the basic assumptions have been detailed and how the strategy could be detailed for the case at hand. In all this, he would of course draw on his experience with (working with) the didactical structure of the topic of radioactivity. I also think that the teacher himself would not be able to construct, for some other topic, material that makes a similar approach possible. This, of course, is no disgrace. I myself, for instance, think that I am able to construct didactical structures for other topics, and that those (re)constructions will much quicker converge to 'good enough' didactical structures than has been the case for the topic of radioactivity, but I do not think of myself as good enough a teacher to be able to work with such didactical structures without any further training. But, as I have already noted, all this is speculation.

Let me speculate a bit further and ask whether other teachers than the one who participated in my research are able to work with the 'good enough' didactical structure of the topic of radioactivity (or some other 'good enough' didactical structure), and what it takes to make them able to do so. One thing that it takes, as the teacher who participated has repeatedly emphasized, is confidence in its basic assumptions and strategy on the one hand, and in the pupils on the other. In order that other teachers gain such confidence, I do not think it is necessary that they go through the whole process that the teacher who participated has gone through (and that has been the main topic of this chapter). Neither do I think that it will be necessary that they study the theoretical background, i.e., something like chapter 4 of this thesis. What I think might be useful is that they actually *have* lessons that are based on the 'good enough' didactical structure at hand and that they watch videos of (fragments of) lessons in an actual classroom. As a pupil and an observer they will thus, as it were in play, get acquainted with why and how the didactical structure is as it is. What they will have to gain confidence from, I guess, is that they see it working, that they also are impressed by the fact that "[t]he pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions." I do not know whether this kind of in-service training will work. We have not (yet) got any experience with it. The teacher and I have run a couple of workshops at a teacher conference, however, in which we, be it in a time span of just one and a half hours, tried to do the sort of things just mentioned. And the fact that most teachers present at our workshops were quite enthusiastic about it, is an argument in favour of attempting an in-service training along the sketched lines.

However, having gained confidence in its basic assumptions and strategy is one thing, being able to work with a 'good enough' didactical structure quite another. It requires, for instance, that one can rather flexibly draw on a quite extensive repertory of management techniques. In the terms of Brekelmans (cf section 10.2), I would without any reservations advise only teachers with an 'authoritative' or 'tolerant and authoritative' communication style to work with a 'good enough' didactical structure. They seem to be the best teachers anyhow, no matter what instructional methods they use. Whether, and how, someone (e.g. a student teacher) can acquire the sort of desired management techniques or communication style is beyond my competence. I do think, however, that such an acquisition will involve the abandonment of some of the common ways in which (student) teachers (learn to) structure lessons, often as a means to keep order. This was once more brought to my attention by Marjolein Vollebregt, a PhD-student who, concerning her first attempts to write a didactical structure (for the introduction of particles, see e.g. 1994), had written in the diary she keeps: "I still don't succeed in writing a scenario that starts from the pupils. Too strongly I hold on to the activities and aims with respect to content in order to maintain with those the *common* control of the teacher."[20)] In a verbal explanation she said that as a student teacher she had learned to structure her lessons as follows: set your goals, i.e., what pupils should be able to do at the end of the lesson; think of activities that are needed to achieve that; think of ways to control that the activities are indeed carried out as desired. So she had learned to think about the appropriateness of activities from the point of view of the teacher's aims and not from the point of view of pupils' motives. And she had learned to keep a tight control with respect to content, especially as a means to keep order, i.e., as a means to survive in the classroom. Now, of course, I also want student teachers to survive, but I wonder whether for that purpose it is necessary that they learn to structure their lessons and to

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5. Quoted with approval.

keep order as indicated above. Are there no other ways that are still within the reach of student teachers? It seems to me that such questions concerning the interconnection between the methodological and the interpersonal aspects of teacher behaviour deserve a thorough investigation.

6 A didactical structure in global outline

6.1 Introduction

In section 5.4 I have advocated, as an attempt to improve science educational practice at a content-specific level, a problem-posing approach to science education, i.e., an approach whose emphasis is on bringing pupils in such a position that they themselves come to see the *point* of extending their existing conceptual resources, experiential base and belief system (with accompanying changes of meaning) in a certain direction. I have also pointed at two essential ingredients of a problem-posing approach. The first is that pupils' process of science learning is, at any stage, provided with a *local* point, in the sense that their reasons for being involved in a particular activity are induced by preceding activities, while that particular activity in turn, together with its preceding activities, induces pupils' reasons for being involved in subsequent activities. The second ingredient is that their process of science learning is, at appropriate stages, provided with a *global* point, which is to induce a (more or less precise) outlook on the direction that the further process will take.

Accordingly, it is an essential ingredient of planning a problem-posing approach to teaching some scientific topic, i.e., of devising a didactical structure of the topic (cf section 5.4.2), that one will have to think of appropriate local and global points, and of appropriate ways to induce those. Since such local and global points (and ways to induce them) are content-dependent, they will vary from topic to topic. Nevertheless I think that, as far as the global points and the ways to induce them are concerned, didactical structures of various scientific topics will have something in common, namely *kinds* of global point, and a *succession* of those that is more or less natural in the sense that they build upon each other: while pupils proceed on their process in the direction suggested by one kind of global point, the next kind of global point is likely to be induced.

In section 6.2 I illustrate these kinds of global point, the more or less natural succession of those, and the articulation of a didactical structure in some main substructures that this succession gives rise to, at the case of the topic of radioactivity. In doing so I hope to at least suggest that the ideas presented in section 6.2 have some wider applicability than just this particular case and, more generally, are of heuristic value in outlining a didactical structure at a global level. In section 6.3 I make some further comments in this respect, by pointing at the work of van Hiele and ten Voorde, which has inspired the ideas presented in section 6.2, and at the work of some others who, like me, have tried to apply their ideas in outlining a didactical structure at a global level.

6.2 Outlining a didactical structure as a succession of global points that build upon each other

6.2.1 Global motivation; practical problems; theoretical problems

The first kind of global point, which I call a *global motivation*, concerns the very beginning of a didactical structure. It is to induce in pupils a sense of purpose for at least beginning to study the topic at hand, and to provide them with a first sense of direction concerning where their study will lead them to. In section 5.4.1 I have already mentioned that a global motivation might be induced by matching the topic to existing interests of pupils. Concerning the topic of radioactivity, one may think here of setting the topic in the context of real life situations involving radioactivity (such as the Chernobyl accident and its consequences) and applications of radioactivity (e.g., in health care), and of treating such issues as safety measures (cf section 6.2.2).

If the induced global motivation is not to be just an ornament, the knowledge that one (as curriculum deviser) intends to make pupils arrive at next will actually have to lie in the direction that the global motivation suggests. Accordingly, this knowledge must be such that it is appropriate to predict and explain the occurrence or non-occurrence of types of event that have some practical interest (e.g., the occurrence and, in particular, the non-occurrence or prevention of someone's receiving radiation), in situations that have some practical interest (e.g., real life situations and applications), and to an extent that is quite sufficient for practical purposes. Let me call this practical knowledge.

That there is indeed something to learn for pupils in this direction, may be clear from the inventory of their pre-instructional knowledge (cf sections 2.4 and 2.5). For example, for them what happened to the spinach in the Netherlands after the Chernobyl accident and what would happen to spinach if it were irradiated is essentially the same: in both cases the spinach would come to contain radiation*, and in order to characterize the spinach they would in both cases use either of the words 'contaminated' or 'irradiated.' So it becomes an important aspect of pupils' arriving at practical knowledge that they come to see the point of distinguishing between the processes of contamination and irradiation, and come to appreciate that irradiation of an object does not make it emit radiation, that a contaminated object does emit radiation, that a contamination-situation demands other safety measures than an irradiation-situation, and so on.

So, on the one hand, the knowledge that lies nearest in the direction suggested by the global motivation is of a practical nature and, on the other, there is something to learn for pupils in this direction. The second kind of global point is to induce in pupils a more precise outlook on this direction, by bringing them in such a position that they themselves come to pose some *practical problems*. From the pupils' point of view, these practical problems (which constitute the global point) must be clear problems, whose solutions are expected to lead to an improved understanding of real life situations involving radioactivity; from the curriculum deviser's point of view, the problems must be such that they offer the perspective that in the course of a further investigation pupils will eventually arrive at the practical knowledge. In section 6.2.3 I will indicate what, for the case of the topic of radioactivity, suitable practical problems might be and how they might be induced.

The third kind of global point, finally, may naturally come forward or be induced in the course of the investigation that follows pupils' posing of the practical problems. That is, in the course of that investigation they are, on the one hand, expected to arrive at the practical knowledge and to come to value that practical knowledge for practical purposes, but on the other hand they may also come (or be made) to recognize problems that not so much cast doubt on the practical use of the practical knowledge but rather demand a deeper understanding or further clarification of it. Such, what may be called, *theoretical problems* constitute the third kind of global point. They are to provide the further process with an initial direction. In section 6.2.5 I will indicate what kinds of theoretical problem can be expected to come forward in the case of the topic of radioactivity.

The above succession of three kinds of global point (global motivation → practical problems → theoretical problems), gives rise to the following rough articulation of a didactical structure in main kinds of substructure: inducing a global motivation → inducing practical problems → solving the practical problems → inducing theoretical problems → solving the theoretical problems. Concerning the topic of radioactivity, I will make on each of those some further comments in sections 6.2.2 to 6.2.6. I refer to chapter 8 for more details.

6.2.2 Inducing a global motivation

When it comes to inducing, on the basis of existing interests, a global motivation, the topic of radioactivity is a relatively easy one. For in general pupils do already have an interest in the topic, probably because the various applications of radioactivity appeal, both in a positive and negative sense, to such basic needs as feeling safe and maintaining good health. This is not to say, of course, that there is an existing interest of pupils in the particular content one intends to make them learn (e.g., the distinction between the processes of contamination and irradiation).

In order to induce a strong enough global motivation it will therefore suffice to include subject matter that appeals to the above mentioned needs relating to safety and good health, such as safety measures and applications in health care, and to point this out to pupils. Thus, on the one hand, they are provided with a global outlook on what is to come and, on the other, get the idea that subject matter will be treated that interests them.

Of course, the global motivation that is thus induced will only make pupils stand ready to start up the process. If, after it has been induced, one continues with an elaborate treatment of (sub)microscopic models, as in the unit *Radiation, you cannot avoid it…* (cf chapter 3, in particular figure 3.1), it turns out that the global motivation is not strong enough for pupils to also take an active interest in that treatment and may even work counter-productive during that treatment (cf section 3.3.1). So it is not enough to induce a global motivation just to butter pupils up, one will also have to continue in the direction that the induced global motivation suggests, i.e., towards practical knowledge.

6.2.3 Inducing practical problems

In this section I indicate what, for the case of the topic of radioactivity, suitable practical problems may be, how those can be induced, and that appropriately inducing those requires careful preparation and guidance.

A suitable practical problem

Consider items 1 to 5 below. Although I have made them up for the purpose of illustration, let us think of them as notes that were (in that order) written or uttered by pupils in a lesson series on radioactivity.

1. We have agreed to call something radioactive if a Geiger counter starts ticking near it.
2. When a Geiger counter that we hold in our hands ticks, we stand in the radiation that is emitted by a radioactive object or an X-ray machine that is switched on.
3. We were asked to make an apple radioactive. So we placed the apple next to a radioactive stone for a while. After we had done so, we checked with a Geiger counter whether the apple had become radioactive. It had not. Well, probably the stone is not strong enough.
4. We then put the apple in an X-ray machine, which is really strong. But again, after the apple was taken out of the X-ray machine, the Geiger counter did not start ticking near the apple.
5. It seems like we cannot make something radioactive. But then, after the Chernobyl accident we were not allowed to eat some fresh vegetables because they had become radioactive. So, how can things be made radioactive?

I think that the general problem that the (fictitious) pupils arrive at in note 5, how things can be made radioactive (in the sense agreed in note 1) and, implicitly also, how not, is a suitable practical problem. Since the pupils understand the problem in accordance with the agreement made in note 1, it will have a clear meaning to them, given that the agreement involves a clear empirical criterion. Furthermore, although they have come to recognize that they do not yet know the solution to the problem, it is also clear to them that the problem does have a solution, given that it was one of the consequences of the Chernobyl accident that things had become radioactive. So somehow it must be possible to find that solution, while finding the solution will also lead to, e.g., an improved understanding of the Chernobyl accident and its consequences.

From the curriculum deviser's point of view, moreover, the problem is such that it offers the perspective that in the course of a further investigation pupils eventually arrive at the practical knowledge. For the actions that the pupils have performed, as they report in notes 3 and 4, and as a result of which the problem has come forward, are all of the kind 'making the apple stand in radiation,' i.e., 'irradiating the apple.' If pupils also recognize this similarity in their performed actions, they will at least have taken one step in the direction of seeing the point of distinguishing between the processes of contamination and irradiation: irradiation of an object does not make it radioactive (in the agreed sense). Furthermore, since the practical problem itself has emerged in an empirical context, pupils' arriving at the practical knowledge too can naturally be supported by further experimentation.

The device used to induce the practical problem

Part of the device that the curriculum deviser has employed in order to make pupils arrive at the practical problem (in note 5), is to simply give pupils a task (Make the apple radioactive; cf note 3) that sounds like a special case of the practical problem. Let me now try to show why the curriculum deviser could confidently plan this device, i.e., why it was reasonable to expect that the device would work. In particular, why it could be expected that, *if pupils stick to the agreement* reported in note 1, they will, given the task to make the apple radioactive, eventually come to appreciate that they do not know how to produce an outcome of the kind that the task calls for (an object's becoming radioactive, in the agreed sense).

A very direct way in which they may come to appreciate this is as follows: given the agreement we have made before, we are now asked to make it the case that the Geiger counter starts ticking near the apple; well, never before in our lives have we tried to make it the case that a Geiger counter starts ticking near some object; so we really don't know how to make the apple radioactive. I think it is not likely, however, that the practical problem will come forward almost immediately after pupils are given the task to make the apple radioactive.

In fact, the task to make the apple radioactive may be rather unproblematic for pupils, in the sense that they are pretty sure what to do: place the apple near a radioactive stone for a while (cf note 3). If they were asked why they expect this proposal to lead to the desired outcome (the apple's being radioactive), they might have argued that thus the apple comes to contain radiation (radiation*), part of which will subsequently be released and measured by the Geiger counter. But if they then indeed measure with a Geiger counter, i.e., if they stick to the agreement, in this case too the practical problem will eventually come forward, perhaps along the lines of a process of rational accommodation as (fragmentary) documented in notes 3 to 5, when again and again they find themselves unable to produce the desired outcome.

The introduction of a scientific term

For the above device to work, pupils must already have arrived at a specific way of using the term 'is radioactive,' namely as applying to objects in the vicinity of which a Geiger counter starts ticking (note 1). Let me call this the scientific use of the term. In section 5.2.4 I have already argued that the educational task of making pupils arrive at a specific way of using some term is in general a non-trivial one. From the curriculum deviser's point of view, the term and the specific ways of using it must be useful in the light of the further development (in this case, towards practical knowledge). On the other hand it must be possible to so introduce the specific way of using the term that pupils too, who do not know the details of the further development, see the point of thus using it.

In the above it may already have become clear that the scientific use of the term 'is radioactive' is indeed useful in the light of the further development. For example, it is because they consistently stick to this scientific use, and thus check with a Geiger counter whether their actions have made the apple radioactive, that they eventually come to pose the practical problem. Furthermore, it is only because the scientific use of the term involves a clear empirical criterion, that it makes sense to challenge pupils to perform actions in the first place. This criterion, moreover, is also of use, e.g., in checking whether someone or something is being irradiated (note 2). And in the even further development of the process, the scientific notion of being radioactive can for instance be turned into a more quantitative one by reference to the ticking rate of a Geiger counter.

Whether in the case at hand the other part of the educational task can be met, depends on whether it is possible to make pupils see the point of classifying objects according to whether or not a Geiger counter starts ticking in their vicinity, and of agreeing to use the term 'is radioactive' to thus classify them. I think this is indeed possible by appropriately linking up with pupils' existing knowledge and use of the term 'is radioactive.' The basic idea is as follows.

From sections 2.4 and 2.5 it is clear that pupils' existing use of the term is such that they apply it to something that according to them emits or contains radiation* and by means of which radiation* might in one way or another get inside other objects. Or, to put it even more loosely, they apply the term to those objects that in one way or another are or have been involved in situations that from hear-say they know have got to do with radioactivity. Let me call this the ordinary use of the term.

Accordingly, if pupils are presented with some objects of which it is well-known that they have or that they have not got to do with radioactivity, it is expected that they will reach mutual agreement on whether or not those objects are radioactive (in the ordinary sense). In this way, moreover, an environment is created in which it is natural to want to reach agreement for a few other objects as well. If these objects are so chosen that pupils are not sure whether they have got to do with radioactivity, or that some pupils may have heard them brought up in connection with radioactivity and other pupils not, there will then be doubt or disagreement about whether or not these objects are radioactive (in the ordinary sense). Their want to reach mutual agreement concerning these objects, combined with their expected failure to reach it, is then to induce in pupils a need for a mutually verifiable criterion to determine whether or not something is radioactive.

This need is expected to create a place in pupils' conceptual apparatus for the term 'is radioactive' in its scientific use to occupy. Indeed, once the need has come forward, it is not a strange idea to try to meet it by the use of a measuring device. It is in fact an idea that pupils themselves may bring forward, given that it is part of most pupils' existing knowledge that there are such devices (cf sections 2.4 and 2.5). In order to meet the need, moreover, pupils are expected to be able to select an appropriate device out of a collection of devices. For it is expected that it will be clear to them that they have to select one that does what it is supposed to do: give the correct indication concerning the objects that are known to be radioactive or known not to be radioactive (in the ordinary sense); settle the dispute concerning the other objects. So if the objects that are known (not) to be radioactive in the ordinary sense are so chosen that most of them are also (not) radioactive in the scientific sense, it can be expected, finally, that pupils will select a Geiger counter as the appropriate device.

6.2.4 Solving the practical problems

In this section I indicate how, in a process that is given an initial point and direction by the practical problem they have arrived at in the preceding, pupils may eventually arrive at, come to value, and further extend the practical knowledge.

Recognizing similarities and differences

In the preceding pupils have come to frame the practical problem how things can be made radioactive and how not. As is often the case in situations where one oneself has framed a problem that has a clear meaning to oneself, also the pupils will already be on the way to solving their problem once they have framed it. They are expected to have an open eye and mind for possible contributions to its solution, for instance, and in the process that has lead to their formulation of the problem they are implicitly also provided with conceptual equipment that is appropriate to recognize possible solutions as such. This is not to say, however, that it is straightforward for pupils how to go about in order to find solutions to the problem. They will need some guidance.

A first step concerns the 'how not' part of the problem. It consists in letting pupils make explicit, consolidate and generalize some of the conclusions that have already implicitly been established in the process that has led to the formulation of the problem, namely by stimulating them to note *similarities* between the actions they have performed and appropriately chosen irradiation-situations, and to frame these similarities in the terms that are prepared in the preceding. In particular, it is expected that pupils will thus arrive at the following generalization: an object does not become radioactive by irradiation.

A second step concerns the 'how' part of the problem, and uses a procedure similar to the above one: stimulating pupils to note *differences* between the actions they have performed and appropriately chosen contamination-situations. It is expected that pupils will recognize the new element in these situations as a possible contribution to the solution of the 'how' part and, in the further process of elaborating that possibility, come to see the point of paying special attention to processes in which something comes to contain radioactive material. They will then also appreciate the point of having available a term to refer to such processes: contamination, and come to formulate the following generalization involving it: an object does become radioactive by contamination.

By challenging pupils, in the above steps, to play an active part in the establishment of the generalizations, such that they know what the evidence for the generalizations is and how the evidence is used to support those, it is also expected that they come to appreciate that the generalizations can be projected to unobserved and counterfactual cases. E.g.: when that X-ray was taken of me, I had not become radioactive; if I had swallowed that radioactive stone, I would have become radioactive.

Coming to value the practical knowledge
By arriving at the generalizations
- an object does not become radioactive by irradiation;
- an object does become radioactive by contamination;

pupils have in effect solved the practical problem. They will, e.g., appreciate why their earlier attempts to make the apple radioactive were doomed to fail, and that the apple could be made radioactive by making it contain radioactive material in one way or another. The generalizations also form the core of the practical knowledge, and pupils will already have appreciated their relevance for, e.g., an improved understanding of the Chernobyl accident and its consequences. In order to explain why after the Chernobyl accident some fresh vegetables had become radioactive, for instance, they are expected to tell a more or less elaborate story about how (part of) the radioactive material that the power plant contained before the accident could after the accident have got in or on those fresh vegetables. Perhaps it is good to point here at the 'specific way of describing' part that, as argued in sections 4.4.2 and 5.2.2, always plays an important role in explanations by means of generalizations. For the second generalization above could not be invoked in order to explain why 'after the Chernobyl accident some fresh vegetables had become radioactive,' before the particular event of which one description is 'the Chernobyl accident' was appropriately redescribed or further described, e.g.: during which an explosion occurred, such that small bits of radioactive material were released, which were transported by wind and rain and eventually precipitated on the fresh vegetables.

Pupils can come to value the established generalizations even more by making them appreciate the relevance of those for other matters relating to existing interests, e.g.: safety measures. By appropriately taking into account the 'specific way of describing' part, moreover, they can at the same time get better at home in applying the generalizations. The idea, roughly, is to first let them think of appropriate safety measures in situations that are explicitly described as cases of irradiation or contamination. What they are left to do here, and what they are quite explicitly challenged to do, is apply the relevant generalizations to the already appropriately described situations. Subsequently, they can be asked to judge the use of given safety measures in situations that are not explicitly described as cases of contamination or irradiation. Here it is up to pupils themselves *both* to first analyze the situations in the appropriate terms *and* to then base their judgement on that analysis by invoking the appropriate generalizations.

Possible extensions of the practical knowledge, induced by further practical problems
The practical knowledge that pupils have arrived at in the preceding might very well serve as a coherent and worthwhile endpoint. It could also be further extended, however, in order to arrive at an even better understanding of real-life situations and applications. Take, for instance, the following applications: the use of a radioactive tracer in a medical investigation; the use of radioactive sources, in the production of sheets of metal and paper, as a means to control the thickness of the produced sheets. I

think that such applications not only are new to pupils, but that they will also arouse questions of the kind: it is somehow strange that radioactive substances are used here, for what about …? In the medical application, for instance, pupils are expected to find it strange that a patient is purposely contaminated. They may, e.g., wonder whether the patient will remain contaminated for the rest of his or her life. And concerning the industrial applications, it is expected that pupils will not find the use of a radioactive source in order to control the thickness of metal sheets very strange (for the metal will partly stop the emitted radiation, and the thicker it is the more it will stop), but in contrast will find it strange that the same procedure can be used to control the thickness of paper: isn't it so that the radiation will go right through paper?

Such questions constitute another global point. Since the questions are of a practical nature, in the sense that they have emerged in the context of applications and that pupils expect their answers to lead to an improved understan ing of applications, this global point is still of the second kind (cf section 6.2.1). It is to give the further process an initial purpose and direction. From the curriculum deviser's point of view, the newly induced practical problems are such that they offer the perspective that in the course of a further investigation pupils may eventually arrive at, what may be called, a quantitative extension of the practical knowledge. For in terms of quantitative notions such as those of penetrating power of radiation, strength of radioactive sources, and half-life of a radioactive substance, and by means of such quantitative regularities as the one that describes the way in which the strength of a particular radioactive substance decreases, the new practical problems can indeed be answered.
In the further process, such quantitative extensions to the practical knowledge too are, as in the above, to be established by pupils, and to be evaluated by pupils in the light of their usefulness for a better understanding of applications.

6.2.5 Theoretical problems, induced in the process of arriving at the practical knowledge

In the preceding pupils have arrived at the practical knowledge, and have come to value it for practical purposes, in a process that was initiated by a practical problem. Perhaps they have also extended this practical knowledge in a quantitative direction, in a process that was set in motion by questions of the same kind, i.e., questions that ask for an improved understanding of situations that are of practical interest. In the course of arriving at the practical knowledge (and its extension in quantitative direction), however, pupils may also have come to pose questions of a different kind. Questions, namely, that not so much ask for an improved understanding of situations that are of practical interest, but rather for an improved understanding of the practical knowledge itself and/or its extension in quantitative direction, and that therefore may be called theoretical questions. Let me give some examples.

I think that without questioning the practical use of the generalization 'an object does become radioactive by contamination,' pupils can be expected to pose questions that are triggered by the generalization itself. E.g.: when we make it the case, in one way or another, that an apple comes to contain radioactive material, a Geiger counter will start ticking in its vicinity; in accordance with the agreement made earlier, we then call the apple radioactive; but it is clear that the apple is then not, let's say, genuinely radioactive; for the Geiger counter then simply measures the radiation that is emitted by the radioactive material that the apple has come to contain; so we can understand why a contaminated object emits radiation, but what is it about genuinely radioactive material that explains why *it* emits radiation? This question implicitly also contains a suggestion for a possible means to achieve an improved understanding, in that it calls for a characterization of genuinely radioactive material in terms other than that of a Geiger counter's starting to tick, and in terms of which it can be understood that genuinely radioactive material emits radiation.[1)]

The generalization 'an object does not become radioactive by irradiation' too is likely to trigger theoretical questions, e.g.: why is it that an object does not emit radiation after it has been irradiated?; what, then, happens to the radiation when it enters an object and, in particular, why is it that receiving radiation can have harmful effects?; and what *is* radiation anyway? These questions contain the implicit suggestion that they might be answered by characterizing radiation in terms that are appropriate to understand its interaction with matter (in particular, living tissue).

A possible quantitative extension to the practical knowledge, finally, may induce additional theoretical questions, e.g.: what is it about different radioactive substances that explains why their half-lifes differ?; what is it about the radiation emitted by this radioactive substance and the radiation emitted by that radioactive substance that explains why the penetrating power of the one is higher than that of the other?; etc.

6.2.6 Solving the theoretical problems

I have already noted that practical knowledge might very well serve as a coherent and worthwhile endpoint, and the same goes for practical knowledge that has been extended in a quantitative direction. But perhaps it is also possible (see below for some doubts), to try to go beyond such practical knowledge towards, what may be called, theoretical knowledge. In that case, theoretical questions like the ones mentioned above are likely candidates to give that further process a global point (of the third kind, cf section 6.2.1). That is, together with the suggestions that are implicitly contained in them, they may give a process towards theoretical knowledge an initial purpose and direction.

Following up the suggestion to characterize radiation in terms that are appropriate to understand its interaction with matter, for instance, the following hypothesis might be proposed to pupils: radiation is nothing but very fast moving particles. Pupils may subsequently be challenged to evaluate an hypothesis like this one in the light of finding

1. It may be said that what the question and its implicit suggestion amount to, is an elimination of *causal concepts* (cf section 4.4.2), in particular of the, what in the above I have called, scientific concept of being radioactive. For clearly, this concept is causal: it has been agreed to call an object radioactive if it causes a Geiger counter to tick in its vicinity (cf note 1). That this concept eventually needs to be eliminated in order to achieve an improved understanding, may become clear from the fact that the agreement, in turn, has been reached on the ground that a Geiger counter is a device that is caused to react near objects that everybody knows to be radioactive. That is, without an appeal to objects that everybody knows to be radioactive, the agreement is circular.

answers to some of their theoretical questions. For example, they may try to tackle the question why it is that an object does not emit radiation after it has been irradiated, by giving a micro-level account of what happens with the fast moving particles when they enter an object (cf section 3.3.2). To the extent that they manage to do so, pupils may come to appreciate the hypothesis as useful, and the more so the more questions it enables them to tackle.

Along the above lines, pupils will get a flavour of how a shift to a different vocabulary might enable a deeper understanding, and I expect that their theoretical questions ask for not much more than just that. In particular, I think that those questions do not in any way offer the perspective that along the above lines pupils might eventually be made to arrive at a fairly detailed nuclear model. Or, to put it another way, I think that radioactive phenomena as such, and the theoretical questions that can be asked about them, provide too slender a basis in order to make plausible the introduction of full-fledged nuclear models.

So I am very modest concerning the extent of what, in the case of the topic of radioactivity, can be achieved in the direction of theoretical knowledge. I also think, however, that in this case there is not really a need to aim at fairly developed theoretical knowledge. That is, the topic could be satisfactorily rounded off once pupils know that there is still much more to be said and explored concerning radioactive phenomena, and have seen a glimpse of the direction of such a further exploration.

6.3 Conclusion

I think that the global outline of a didactical structure I have just now illustrated at the case of the topic of radioactivity, might very well also be useful for other scientific subjects and topics. In fact, my sources of inspiration, van Hiele (e.g., 1986) and ten Voorde (e.g., 1990), have applied it to primary and secondary mathematics education and to secondary chemistry education, respectively. De Miranda (1979, 1981) has used it to devise graduate courses in economics. Lijnse (1990) was inspired by it in thinking about a way to teach energy in secondary physics education. Kortland (1995) has used it to outline secondary environmental education. In chapter 11, I try to further illustrate its use in thinking about a didactical structure of the topic of heat and temperature, and about what I consider to be the eventual aim of science educational research (cf section 5.4.3): a didactical structure of the whole of science.

Let me now summarize the global outline and, in the process, introduce van Hiele' and ten Voorde's terminology of *ground level*, *descriptive level* and *theoretical level*, i.e., indicate how I will use these terms[2)] (in the remaining chapters). I will use the term

2. I am aware that I may not quite use these terms as van Hiele or ten Voorde intended.

'descriptive level' for what in the above I have called 'practical knowledge,' i.e., specific ways of describing and a set of generalizations involving these ways of describing, by means of which it is possible to explain and predict a range of events that are of practical interest to an extent that is quite sufficient for practical purposes.

Pupils' process of arriving at a descriptive level is set in motion, i.e., provided with an initial purpose and direction, by inducing a global motivation and practical problems. A global motivation may be induced by introducing the subject matter in the context of situations that are of practical interest and/or issues that are of personal or social relevance, or by letting the pupils themselves formulate why it would be relevant to learn more about the subject matter. The practical problems are to make pupils aware that there is something to learn for them in a certain direction, and may concern a surprising element in a familiar situation or some unclarities concerning situations that are of practical interest or bear a close relation to such. The process of inducing practical problems may involve, or even be triggered by, specific ways of describing (e.g., a new use of an old term, such that also changes of meaning may be involved). Especially in case the specific ways of describing play an important role in pupils' arrival at, and formulation of, the practical problems, appropriate places for those will first have to be created in pupils' conceptual apparatus, by productively making use of their existing knowledge and uses of language.

When pupils have come to pose the practical problems, I will say that a ground level for the descriptive level has emerged. A ground level, therefore, is not a worthwhile endpoint. It is rather, from the pupils' point of view, an inventory of problems that need to be solved at least before a worthwhile endpoint can possibly be reached. From the curriculum deviser's point of view, it must contain enough germs that can reasonably be expected to develop into the descriptive level for which it is a ground level.

In particular it must be reasonable to expect that pupils come to establish, and recognize as solutions to the practical problems, the generalizations of the descriptive level, e.g. by stimulating them to recognize similarities and differences among the situations in which the practical problems have emerged and appropriately chosen new situations, and to frame these similarities and differences in terms of the prepared ways of describing. In this process the point of some additional specific ways of describing that are part of the descriptive level may also come forward.

In order that pupils best come to appreciate how, when, and when not to use the vocabulary and generalizations of the descriptive level, they are challenged to play an active part in the establishment of those. Furthermore, in order to make them feel at home in using those, special attention will have to be paid to the 'specific way of describing' part that plays an unavoidable role in applying the generalizations to specific cases. In order that pupils come to value the descriptive level, moreover, its relevance for matters of practical interest will have to clearly come forward.

Although the descriptive level that has thus emerged forms a coherent endpoint, one may choose to link up with further practical problems that may have come forward in the process of arriving at the descriptive level or to induce further practical problems, in order to initiate an extension of the descriptive level.

In the course of arriving at the descriptive level, pupils may also have come to pose theoretical problems, i.e., problems that demand a deeper understanding and further clarification of the descriptive level itself. Pupils may wonder, for example, why the established generalizations are as they are, or may have noticed points where the available ways of describing stand in need of improvement. Such theoretical problems and the descriptive level from which they derive may, from the curriculum deviser's point of view, contain enough germs that can reasonably be expected to develop into, what in the above I have called, theoretical knowledge, and for which I will from now on use the term 'theoretical level.' In that case, one may choose to link up with those theoretical problems in order to initiate a process towards a theoretical level: a new vocabulary and a new set of generalizations.

A first step may then be a switch to a way of describing in other terms than the ones of the descriptive level. That is, a switch to a new way of describing that promises to meet the need for improvement at the points where the terms of the descriptive level are somehow insufficient, and that may involve the elimination of causal concepts. The demand for better understanding and further clarification will then be met if pupils are able to deduce, from appropriate new generalizations involving the new ways of describing, something like the generalizations of the descriptive level. 'Something like,' because in the process of deducing the generalizations of the descriptive level pupils may also become aware of those generalizations' crude, imprecise and far from exceptionless character.

These two merits of the switch, i.e., being able both to argue to something like the old generalizations and to uncover some of their limitations, then provide good reason to believe that by means of the new vocabulary and the new generalizations (i.e., the theoretical level) it is possible to explain and predict more and with more precision. This may then, in turn, lead to an intention of pupils to further explore that possibility, by actually trying to make new predictions or to deliver more precise explanations. To the extent that pupils manage to do so, they may come to further value the theoretical level.

Let me close with a few additional remarks. Firstly, whereas a single descriptive level and the theoretical problems that are triggered by it may provide too slender a basis for initiating a process towards a fairly developed theoretical level, several descriptive levels together, along with the theoretical problems that are triggered by them, may contain enough germs that can reasonably be expected to develop into a theoretical level. Secondly, in the process of arriving at a theoretical level new theoretical problems may come forward or be induced, which may initiate a renewed process towards a vocabulary and a set of generalizations with the same two merits as mentioned above, and with the same positive fall-out as mentioned above: to be able to explain and predict more and with more precision. Pupils may thus also come to appreciate, finally, a basic mainspring of fundamental science.

7 Some aspects of devising a didactical structure

7.1 Introduction

In this chapter I pay attention to some aspects of the process of constructing and reconstructing a didactical structure. In section 7.2 I point at one aspect: further detailing the general outline presented in chapter 6. Another important aspect is, of course, that of comparing a devised didactical structure, as a prediction of what was expected to happen, to an interpretation of what actually does happen when it is tried. In this way, the didactical structure goes empirical and thus becomes open for revisions. In section 7.3 I discuss its status as an empirical theory. On a global level, the process of constructing and reconstructing a didactical structure will follow the cyclical (or spiral) procedure that is common in developmental research (see, e.g., Lijnse, 1995): devising, trying out, revising in the light of the results of the try-out, retrying, etc. In my PhD-study, two cycles (or spiral loops) of constructing and trying were completed in two successive years. In section 7.4 I describe some of the revisions that were made in the first loop, in the transition from the first version to the second version, and I try to describe them in such a way that what I have to say may be of more general use. In chapter 8 I will in more detail describe the second version. In chapters 9 and 10, finally, there is some more on the 'revising in the light of the results of a try-out'-part of the procedure, concerning the second version and the teacher's role respectively.

7.2 Further detailing the global outline of a didactical structure in a problem-posing manner

In chapter 6 I have illustrated a global outline of a didactical structure that supports a problem-posing approach. A further step in constructing a didactical structure involves detailing it in a problem-posing manner, such that for pupils every activity is given a point by preceding activities and, together with these preceding activities, gives a point to following activities. Or, to put it more realistically, my (re)construction of the didactical structure was some sort of a mixture of two processes.

The first one started at the level of concrete activities. When I had an idea about a concrete activity that I thought would somehow be useful without being able to say how and where (or even whether) it would fit in the structure as a whole, I would in that process not bother about the how, where or whether. I would rather think about what kind of activities might precede (or: prepare for) the particular activity I had in mind and/or what kind of activities might follow it (or: be prepared by that particular activity and the ones that precede it) -i.e., I tried to think of a string of activities around the particular one I had in mind. If I succeeded in that, this string would usually give me a good insight -and a more extended string would usually give a better insight- in the how, where or whether *it* would fit in the structure as a whole.

The second process started rather from the global outline of the total structure and was sort of the reverse of the first one. In the second process my ideas about the global outline of the total structure would enable me to formulate constraints that the activities in some part of the structure would have to satisfy. The range of suitable such activities would thus be narrowed down, though not, of course, to the level of concrete activities (or concrete strings of activities).

As already noted, most of the time the (re)construction of the didactical structure was some sort of a mixture of these two processes: having an idea about what kind of string of activities is needed in some part of the structure; having an idea about a concrete activity that may be useful; trying to think of a string of activities around that particular activity, while bearing in mind the constraints put on the string, etc. As more and more strings were worked out, there arose the problem that one also faces when digging a tunnel from opposite sides: things should neatly connect. This further constrained the construction of strings and required modification of already devised strings, and gave rise to a process of linking, matching, fitting and gluing together strings to a coherent structure, while avoiding loose ends as much as possible. Of course there were also practical constraints, among which the time-constraint was most pressing. Although I had planned a 3 to 4 month period for the construction of the didactical structure (both for the first version and, in the following year, for the revised version), in both cases this was barely enough.

It will also be clear that consulting colleagues at appropriate stages was an integral part of the total procedure. Their comments were especially valuable for helping me overcome deadlocks, which usually turned out to be apparent.

7.3 A didactical structure as an empirical theory

In section 5.4.2 I have characterized a didactical structure of some topic as an account of a planning of pupils' learning about that topic in terms of a dynamical process of rational accommodation. It predicts the route that this process, guided, of course, by teacher and teaching materials, is expected to follow. It does so by appealing to basic standards of rationality that pupils share with us. The predictions a didactical structure makes are thus to be understood like the teleological (or: reason-) explanations we give of human thought and action. The latter render someone's behaviour intelligible to us, precisely because they describe her behaviour as being governed by the basic standards of rationality she shares with us (cf section 4.2.1). They are, because of their appeal to rationality, description and explanation (rationalization) *in one*. Likewise, it is in justifying the predictions that a didactical structure makes, that an appeal to pupils' rationality comes in. For it will then be assumed that when devising experiments pupils will think of ones that can reasonably be expected to give answers (to questions they preferably posed themselves); that they will base their hypotheses in a sound way on the relevant evidence and will collect appropriate new evidence in order to choose between various hypotheses; that they will be able to find out how each of them uses his or her words (that they will be able to set up the right sort of triangular relations, cf section 4.3); that they will see the point of agreeing to use some terms in a particular way, etc.

By comparing the predictions of a didactical structure to what actually does happen in a series of lessons, a didactical structure goes empirical. The point of this comparison is not to empirically test whether pupils are rational or not. In fact, in order to make the comparison, what actually does happen will first have to be interpreted in terms of what, at various stages of the process, pupils believe, mean by what they say, intend to achieve with what they do, etc. Again, such an interpretation requires a background of rationality. To say that pupils have beliefs, desires, intentions, or that they perform intentional actions, etc, is to say that they are rational.[1)]

The point of the comparison is rather to improve the didactical structure. Suppose, for instance, that what pupils actually do cannot be understood as an action of the kind that would be reasonable to perform if they held the beliefs and desires that, according to the didactical structure, they were assumed to hold. If, on the other hand, what they actually do can be understood as an intentional action, as something that is reasonable to perform in the light of other beliefs and desires, the comparison then thus calls in question whether pupils actually hold the beliefs and desires they were, according to the didactical structure, assumed to hold. One may then look further back and try to understand why it is that pupils actually hold such and such beliefs and desires instead of the ones they were supposed to hold. One may thus e.g. conclude that much more preliminary work than supposed by the didactical structure has to be done before pupils will actually hold the beliefs and desires in the light of which it is reasonable to perform an action of the kind that, according to the didactical structure, they were supposed to perform. So if it still is desirable in the light of the further development that pupils come to perform an action of that kind, one may e.g. adjust the didactical structure by adding some appropriate preliminary work.

As for any empirical theory, there are of course no strict rules that tell where (and which) adjustments are to be made to the didactical structure. Moreover, because a didactical structure is a complicated and highly interrelated complex, necessary changes in one area of the didactical structure are likely to be accompanied by changes in several other areas. So when researchers, preferably in close cooperation with teachers, in this way study the outcomes of their efforts to bring about a problem-posing educational process, they will, like pupils in *their* study of physical phenomena, have to engage in a

1. To say that pupils are rational is not to say that they never act irrationally. In fact, only rational creatures can, once in a while, be irrational. Irrationality does not apply to the non-rational; it is a failure within the house of reason.

process of rational accommodation. If they are forced to adjust the didactical structure, they must do so as rationally as possible and stand ready to tinker where tinkering does the most good. I note in this respect that the more detailed a didactical structure is, the more a comparison with what actually happens will direct one's attention at points where it stands in need of improvement. Furthermore, by carefully trying to understand what pupils actually do and say, they themselves may, as it were, suggest adjustments at those points.

The aim of improving didactical structures is not the same as the aim of improving empirical theories in the physical sciences. Theories of the latter kind aim at a vocabulary containing concepts with precise conditions of application and at a closed system of strict laws in which those concepts are related, such that (the probability of) the occurrence of events, as described in that vocabulary, can be predicted and explained with (maximum) precision by the strict laws. The ultimate aim of at least basic, fundamental physics is to explain all that happens according to this mode of explanation. So if described in the appropriate (physical) terms, it may eventually be possible to thus explain and predict with precision everything that happens in a classroom. A didactical structure cannot aim at that, however. For a didactical structure essentially deals in mental concepts such as belief, desire, meaning, intention, etc. And it is precisely because those mental concepts only have application against a background of rationality that they resist incorporation into the closed system of strict laws that a developing physics aims at (cf section 4.4.2). A didactical structure does not predict or explain by recourse to a system of strict laws, but by an appeal to rationality.

The aim of improving didactical structures thus cannot be to eventually arrive at 'the ultimate' didactical structure, one which is guaranteed to lead to the predicted result in exactly the predicted way. There is also no need for such an ultimate didactical structure, however. What matters is whether a didactical structure is 'good enough' - whether it serves as a valuable guideline for understanding and guiding what goes on in actual classes. In each of these classes, however, the process will without doubt meander in a somewhat different way around the main path predicted by the didactical structure. So the aim is a didactical structure that is 'good enough.' Several revisions will generally be needed before the didactical structure can be judged as 'good enough' and the first revisions will most likely lead to considerable improvements (as may become clear from section 7.4). But no matter how many revisions have been made, no education could ever be successful without the creativity of a rational teacher who guides the process.[2)]

7.4 Some mistakes and improvements

In this section I pay attention to some of the mistakes and improvements I made (i.e., I

2. This is why I think a computer cannot fully replace a good human teacher as long as it has not passed Turing's test. I refer to Davidson (1990a) for a modification of Turing's original proposal to test whether an artificial machine thinks (believes, wants, speaks, intends, etc.)

made the mistakes and others made some of the improvements) in the process of constructing a didactical structure of the topic of radioactivity. The mistakes and improvements concern the first version of the didactical structure, and in particular my expectations about pupils' actions in relation to tasks given to them. I present the mistakes as cases in which my expectations about pupils' actions are too far out of line with (my interpretation of) what the pupils actually did in the first try-out. I have tried to so choose jljljl
and describe the mistakes and improvements that I think my remarks on them do not specifically concern the topic of radioactivity, but may be of more general use.

7.4.1 Too unspecific formulations

An often recurring mistake concerning the first version was that a given task did not direct pupils' attention to what had been intended. From an analysis of their reactions to such a task, I conclude that quite often the rather unspecific formulation of the task had led them astray. A first case to illustrate this point at is the recurring use of the word 'dangerous,' for instance in questions such as: Do you think it is dangerous that the jar with radioactive stones is in your classroom?; Do you think it is dangerous to stand at about a hundred feet from a vessel of radioactive waste?; Is it dangerous at the X-ray department of a hospital? Furthermore, chapter 2 of the first version of the textbook is called 'Is radioactivity always dangerous?,' and chapter 3 'Are irradiated objects dangerous?' One of the sections of the latter chapter reads (in translation) as follows.

> 3-2 FOOD IRRADIATION
>
> Radioactive radiation is sometimes used in order to make food keep longer. Strawberries, for example. Strawberries quickly go off because they are easily effected by bacteria. When strawberries are irradiated the bacteria die. The strawberries will then keep longer. Potatoes too are irradiated in order to prevent that they will sprout.
>
> [Pictures of irradiated and not irradiated strawberries and potatoes]
>
> There is a factory in Ede where food is irradiated by radioactive radiation. Below is a drawing of the room in which that happens. The radioactive radiation is emitted by a closed source at the centre of the room. Crates with food rotate around the source.
>
> [Drawing of irradiation room]
>
> 2 Irradiated food is actually sold in shops. Some people protest against that. They say it is dangerous to eat irradiated food. But then others say it is not dangerous at all.
> a Do you think it is dangerous to eat irradiated food? Why?
> b How would you check whether it is dangerous to eat irradiated food?
>
> In order to check whether or not it is dangerous to eat irradiated food, it would be best to use real irradiated food. But on food as it is sold in shops it does not say whether it has been irradiated or not. In order to be sure that you've got irradiated food, you would in fact have to go to the factory in Ede. But that would take too much time.
>
> 3 a Think of an experiment that can be carried out in the classroom and that simulates the irradiation of food on a small scale.
> Also note down all the things you need for that experiment.

b How can you check in this simulated situation whether or not it is dangerous to eat irradiated food?

Although I was to some extent aware of the rather unspecific nature of such formulations of tasks and questions when writing the first version of the textbook, I nevertheless used those formulations mainly for the reason that thus the tasks and questions would link up with existing knowledge, interests and concerns of pupils. For pupils know, for example, that radiation (or: radiation*) has harmful effects, they are concerned to maintain good health and so they will be interested in ways to prevent that the harmful effects will occur. Moreover, one of the aims of the lesson series is that pupils, whereas initially they are likely to judge every situation having to do with radioactivity as dangerous, learn to differentiate among such situations: that one can easily protect oneself against closed sources by keeping some distance; that objects will not emit radiation because of being irradiated, etc. The problem is, however, whether, if that is the aim, it is appropriate to keep framing the questions and tasks in unspecific terms such as 'dangerous.' That it is not I will briefly try to illustrate at some reactions of pupils who worked with the first version of the textbook.

Some of the reactions were as follows: "if it were dangerous, you [the teacher] would not have allowed the presence of the jar in the classroom, would you?;" and to question 2a above: if it were dangerous, "they would not sell it in shops" or "we would have been ill for a long time." Although such reactions make a lot of sense, of course, I had not intended them.

What I intended to achieve with question 2b and 3b above, was that pupils would want to check with a Geiger counter whether irradiated food emits radiation. So what I really wanted to ask was whether irradiated food is radioactive, whether one receives radiation from irradiated food (and thus has a chance of being affected by it). So I meant 'dangerous' to be understood as something like 'emitting radiation and because of that potentially harmful.' But of course the term 'dangerous' is not specific enough to be understood in precisely this way. Opponents of food irradiation, for instance, argue that irradiated food may have harmful effects, not because it is radioactive but because the irradiation may have caused chemical changes in the food. Some pupils too understood the term 'dangerous' not as I intended. They argued as follows: "You first have to know how many radiation a human being can stand and then you simply have to measure with a Geiger counter how much radiation those strawberries emit." For those pupils, irradiated strawberries may indeed emit radiation while they are not dangerous -as long as the amount of radiation they emit is below what a human being can stand. Other pupils suggested to test whether it is dangerous to eat irradiated food by using experimental animals and "to let the one eat irradiated food and the other not." For those pupils, whether or not the food is dangerous will show up in whether or not the one animal's physical condition will deteriorate in comparison to the other animal's. Although their suggestion does indeed constitute a plausible test for what they thought they were asked to test, it is not what I intended them to suggest -let alone to actually carry out.

The same sort of comments apply to what I intended them to learn from their simulation of food irradiation in task 3 above, namely: what they had irradiated had not become radioactive. So what I really wanted to ask was whether what they irradiated emits radiation, whether one receives radiation from it (and thus has a chance of being affected by it). Again, I meant 'dangerous' to be understood as something like 'emitting radiation and because of that potentially harmful.' And again, the term 'dangerous' is not specific enough to be understood in precisely this way. Not only can it, as above, be understood as applying to the potential harmfulness of an irradiated object for other reasons than that object's emitting radiation, but also as applying to the process of irradiation -to the potential harmfulness of that process for the irradiated object itself. This may explain why some pupils found it strange to conclude that irradiation is not dangerous. For those pupils, the term 'dangerous' was not specific enough to make them focus on what I intended them to focus on.

I hope it is clear that the above should not be read as making a plea for never using unspecific words such as 'dangerous.' My point is that, if more specific and mutually understood terms are available, those more specific terms be used in order to secure as much as possible that the pupils understand the given tasks in the same way and as intended, are challenged to use those terms themselves in e.g. their proposals for experiments and descriptions of results, and are able to reach mutual agreements on e.g. the results of their experiments. In fact it is an essential feature of their progress that pupils are going to use and understand specific terms in a mutually agreed way. An essential part, for instance, of their learning to differentiate among situations having to do with radioactivity, every one of which they initially were likely to judge as dangerous, is precisely that they are going to characterize such situations in the terms they have (e.g. in the first period, cf section 6.3.2) mutually agreed to use in a specified way -terms like 'is radioactive,' 'emits radiation,' 'is irradiated,' etc.

Let me illustrate the same point at yet another experience with the first version of the textbook. The example relates to chapter 4 of that textbook, a chapter called 'How to protect oneself?' In chapter 3 the term 'is contaminated' had been introduced as applying to objects that contain radioactive material. Furthermore it had been noted that contaminated objects emit radiation and, in particular, receive radiation from the radioactive material they themselves contain. The question in chapter 4 that I now want to focus on is the following.

> What ways do you know to take care that one receives as less radiation as possible?

My expectation was that the pupils would think both of ways to take care that one does not get contaminated and of ways to take care that one does not get irradiated (by an external source). It turned out, however, that they did not. They just mentioned some well-known protection measures: shelters of lead and concrete, lead aprons, keeping distance. On the other hand, when the teacher then mentioned some other measures, such as wearing a gas mask and taking a shower, the pupils were quite capable of explaining that such measures are useful because they take care that one does not get contaminated or because, if one already is contaminated, they may reduce the contamination. So although they were able, when given measures to prevent or reduce contamination, to judge such measures useful precisely for the reason that they prevent or reduce contamination, the above question did not challenge them to themselves come up with ways to prevent or reduce contamination. But if we want to challenge them to do the latter, then why not explicitly ask them to do so, given that the appropriate terms to do so are available in a mutually understood way? For instance as follows:

> Think of some ways to take care that one does not get contaminated.
> Think of some ways to take care that one does not get irradiated (by an external source).

7.4.2 Too little coherence

Another mistake concerning the first version was that sometimes the pupils did not perceive the coherence between successive tasks or did not perceive the intended coherence. A series of tasks for which this happened to be the case is taken from chapter 2 of the textbook, a chapter called 'Is radioactivity always dangerous?' One of the sections of that chapter reads (in translation) as follows.

> 2-3 SOURCES WITH RADIOACTIVE MATERIAL
> In the previous section you have noted that R-sources[3)] need not always be dangerous. At some distance from a jar with radioactive stones, for example, it was no longer dangerous.
> The stones in the jar emit *radioactive radiation*. That is why we call those stones *radioactive*. At some distance one hardly measures the radioactive radiation that is emitted by the stones. The Geiger counter then ticks as fast as when the jar with stones would not be there.
> This is the same with sound. If one stands at a far enough distance, one cannot hear (or measure) the sound that is emitted by a radio.
>
> 4 Up to how far can the radiation from the jar with radioactive stones still be measured? How did you check that?
>
> 5 The jar with radioactive stones is an example of a source that contains *radioactive material*.
> a Do you know any other sources that contain radioactive material? Which?
> b Up to how far do you estimate that the radiation from those sources can still be measured? Why do you think so?
>
> [Picture of some nuclear fuel elements, with the subscription: "In a nuclear power station there are rooms in which radioactive material is stored. Those rooms have thick concrete walls."]
>
> 6 In the Netherlands there are two nuclear power stations. In Borsele and in Dodewaard.
> [Map of the Netherlands, in which Borsele and Dodewaard are indicated. Pictures of

3. In chapter 1 of the textbook this term had been introduced to characterize an object or apparatus in the vicinity of which a Geiger counter starts ticking.

the nuclear power stations in those places.]

Do you think that where you live one can still measure radiation from those nuclear power stations? Why?

[Picture of the nuclear power station in Chernobyl before the accident.]
Unfortunately, accidents happen now and then in nuclear power stations. Perhaps you can still remember the accident with a Ukrainian power station in Chernobyl that happened in 1986. The picture above shows the power station in Chernobyl before the accident. Below after the accident.
[Picture of the nuclear power station in Chernobyl after the accident.]

7 Also in the Netherlands radiation was measured because of the accident in the nuclear power station in Chernobyl. Chernobyl is more than 1500 km away from the Netherlands.
- a Could we in the Netherlands measure radiation from the nuclear power station in Chernobyl before the accident had happened? Why?
- b How come that after the accident we could measure radiation from it in the Netherlands?

8 The jar with radioactive stones is standing in front of the classroom. You have already learned that at the back of the classroom you won't receive radiation from it.
Think of what would have to happen in order that at the back of the classroom radiation can be received by it.

I think the idea behind this series of tasks will be clear to anyone who already understands the point of distinguishing between open and closed radioactive sources. Starting with a source containing radioactive material that pupils have worked with (the jar with stones) and of which they have already noted that at some distance one hardly measures the radioactive radiation that is emitted by it (task 4), pupils are asked to say of other sources containing radioactive material (task 5), and in particular nuclear power stations (task 6), up to how far they think the radiation emitted by those sources can still be measured. It is expected that, aided by the suggested analogy to the jar with radioactive stones, they will be inclined to believe that if one stands at a far enough, but still rather limited distance, one also will not measure any radiation emitted by those sources. In particular, they will then hold that before the accident in Chernobyl happened no radiation from it could be measured in the Netherlands (task 7a), and thus see the point of the question why after the accident it could (task 7b). Furthermore it is expected that pupils will use whatever they know about the Chernobyl accident when thinking about what would have to happen in order that at the back of the classroom radiation can be received by the jar with stones (task 8). Finally it is expected that they will use whatever they have learned from their attempts to make it the case that at the back of the classroom radiation is received (e.g., that simply to open the jar is not sufficient), to (re)consider how it can be that after the Chernobyl accident radiation could be measured in the Netherlands.

From an analysis of their reactions to this series of tasks, I conclude that there is too little coherence in it *for the pupils*. Although for them too the jar with stones and the power station in Chernobyl, for examples, are similar in the sense that both contain radioactive material and that from both of them, if properly sealed, hardly any radiation can be measured (at some appropriate distance), this similarity was not relevant, important or striking enough for them in order to transfer things known or learned about the one situation to the other.[4)] In response to task 7b, for instance, both the power station's being broken (because of an explosion) and the wind were mentioned by pupils as important factors. In response to task 8, however, none of them mentioned wind, as can be expected if they treat the situation of the jar in the classroom as a situation not relevantly related to the situation of the power station in the open air. To further illustrate that the two situations are not relevantly similar for pupils, the suggestions "double the amount of stones a few times" and "more stones," in response to task 8, can be mentioned. Carrying out that suggestion would, for them, make the two situations more similar. In the same vein a pupil remarked, after having concluded that simply opening the jar is not sufficient to measure radiation at the back of the classroom, that "if the jar was very strong like Chernobyl" simply opening it would have been sufficient. The coherence between e.g. tasks 7 and 8, which I expected to emerge from thinking back and forth between the two similar (for me) situations, did not emerge for the pupils (or at least not in the way I intended).

The aim of tasks 7 and 8 above was that the pupils made progress by thinking back and forth between the Chernobyl accident and their attempts to make it the case that at the back of the classroom radiation can be received by the jar with stones. The aim was not reached because their not finding the Chernobyl-situation and the 'jar with stones'-situation relevantly similar prevented that their actions in the 'jar with stones'-situation were guided by what they knew about the Chernobyl-situation. Having put matters this way, a way to improve matters suggests itself: if pupils are to make progress by thinking back and forth between two situations, the two situations should already be relevantly similar for the pupils before they have made the progress (and not just be relevantly similar to someone who already has made the progress). For the case at hand, I now briefly sketch a concrete attempt at improvement along the suggested line.[5)] It simply consists in replacing the 'jar with stones'-situation by a classroom-situation in which pupils can act, as is the case for the 'jar with stones'-situation, and that pupils already before they are going to act in it find relevantly similar to the Chernobyl-situation, as is not the case for the 'jar with stones'-situation. The idea is that a classroom-situation meeting these conditions can be brought about by first giving pupils a task like the following.

4. The relevance or importance of the similarity derives, of course, from the fact that it is only when the radioactive material is somehow able to escape from what used to contain it (the jar, the power station), that radiation can be measured at a fairly large distance from where the radioactive material was originally contained. However, it is precisely this fact that the pupils do not yet know and that, conversely, they are supposed to learn from carrying out their suggestions to task 8.

5. For details I refer to chapter 8. I owe the idea for the concrete improvement to Hans Créton, who by suggesting it helped me overcome the deadlock in my own up to then unsuccessful attempts.

> **A small scale 'nuclear power station'**
> In your classroom lies some radioactive material. Now suppose that is the material that will be used in a nuclear power station. So the required radioactive stuff is ready. There is just this problem: the power station itself is not yet there.
> It is up to you to go build the 'nuclear power station.' Or better: a storage room in it. That is, a room in which the radioactive stuff can be safely stored. The storage room of your 'power station' thus has to meet one important condition. Outside your 'power station' one should receive no radiation from the radioactive stuff stored inside.
> Devise a building plan for the storage room in your 'nuclear power station.' Make sure that your plan can actually be carried out.

In the process of carrying out their building plans, the pupils will eventually build their own 'nuclear power station,' which meets the required condition. By construction, then, their 'nuclear power station' is relevantly similar to real nuclear power stations in the sense that it meets an important safety requirement that -obviously, and well-known to pupils- real nuclear power stations have to meet as well. Moreover, after the accident the power station in Chernobyl clearly, and usually still well-known to pupils, did not meet the safety requirement for some time: even in the Netherlands, at more than 1500 km from Chernobyl, radiation could be measured after the accident had happened. A follow-up task, in which the pupils are going to act in the 'power station of theirs'-situation they themselves have just created, and in which it is likely that their actions are going to be guided by what they know about the Chernobyl accident, now suggests itself.

> **Imitations of the Chernobyl accident**
> You have just built a 'nuclear power station.' Let us call the place where it is standing 'Chernobyl.' And let us call some place at the opposite side of the classroom 'the Netherlands.'
> How can it be brought about that radiation is measured in 'the Netherlands?' What would have to happen for the latter to be the case?
> Write down a plan to make it the case that radiation is measured in 'the Netherlands.' Or several such plans if you can think of more than one. (Make sure, however, that all your plans can actually be carried out.)

7.4.3 Too little preparation

Let me go back to the original series of tasks (tasks 4 to 8 above), in order to draw attention at some other mistakes in my intentions with them and expectations about them. It was not my aim that the pupils in the process of working on these tasks would *come to* recognize, and *come to* understand in a particular way, some central theme, and *come to* formulate some problem relating to that theme. I rather assumed that the pupils would recognize the central theme that I recognized in the tasks -something like: under what conditions can where radiation be measured. I further assumed that they would understand the problem relating to that theme as I did, and so would understand the tasks as I did. My aim simply was that the pupils in the process of working on these tasks would come to solve the problem. My expectation was that they could, that in carrying out the tasks they would find out something like: in order that radiation can be measured at a large distance from a radioactive source, it must have been the case that radioactive material has escaped from that source. No further preparation and guidance would be needed.

Below I describe fragments of what, concerning these tasks, actually did happen in the try-outs of the first version, and how I think those fragments of what actually did happen relate to the just mentioned complex of assumptions, aims and expectations concerning these tasks. I have picked out fragments that have made me doubt about that complex of assumptions, aims and expectations, and have thus contributed to my arriving at ideas to detail the global outline in a more problem-posing manner.

The most important thing to note is that in the course of carrying out the tasks many pupils did not, contrary to my expectation, arrive at something like:

> In order that radiation can be measured at a large distance from a radioactive source, it must have been the case that radioactive material has escaped from that source. (A)

I think that several factors contributed to their not arriving at something like A. The first one is, paradoxically, the exclusive aim to make them arrive at something like A. This exclusive aim made the teacher 'hear more' in what the pupils said than I think they actually meant to say, and in particular it made him hear them say something like A when, in fact, I think that by saying what they said they did not mean anything like A at all. In response to task 8, for instance, the pupils not only brought forward the already mentioned suggestions "double the amount of stones a few times" and "more stones," but also the following ones: "open the jar," "take the stones out of the jar," and "smash the jar." The teacher heard in the latter suggestion something like A, i.e., a suggestion to smash the jar so violently that the stones will crack and pieces of them will spread all around. For when he addressed the suggestion, he immediately took a board eraser, threw it to the floor, and noted that the chalk powder spreads all around. I think, however, that the suggestion to smash the jar should be understood on a par with the suggestions to open the jar and to take the stones out of the jar, as all suggesting, namely, to reduce the resistance and enable the radiation* to escape (cf section 2.5). I feel strengthened in this interpretation by the fact that, while working on task 8, one of the pupils in the group that made the suggestion to smash the jar remarked that "glass partly stops the radiation, doesn't it." As a consequence the pupils did not add much to what they already knew, namely that radiation* can be made to escape in several ways, some of which are more efficient than others. As they understood it, they could agree with the teacher's concluding remark on what had been established in task 8: "so we have found that, while opening it perhaps makes a difference, it's still worse if it is suddenly thrown very fast to the ground."

Furthermore, when subsequently the teacher asked them to reconsider their answers to task 7b, there was not much to reconsider for them: they still held that radiation (radiation*) was released, because of the explosion, and transported towards the Netherlands, because the wind happened to blow in the direction of the Netherlands. This is not surprising, of course, given that for them the Chernobyl-situation and the 'jar with stones'-situation were not relevantly similar and, moreover, they had not arrived at something like A in the 'jar with stones'-situation. The only thing that did become problematic for them was the teacher's question: "but *what* was it that was blown towards us?" Or to be more precise, it was not so much the question itself that became problematic, because they knew and had in fact just given the answer, but rather that the teacher repeated the question again and again, and more and more emphaticly. That must have given them the impression that the teacher was not satisfied with their answer. This lead to a situation in which the pupils started to propose things that they thought might please the teacher, a situation, moreover, that the teacher did not want to be in and tried to extricate himself from. The below fragments may illustrate the awkwardness of the situation.

Anastasia: That was because of the wind.
Teacher: But what is it that was blown with the wind up to here?
Marian: Molecules.
Teacher: Ow! I find that a scary word. Why do you say …?
?: Electrons.
?: Nuclei.
Teacher: That is a word I've never heard of. What do you [Anastasia] think was blown up to here?
Several pupils: Radiation.
Anastasia: Well, those particles. I don't know.
Teacher: Those particles. In a moment we are to choose from … and you will have to talk about that with the others in your group for just a little while, say, about ten seconds … you are to choose from material …
?: Atoms and cells.
Teacher: … I said, material and radiation. What is it that was blown to here?

[While the groups are deliberating on the matter, all options are being called out: "radiation," "material," "both."]

Teacher: What do you think?

[The teacher asks each of the six groups what they have chosen. Three groups have chosen 'radiation,' two 'material,' while one group is divided on the matter.]

Teacher: Aha, here we have a problem.

[Several pupils are, rather excitedly, speaking at the same time. The teacher quiets them down, and invites Bouzian to speak his mind.]

Bouzian: I think it gets inside the air particles and is then carried along with the wind.
Teacher: What gets inside the air particles?
Several pupils: Radiation.
Teacher: Radiation gets inside.
Several pupils: Right.

…………………………………………

Bouzian: I think it got inside the air … the radiation …
Teacher: The radiation.

Bouzian: … because that rain came down on the … the farmers got into trouble, because the …

[A murmur of approval comes from some other pupils. I can discern additions such as "Cows."]

…………………………………………

Teacher: Is it radiation that was blown up to here or is it …? My car … oh yes, that just occurs to me … my car looks a mess right now, it's like a

	beach. How on earth did that come about?
Several pupils:	Sahara sand.
Teacher:	That's not Sahara sand, is it, that's Sahara radiation.

Eventually the teacher gave his solution to the (his) problem: because of the explosion the radioactive material was spread around in many tiny pieces, all of which emit radiation; those tiny pieces can be carried along with the wind for thousands of kilometres, just like Sahara sand. All the time, however, there was not really a problem for most of the pupils, though they did of course find out that to please the teacher they would have to say something like material rather than radiation. In fact, in their attempts to meet the teacher's standards (cf section 5.3.1), they came up with all sorts of hybrid constructions such as air particles with radiation (radiation*) inside (cf Bouzian above). Other examples are: "irradiated dust," "particles of radiation" and "dust particles covered with radiation."

Probably many pupils did not recognize the central theme that the teacher and I recognized in the tasks (under what conditions can where radiation be measured), but in any case they did not, contrary to my assumption, understand it in the way the teacher and I did. Nor did they come to appreciate the problem relating to it. They have probably learned (if they did not already know) *how it could have been* that radioactive material was transported from Chernobyl to the Netherlands, but certainly not *why it must have been* that radioactive material was transported from Chernobyl to the Netherlands. Had the pupils in the process arrived at conclusions such as

> A geiger counter ticks near radioactive material, but no longer does so some distance away from it. (B)
>
> By applying a resistance (e.g. a lead covering), also nearby the Geiger counter does no longer tick. (C)
>
> Removing the resistance will make a Geiger counter nearby start ticking, but not a Geiger counter some distance away. (D)
>
> The Geiger counter some distance away also does not start ticking when there is a draught towards it, even if the resistance has been removed. (E),

then those might have been intermediate steps in their coming to understand the central theme in the intended way, in their coming to appreciate the problem relating to it, and, eventually, in their arriving at something like A as part of the solution to that problem. I have already noted that they did not arrive at conclusions like B to E, because for them the 'jar-with stones'-situation was not relevantly similar to the Chernobyl-situation and because of the exclusive aim to make them arrive at something like A. A way to improve matters might be the following: replace the first version tasks 4 to 8 by the alternatives suggested above ("A small scale 'nuclear power station'" and "Imitations of the Chernobyl accident"); replace the aim to make them arrive at something like A by the aim to make them arrive at something like B to E. The function of the two alternative tasks would thus be that they contribute to pupils' coming to understand the central theme in the intended way and their coming to appreciate the problem relating to it.

But even if those tasks do contribute to it, they still will not sufficiently prepare the stage for pupils' coming to understand the central theme in the intended way and coming to appreciate the problem relating to it. For what then also needs to be prepared is that the pupils no longer use expressions like '*x* contains radiation*' (as in 'the radiation* got inside the air' or 'the radiation* got inside the cows'). In section 6.2.3 I have already argued that this might be achieved in a process in which the pupils more and more consistently stick to an agreement made with regards to the expression '*x* is radioactive,' and in which they also come to conclude something like:

> A Geiger counter does not start ticking near an object because of the fact that the object has been irradiated. (F)

Now, in the first version something like F was not prepared until section 3-2 (see section 7.4.1 above), while if I am correct in my analysis, it was in fact already needed in section 2-3. So what actually belongs together was, in the first version, too widely separated, both in context (Chernobyl vs food irradiation) and time. Again, a way to improve matters suggests itself: somehow merge sections 2-3 and 3-2 into a (for pupils) coherent whole, while taking into account all the suggestions for improvement made earlier.

I postpone to chapter 8 the further details of this merger or, alternatively, of my resolute attempt to couch the case at hand in a more problem-posing form. Let me here just make one more comment concerning a problem-posing approach. For one might argue that also in a problem-posing approach the same danger looms as described above: to 'hear and see more' in what the pupils say and do than they actually mean to say and do, e.g., if the aim was that they would come to frame some problem, the teacher or researcher might easily hear them frame that problem while, in fact, they did not mean to frame that problem at all. I do admit that there is some tension here, which ten Voorde (1977) has called an *anticipation tension*. But I also observe that being aware of the tension is already a first step in avoiding or reducing the danger associated with it. Moreover, it will be remembered that it is the point of a problem-posing approach to enable pupils to themselves perceive their learning process as an internally coherent one with a certain direction that in important respects is being driven by their own questions. But then it is clear that to directly march, as if blinkered, towards the aim (whether the aim is that they come to frame some particular problem or arrive at a particular solution), and thus to 'hear and see much more' than is actually there, is to miss this point altogether. If one really understands the point, one will, on the contrary, be even more sensitive to find out what pupils actually say, believe, want, etc. And it is only then that one can really learn something from a try-out, for the pupils will then, as it were, themselves point at e.g. necessary intermediate steps that one had overlooked. In chapter 10 I will say more about the teacher's efforts to deal with his anticipation tension and to transform it into an attitude of being prepared to learn along with the pupils.

7.4.4 Too early introduction of scientific terms

In this section I point at a consequence of mistakes described in previous sections: premature introduction of scientific terms. Let me illustrate this at section 2-4 of the first version of the textbook, which follows the above quoted section 2-3 of the textbook. In section 2-4 (Open and closed sources), the distinction between open sources (sources from which radioactive material is able to escape) and closed sources (for which this is not the case) is introduced. Now, of course, there were some pupils who were able to make the distinction as intended: one pupil said about a closed source that "the material does not come out, but the radiation does;" another one remarked about the jar with stones that "when it is dropped it will become an open source and then it is possible that radioactive material will come out, and if then there is a breeze through the classroom it will spread all over the classroom;" concerning one of the radioactive materials that the pupils had worked with earlier, a bathroom tile, a pupil said that "it is closed too, because the material does not now come out, does it, but only when you smash it." Those pupils were able to make the distinction as intended, because they had in section 2-3 arrived at something like A: that in order for it to be possible to measure radiation at a large distance from a radioactive source, it must have been the case that radioactive material has escaped from that source.

In the previous section I have already noted that many pupils had not arrived at something like A. For those pupils, the point of the distinction between open and closed sources could thus not derive from their knowledge of something like A. Instead, they had to find other characteristics on the basis of which they could use the words 'open source' and 'closed source' distinctly, and in doing so they did not make the distinction as intended. Here are some examples: concerning an open source a pupil said that "everything that the source contains comes out," and concerning a closed source that "nothing comes out of the source itself … well, something does, but just a little bit;" another pupil remarked that "only if the source emits, that is, only if it is open, you can get radiation from it;" one group would hand out lead gloves to the personnel of an X-ray department, because an X-ray machine "is an open source." Those pupils seem to have found as characteristic difference that (almost) nothing comes out of a closed source while quite a lot does come out of an open source. Somewhat related to this, some pupils seem to have found as characteristic difference that closed sources are still intact while in open sources the original resistance has been broken: "if it is not stopped by anything, if for example the stone is just lying on the table, it is an open source;" another pupil remarked that if the stone was just lying on the table, it still would not be an open source because "it is inside the stones, first the stones would have to be totally broken;" one group indicated that an X-ray machine would become an open source if "the X-ray machine was smashed to pieces." Some pupils, finally, seem to have picked up as characteristic difference that open sources are dangerous while closed sources are not: "it is an open source, and thus dangerous."

It is of course not strange at all that pupils who had not arrived at something like A come to characteristic distinctions such as just a little bit/quite a lot comes out or intact/broken when they hear such things as: "when it is dropped it will become an open source and then it is possible that radioactive material will come out," or "it is closed too, because the material does not now come out, does it, but only when you smash it." Given e.g. the title of chapter 2, 'Is radioactivity always dangerous?,' the not-dangerous/dangerous distinction, finally, is very much suggested by the text itself, just as it is in section 3-2 of the textbook (cf section 7.4.1 above).

The above is meant to illustrate that (scientific) terms should not be introduced before the pupils will be able, because they have come to see the point of introducing them, to interpret the terms as intended (cf section 5...). They should only be introduced when, as it were, all that is lacking is just the words -in the case just discussed, the words 'open source' and 'closed source.'

7.4.5 Concluding remarks

From the examples in sections 7.4.1 to 7.4.4 it will be clear that the first version of the didactical structure cannot be judged 'good enough.' In order to improve it some structural, instead of merely cosmetic, changes are needed, and some suggestions for changes have been made. The second version of the didactical structure that has resulted from these changes will be described in the next chapter.

In conclusion of this chapter I want to draw attention to the method of developmental research itself, and especially to the use of constructing a problem-posing didactical structure: a process of rational accommodation that pupils themselves are expected to establish and give shape, guided of course by teacher and teaching materials. Firstly, it is thus tried to secure that an actual process in which such a didactical structure is taken as a guideline develops as explicitly as possible, in the sense that pupils' reasons for doing what they are doing, the conclusions they reach, the questions they frame and want to find an answer to, etc come forward as explicitly as possible. As a result, pupils', teachers' and researchers' chances for a successful interpretation of what, at various stages of the process, pupils believe, mean by their words, intend to achieve with what they do, etc are increased. Secondly, it thus becomes possible to compare the actual process with the one that pupils were expected to establish and give shape. As a result, the comparison will lay bare where the didactical structure stands in need of improvement, and may point at possible improvements.

In short, the method of constructing a didactical structure of some topic, trying it, reconstructing it in the light of the results of the try-out, retrying it, etc, is designed to lead to a 'good enough' didactical structure of that topic. And in section 5.4.3 I have already urged that it are 'good enough' didactical structures that science education should strive at.

8 A didactical structure of the topic of radioactivity

8.1 Introduction

In this chapter I describe the didactical structure of the topic of radioactivity that I arrived at after the first try-out and evaluation -i.e., the second version of the didactical structure. It aims to give an account of how, for the topic of radioactivity, a given order of tasks and teacher interventions, in relation to pupils' reactions to those tasks and interventions, and with pupils' rationality as a driving force, is expected to lead to which changes of meaning, additions of belief, changes of intention, etc. It does not consist of a series of tasks, but consists in the design of a good educational process in the light of which such tasks are justifiable. So the natural way to devise and present a didactical structure is in the form of, quite literally, a *scenario* of what is expected to happen in a lesson series. By doing so one is forced to take into account the relevant interrelations between tasks, teacher interventions, pupils' understanding of and reaction to those tasks and interventions, changes of meaning, additions of belief, changes of intention, etc. Furthermore, a scenario can most easily be compared with what actually does happen. In fact, an important reason for devising a detailed as possible didactical structure in the form of a scenario is that it will serve as an important research tool in interpreting what actually does happen.

In section 7.3 I have already noted that there is no need for a didactical structure that will for sure lead to the desired result in exactly the predicted way. All that is needed is a didactical structure that is 'good enough.' In chapter 9 I will try to answer the questions in what respects the didactical structure to be presented now is 'good enough' and in what respects it stands in need of improvement. In section 7.3 I have also noted that without the creativity of a good teacher no education could ever be successful. In chapter 10 I will go into the important role of the teacher in devising, trying and improving the didactical structure.

Along with the didactical structure (in the form of a scenario) also the textbook that pupils would have to work with was written. This textbook, the format of which I describe in section 8.2, should not be thought of as a conventional textbook, but rather as a sequence of tasks or worksheets. And although it should not be equated with the didactical structure, it does serve as a guideline for the below presentation of the didactical structure. The didactical structure itself is structured according to the general outline described in chapter 6. Section 8.3 concerns the preparatory period in which a ground level for the following descriptive level emerges; section 8.4 the transition from this ground level to a qualitative descriptive level. Since in my PhD-research I have mainly focused on these two periods, I will discuss them at length. Because there is hardly anything new in it, I will pay less attention to an extension of the descriptive level in quantitative direction (section 8.5), in which aspects like the penetrating power of radiation, and the strength and half-life of radioactive materials are considered. I am not confident at all about the transition from descriptive level to theoretical level (section 8.6), in which it is tried to induce some kind of theoretical need (cf section 6.3.6) and to introduce nuclear models that satisfy this need. I doubt, for instance, whether it makes sense to even try to meaningfully introduce fairly detailed such models for middle ability pupils of about 15 years of age (the target group). In section 8.6 I give some grounds for those doubts, and explain why, then, it has been tried to introduce nuclear models at all. In section 8.7, finally, I briefly reflect on the status of the didactical structure.

8.2 Format of the textbook

The textbook was written by Wouter Moerman[1] and me, and the two of us regularly consulted, and got valuable comments from, Chris Janssen, Piet Lijnse, Harrie Eijkelhof, Rupert Genseberger and Hans Créton. It consists of 94 A4-sized pages. In order to increase readability, a relatively large letter is used, sentences are kept relatively short, and hardly any punctuation is used (apart from capitals and full stops). I refer the reader who wishes to get an idea of what the textbook looks like to appendix 2, which contains copies of three pages of the textbook. Figure 8.1 gives the contents of the textbook.

1. He also took care of the lay-out.

Figure 8.1 Contents of the textbook

I have already noted that the textbook is not made up like a conventional textbook. It does not, or hardly, contain explanations of theory, instructions for experiments, exercises, etc. It rather consists of a sequence of tasks by means of which the pupils are challenged to themselves think of experiments, carry those out, draw conclusions, formulate questions they want to further work on, think about the main things they have learned or mutually agreed on, etc. Furthermore, it has been tried to sequence the tasks in such a way that all along the pupils themselves know what they are doing and why, and that by building on what they already know are given ample chance to further extend what they already know, driven by what they themselves are doing, by their reasons for doing it, and by the conclusions they reach and problems they encounter as a result of doing it. As will become clear below, the function of many tasks is, for instance, not so much that definite conclusions are reached, but rather that they contribute to making pupils see the point of, or even to pupils' putting forward proposals for, following activities. Furthermore, the summaries at the end of each chapter in many cases consist of just the two headings 'Important to remember' and 'Questions we still have to find an answer to' (see appendix 2 for an example). It is up to the pupils, guided, of course, by the teacher, to note down under these headings what for them are the important things to remember from what they have done in the chapter and the questions worth finding an answer to that have arisen while working their way through the chapter respectively.

So the textbook as the pupils get it is not yet a textbook at all. It is rather something that helps the pupils in writing their own textbook. Its function is to make the pupils more involved in their own learning process and to give them more control over the progress they make with respect to content. For they are expected to be more involved when they are challenged to carry out their experiments, to draw their conclusions, to formulate their questions, etc. And they are expected to take more control over their progress with respect to content when they are challenged to reflect on their own learning process: what have we done and why?; what have we learned and how?; what do we still have to find out?, etc.

I just note here, and will discuss at greater length in chapter 10, that giving the pupils more control over, and thus more responsibility for, their progress with respect to content does not imply the teacher's loss of control or responsibility, but only a shift in his or her control and responsibility: a shift towards procedural control and responsibility for managing the process. The teacher will e.g. have to take care that each group of pupils has its say, praise each group for its contributions, make the groups carefully listen to each other, challenge them to reach agreements, etc. The shift towards procedural control also involves a shift from wanting to make the pupils say and do particular things (with the associated danger of 'hearing and seeing much more' in what the pupils say and do), towards the teacher's being more prepared to find out what the pupils actually do say, believe, want, etc, and to match his or her goals to what they actually say, believe, want, etc (cf section 7.4.3). It may thus help the teacher to better deal with his or her anticipation tension by transforming it into an attitude of being prepared to learn from the pupils (*ibid*), to better link up with the pupils' use of words, to give more adequate feedback, etc.

8.3 The emergence of a ground level

The first period, in which a ground level for the following descriptive level emerges (cf section 6.3.2), more or less[2)] takes place in chapter 1 and sections 2-1 to 2-3 of the textbook. In here it is tried, by linking up with their existing knowledge, interests and uses of language, to induce in pupils a global motivation for the topic and a want to extend their knowledge and uses of language in certain ways. As regards the uses of language it is tried to make them agree, for reasons that make good sense to them, on a specific use of in particular the term 'is radioactive,' namely as applying to objects in the vicinity of which a Geiger counter starts ticking. Concerning the knowledge it is tried to make pupils recognize that they do not yet know the solution to the general problem how things can be made radioactive (in the agreed sense) and how not, by bringing them in such a position that they themselves come to pose this problem. By setting the aim that the pupils themselves come to pose the problem, and come to understand it in accordance with the agreements made earlier, it is tried to secure as well as possible that the problem has a clear meaning to them and that they will appreciate an attempt to solve it as intention-worthy.

2. I do not see any point in trying to draw a sharp line between, for instance, the first and second period. There simply is no such sharp line.

8.3.1 A global outlook

To start the lesson series, the teacher pages through the textbook with the pupils, while pointing at some characteristic features of it. In particular the teacher points at the empty spaces between the tasks, which the pupils themselves will have to fill up, and at the summary at the end of chapter 1, which the pupils themselves will have to write. The teacher also notes that every chapter ends with a summary like that.

Furthermore, the teacher draws attention to some empty pages at the end of chapter 1, and asks the pupils to fill these up with newspaper-cuttings concerning the topic of radioactivity that they come across the coming weeks. The teacher also asks them to mark in such articles the passages that they do not understand. At the end of the lesson-series it can be seen whether they then do understand. In order to illustrate that regularly there do appear articles concerning the topic in papers or periodicals, the teacher may show the pupils a folder containing cuttings of such articles that he or she has collected throughout the years.[3)]

Subsequently the pupils are given the first task.[4)]

> **1 What has got to do with radioactivity?**
> Note down below what kind of things have got to do with radioactivity.

After the pupils have written some things that, according to them, have got to do with radioactivity, the teacher asks some pupils to read what they have noted down, asks others whether they need further clarification or want to make additions, etc. This exchange is not meant to start an in-depth discussion about the things that according to some pupil have got to do with radioactivity. Its point is, firstly, that everybody gets an idea which things are being mentioned. If, for instance, some pupil mentions 'Chernobyl,' informative questions such as 'Tell us some more about Chernobyl' may be asked. Secondly, the exchange can be used to give a global outlook on the things that will be treated further on. If, for instance, radiotherapy is mentioned, the teacher can point at the table of contents and note that it will be discussed at some length in section 3-4; if nuclear weapons are mentioned, the teacher may note that that subject will hardly come up during the lesson series.

It is expected that from this global outlook pupils will get the idea that subject matter will be treated that interests them, such as safety measures, (accidents with) nuclear power stations, applications (in health care), etc, and that this will induce in them a global motivation for the topic.

8.3.2 Coming to agree on a specific use of the term 'is radioactive'

This section concerns the attempt to let the pupils make use of an easily manageable and verifiable criterion to determine whether or not an object is radioactive. This is not done by first providing them with such a criterion and then letting them practice with it, but rather by first making them feel a need for such a criterion and then letting them discover a suitable such criterion. In this way it is tried, by making the pupils discover and make explicit their

3. It is not only for this reason that it is useful for the teacher to have available a collection of newspaper-cuttings concerning the topic of radioactivity. Later on, this collection will again be used (see section 8.3.2).
4. Throughout this chapter I present tasks of the textbook. I have tried to be as faithful as possible to the Dutch originals. In the presentations I have not included, however, the spaces in which the pupils are to note down their answers.

reasons both for wanting such a criterion and for choosing their criterion, to provide them with a secure foundation on the basis of which they will, in what is to follow, be tempted to use, and can be incited to use, the term 'is radioactive' in a disciplined way in accordance with their criterion.

Coming to feel a need for a criterion of being radioactive

The teacher closes the above discussion on task 1 by noting that the pupils already know quite a lot about what has got to do with radioactivity, and introduces section 1-2 (How do you know that something has got to do with radioactivity?) by saying something like: 'I wonder whether you are also able to tell of the objects that I have brought in the classroom which ones have got to do with radioactivity and which ones not.' The first task of section 1-2 consists of a table that the pupils have to fill in and whose three columns are headed: name of the object; yes, no, don't know; has got to do with radioactivity, because.

The following list is meant to give an idea of the sort of objects that may be used: a gas mantle; a bathroom tile that happens to be radioactive; a shoe of someone who was in Kiev at the time the accident in Chernobyl happened; a battery; a laser; a jar with stones, on which a sticker with a 'radioactivity-sign' is stuck; a portable X-ray machine; a magnet; a light bulb; a remote control; a folder containing newspaper-cuttings about radioactivity. Of course I do not mean to suggest that objects of these and only these kinds should be present in the classroom. I would like to suggest, however, that there should be enough variation among the objects that are put in the classroom (later on I will say why). By this I mean that:

- there should be objects on whose 'having to do with radioactivity' the pupils are expected to unanimously agree (out of the above list this might be satisfied by: the shoe, the jar with stones, the portable X-ray machine; the folder with newspaper-cuttings);
- there should be objects whose 'having to do with radioactivity' *in a very special sense* the pupils are expected to appreciate; this 'very special sense' may be put as follows (though pupils will without doubt put it differently): it has got to do with radioactivity, but is not itself radioactive (out of the above list this might be satisfied by: the folder with newspaper-cuttings)[5];
- there should be objects on whose 'not having to do with radioactivity' the pupils are expected to unanimously agree (out of the above list this might be satisfied by: the gas mantle, the bathroom tile, the light bulb);
- there should be objects on whose 'having to do with radioactivity' the pupils are expected to be and remain in doubt or diverted (out of the above list this might be satisfied by: the battery, the laser, the magnet, the remote control).

After the above introduction the groups are asked to fill in the above mentioned table (task 3) and to do the following task.

4 Differences and similarities

You will have said of some of the objects that they have got to do with radioactivity. But have they all got to do with it in the same way? That's what this task is about.

5. I owe the idea to include objects satisfying this condition, and to use a collection of newspaper-cuttings as one satisfying it, to Olle van Sprang.

a Note down below two objects from task 3. Of course not just any two objects. Both of them must have got to do with radioactivity. And they must have got to do with it *in a different way*. Also write down what according to you the difference consists in.

b Again note down two objects from task 3. Again both of them must have got to do with radioactivity. But now they must have got to do with it *in the same way*. Also write down what according to you the similarity consists in.

While the pupils are doing these tasks in groups, the teacher may briefly go into some of the objects: what a gas mantle is used for, X-ray a wallet with the X-ray machine, etc.

The expectations concerning task 3 are that the pupils within their groups
- will in a lot of cases be able to reach agreements as to whether or not an object has got to do with radioactivity;
- will notice that in some cases they have difficulties in saying *why* an object does or does not have got to do with radioactivity, even though they may find no difficulty in saying *that* it does or does not have got to do with it (it's just like that);
- will in some cases not be able to reach a definite or unanimous decision as to whether or not an object has got to do with radioactivity.

Concerning task 4 the expectations are, among other things, that the pupils will at least intuitively see and bring forward in one way or another that the class of things that have got to do with radioactivity contains objects that are not themselves radioactive. Also the special position of the X-ray machine may capture the pupils' attention: it can be switched on and off, it is purposely designed that way, etc.

While the pupils are working on the tasks, the teacher will have to walk and look around in order to form an idea of the extent to which these expectations are justified.

The above group work is followed by a class discussion of tasks 3 and 4. The point of this discussion is not so much that definite conclusions are reached (e.g., as to which objects do have got to do with radioactivity and which don't), but rather that the pupils come to feel a need for an objective and verifiable criterion to determine whether or not an object is radioactive. The discussion is thus preparatory for the following activity, in which the pupils are challenged to discover a suitable such criterion. Below I sketch how, based on the above expectations, the discussion is expected to proceed in global outline. Any actual discussion will of course, and certainly in the details, proceed somewhat differently. In particular, the teacher's participation will also have to be informed by what he or she has picked up from walking and looking around while the pupils were working on the tasks.

The teacher starts the discussion with task 4. The several groups are asked to bring forward and, if needed, to somewhat elaborate on the differences and similarities in 'having to do with radioactivity' that they have found. The teacher then concentrates on the difference in the way that, e.g., the shoe and the newspaper-cuttings have got to do with radioactivity, which is expected to be brought forward by the pupils. At any rate the difference is expected to be intuitively clear to the pupils so that they will also be open for a way to express the difference. The teacher proposes, preferably guided by suggestions from pupils, to agree on the following way: both the shoe and the newspaper-cuttings have got to do with radioactivity, but only the shoe *is* radioactive. In this way an intuitive difference between the concept 'has got to do with radioactivity,' which because of its broadness and vagueness is expected to have served well as a lead to get the pupils talking about the topic in the preceding global outlook, and the more specialized concept 'is radioactive,' on which their attention will subsequently be focused.[6] Of course no objective and verifiable criterion to determine whether or not an object is radioactive has yet been established.

The need for such a criterion, however, is to come forward in the discussion of task 3. To start this discussion the teacher lists, for each of the objects, the number of groups that have answered 'yes', 'no' and 'don't know' in the form of a table on the blackboard. In order to link up with the discussion of task 4, in this stock-taking the teacher asks the groups to give a 'yes', 'no' or 'don't know', not to an object's having to do with radioactivity (as they have done while working on task 3), but to its being radioactive. According to the above mentioned expectations, the result of the stock-taking will enable the teacher to compliment the pupils on the fact that concerning the majority of objects the groups are in unanimous agreement. The inventory thus naturally sets the stage for wanting to reach agreement on all the objects.[7] The teacher takes up that want by focusing on the objects on whose being radioactive the groups are in doubt or diverted, and by asking the groups to exchange arguments in order to reach mutual agreement on those objects too. It is their expected failure to reach such agreement[8] that, combined with their desire to actually reach it, is expected to provide them with a sensible reason for wanting an objective and verifiable criterion to determine whether or not an object is radioactive. This need may even be heightened by also letting the pupils exchange some arguments concerning the objects on which the groups are in agreement. In this way it may be explicitly brought to pupils' attention that in some cases the arguments are diverting, not very convincing (e.g.: the stones in the jar are radioactive, because a 'radioactivity-sign' is stuck on the jar), or, in fact, really lacking.

All along this discussion the teacher will have to see to it that the pupils are in the right sort of state between hope and frustration,[9] in order that they come to meaningfully appreciate a need for a criterion to determine whether or not an object is radioactive. To that end the teacher will at some moments have to add fuel to the fire (e.g.: what a shame that you cannot reach an agreement on those three things), while at others he or she will have to amplify the light coming from the end of the tunnel (e.g.: we are actually very near to a total agreement).

Coming to find a criterion of being radioactive

It is expected that the more evident the reasons for wanting such a criterion become for the pupils, the more they will be open for possible such criteria. This 'being open' may take the form of explicitly thinking about such a criterion and, perhaps with some help of the teacher (e.g.: there really ought to be something with which it can be determined whether

6. This is why among the objects there should be ones whose having to do with radioactivity in the special sense of 'having to do with radioactivity but not radioactive' pupils are expected to appreciate.
7. This is why among the objects there should be ones on whose being or not being radioactive pupils are expected to unanimously agree, and, moreover, why those objects should constitute a majority.
8. This is why among the objects there should be ones on whose being radioactive pupils are expected to be and to remain in doubt or diverted.
9. Of course this way of putting it is a bit exaggerated. It is not expected that the pupils will start crying or cheering, or that they will lose any sleep over this issue.

or not an object is radioactive; then we might come to a total agreement), remembering that there is some kind of device that might be of use here. Or perhaps they will remember it when the teacher introduces the idea of a 'radioactivity-meter.' At any rate it is expected that, no matter how the idea of such a device or meter is put forward, pupils' being open will take the form of being prepared to investigate whether some such device might be of use. This, then, is the proper time to set them, in small groups again, to work on the following tasks.

5 In search of a radioactivity-meter
In your classroom are some meters: meter A, meter B, meter C, ... In this task you are going to find out whether there are radioactivity-meters among them.

a Take one of the meters.
Check whether that meter is a radioactivity-meter.
Note down your conclusion by completing the below sentence.
Meter ... *is / is not* a radioactivity-meter. We have figured that out as follows:

b Check of the other meters too whether they are radioactivity-meters.
Note down below your conclusions.

Meter ... *is / is not* a radioactivity-meter. We have figured that out as follows:
[This line is repeated several times.]

6 Which things *are* radioactive?
This task looks very much like task 3. Again you are going to fill in a table.
But there are also two differences:
1 You now have to indicate whether an object *is* or *is not* radioactive.
2 You now have to do so in such a way that all the other groups will agree with you. So especially the explanation you give in the third column is important. For with that explanation you will have to convince the other groups of your being right.

[There follows the frame of a table with three columns, which are headed 'name of the object', 'yes / no' and 'is radioactive, because...' respectively.]

Let me briefly comment on these two tasks. Meters that, properly disguised, may be used in task 5 are: different kinds of sound level meters, different kinds of luxmeters, different kinds of Geiger counters or dose meters. Concerning task 6 it is expected that, in the light of the discussion of tasks 3 and 4, the pupils will appreciate the differences with task 3: its gearing to the concept 'is radioactive,' and its demand for a way of telling whether or not something is radioactive that is guaranteed to lead to the desired mutual agreement (we might say: for an objectively verifiable criterion of 'is radioactive').

It is expected that the groups will be able to find out which of the meters are radioactivity-meters: by holding a particular meter near objects of which a group is pretty sure that they are radioactive, by playing with it near things that are not radioactive (not necessarily things from the above list but, for instance, also themselves, other pupils, tables, etc), by noticing that it seems to react to something else (speech, light). When the groups are administered a meter, the teacher may here and there do some explaining: how to put the meter on, where its 'nose' is, etc.

Concerning task 6 it is expected that each group will want to use one of the meters it has just identified as a radioactivity-meter in order to check of all the objects whether or not they are radioactive. In effect, this would be an implicit formulation of the idea that a radioactivity-meter may satisfactorily fulfil the need for a mutually verifiable criterion: it classifies those objects as radioactive that were believed to be radioactive or, rather, that it does so was part of the identification of a radioactivity-meter in task 5; it obviously also promises to guarantee the desired mutual agreement concerning the objects on whose being radioactive the groups were in doubt or diverted, since reaching such mutual agreement involves nothing more than noticing whether or not a radioactivity-meter reacts. All this is expected to provide the pupils with plausible reasons for accepting as the desired criterion one that makes use of a radioactivity-meter. But, of course, as a new criterion (in the sense that the pupils have never before explicitly and consistently applied it) it brings along its own unavoidable and, in some sense, unexpected consequences. The groups may become aware of this when they find that a radioactivity-meter also happens to react to some objects that they did not know to be radioactive (e.g., the gas mantle). Accepting the new criterion then amounts to sticking to it. It is expected that the groups will do so: that the plausibility and unambiguity of the new criterion will have sufficiently emerged for them in order to e.g. conclude that the gas mantle is radioactive (because the radioactivity-meter reacts near it), even though they would never have guessed that.

It is clear that in the course of working on tasks 4 and 5 the pupils will, as it were in play, also get acquainted with some radioactivity-meters and radioactive sources.

Tasks 5 and 6 can subsequently be briefly discussed in the class as a whole. The emphasis in it should not so much be on the final results, but on how they have come about. When discussing task 5 the emphasis should be on how the groups have figured out which meters are radioactivity-meters. The teacher may then also give the official name of the latter meters: Geiger counters. When discussing task 6, the emphasis should be on the fact that the groups have now managed to reach total agreement (which deserves a compliment by the teacher), and on what it is that has enabled them to reach it. Furthermore, the teacher emphasizes that thus the pupils have also arrived at an agreement as to when, from now on, something will be called radioactive. To stress the importance of this agreement, and to give the pupils a first help in writing a summary, the teacher lets the pupils note down and complete the sentence 'We call something radioactive if ...' in the summary of chapter 1, under the heading 'Important to remember.' It is very likely that there will be pupils who want to know why it is that e.g. the gas mantle is radioactive. This, then, would be an example of a question that is worth being stored, under the heading 'Questions we still have to find an answer to' in the summary. The teacher may also once more point at the special position of the X-ray machine: it is, according to the agreement just made, only radioactive when it is switched on, since it is only then that a Geiger counter reacts.

A slight modification

During the above discussion the teacher leaves the Geiger counters on, so that, once in a while, they will have ticked. If the pupils themselves have not already noticed that while working on tasks 5 and 6, the teacher, by making some casual remarks about it, focuses their attention to it during the discussion. It seems that the Geiger counters tick all the time. Some pupils may suggest that the Geiger counters are ticking because of all the radioactive things in the classroom. To check that suggestion a pupil may be sent out with a Geiger counter to e.g. the great hall or the schoolyard. The conclusion is that Geiger counters do in fact tick, at a slow rate, everywhere and all the time. The teacher may point out that this is not as strange as it seems to be: the pointers of the other meters that the pupils have worked with normally show some deflection too.

At any rate it is expected that these observations justify a slight modification of the just made agreement along the following lines: we call something radioactive if in its vicinity a Geiger counters starts ticking *at a more than normal rate*. The point of this modification is, of course, that the pupils will in what is to follow not immediately conclude that an object is radioactive when a Geiger counter just once or twice happens to tick near it.

8.3.3 Standing in the radiation that is emitted by a radioactive object

In the formulation of the tasks so far the term 'radiation' has not been used, although the pupils will undoubtedly have used it (probably in the sense of radiation*, cf section 2.5) while working on the tasks. The point of the next tasks is to bring the term or, better, expressions containing it, such as 'to stand in the radiation that is emitted by a radioactive object,' in connection with the criterion just established. The idea is as follows.

1. It can be noticed that some distance away from a radioactive object a Geiger counter no longer ticks (at a more than normal rate). Or, to be more precise: nearby the object it ticks at a higher rate (this is why, according to the new criterion, the object is called radioactive); the farther away from the object the counter is moved, the lower its ticking rate becomes; from some (relatively short) distance on the counter's ticking rate is comparable to what it normally is.
2. Yet it seems clear that these observations cannot be accounted for by supposing that the object's being radioactive is somehow affected by the Geiger counter's being moved away from it. If necessary, it can in fact be observed that the ticking rate of a counter that is kept near to the object is not affected by another counter's being moved away from it.
3. It will be a matter of plain sailing to make a link here with expressions containing the word 'radiation:' a radioactive object emits radiation that can be measured with a Geiger counter; one stands in the radiation that is emitted by a radioactive object or, alternatively, one is being irradiated by the object, if a Geiger counter that one holds in one's hand ticks (at a more than normal rate).
4. The observations under 1 can then simply be accounted for as follows: since the radiation emitted by the object spreads out, the counter measures less radiation the farther it is moved away from the object; apparently the radiation that is emitted by the object does not reach very far; from some (relatively short) distance on one no longer stands in the radiation emitted by the object.

The way to start this train of thought is thus to make pupils notice that some distance away from a radioactive object a Geiger counter no longer ticks. In section 1-3 (Does it bother you that there are radioactive things in the classroom?), it is tried to achieve this by means of the following task.

> **7 Radioactive things in the classroom**
> Last year there were also some radioactive things in the classroom. Some pupils then

wondered whether those things are giving them trouble.
In a moment you may by means of experiments check whether they are giving you trouble. But first you will now have to think of such experiments.

a Are the radioactive things giving those pupils trouble that are sitting some distance away?
Note down below an experiment to find that out. Also write down what you need for the experiment.

b Are the radioactive things giving those pupils trouble that are sitting nearby? Also think of an experiment to find that out.

When writing this task I was well aware that its formulation might be too unspecific to indeed make pupils measure with a Geiger counter nearby and some distance away from a radioactive object. The ambiguity lies of course in the phrase 'are the radioactive things giving us trouble?' I have chosen this formulation because it links up with a similar question that some pupils had asked in previous try-outs, and because it is a more 'neutral' formulation than the one that was used in the first version: 'is it dangerous that there are radioactive things in the classroom?' (cf section 7.4.1). Still, also the new formulation may be understood as something like 'will we get ill because of the radioactive things in the classroom?', and this may also be the sense in which the pupils who had asked a similar question meant it. All this means that I would pay special attention to pupils' actual reaction to the task in the try-out.

Assuming that the task makes the groups suggest to measure with a Geiger counter nearby and some distance away from a radioactive object, the groups are expected to make, by carrying out this suggestion, observations as described under 1 above. Furthermore it is expected that in a class discussion, if necessary aided by some questions of the teacher such as 'Do the stones in the jar cease to be radioactive when one moves away from them?', steps 2 to 4 above can be followed.

The pupils are finally asked to note down in the summary what they consider to be the main points as well as possible questions that may have arisen.

8.3.4 Coming to recognize a problem in a particular way

This section concerns the attempt to bring pupils in such a position that they themselves come to pose the general problem how things can be made radioactive (in the agreed sense) and how not. In section 7.4.3 I have indicated that the following will serve as appropriate intermediate steps in their coming to appreciate this problem in the intended way:

- a Geiger counter ticks near radioactive material, but no longer does so some distance away from it;
- by applying a 'resistance' (e.g. a lead covering), also nearby the Geiger counter does no longer tick;
- removing the 'resistance' will make a Geiger counter nearby start ticking, but not a Geiger counter some distance away;
- the Geiger counter some distance away also does not start ticking when there is a draught towards it, even when the resistance has been removed;
- making an object stand in the radiation emitted by a radioactive object or X-ray machine does not result in the object's becoming radioactive.

In section 7.4.2, moreover, I have indicated how the process that eventually leads to the formulation of their problem can build on and be informed by what pupils already know, namely by letting them think back and forth between some well-known situation and a classroom-situation in which they can perform actions, but provided that the two situations are relevantly similar for the pupils and for them form a coherent whole. I have chosen to use nuclear power stations and the Chernobyl accident as well-known situations, and a small scale 'nuclear power station' and imitations of the Chernobyl accident as relevantly similar classroom-situations.

In section 6.2.3, finally, I have indicated that simply by asking pupils to bring about, in the classroom-situation, one sort of consequence that the real Chernobyl accident had, namely that things had become radioactive, a process will be set in motion that, as long as they stick to the agreements made earlier, eventually leads to their formulation of the general problem.

Creating a classroom-situation in which pupils can act guided by what they already know
The teacher briefly introduces the topic of chapter 2: nuclear power stations, for instance by remarking that a nuclear power station has got to do with radioactivity because radioactive material is used in there. Subsequently the pupils work in small groups on the following tasks of section 2-2 (Building a nuclear power station).

1 **Living safely near a nuclear power station**
Nuclear power stations are sometimes situated near a city. But the inhabitants of such a city should receive no radiation from it.
How does one take care of that?

2 **A small scale 'nuclear power station'**
In your classroom lies some radioactive material. Now suppose that is the material that will be used in a nuclear power station. So the required radioactive stuff is ready. There is just this problem: the power station itself is not yet there.
It is up to you to go build the 'nuclear power station.' Or better: a storage room in it. That is, a room in which the radioactive stuff can be safely stored.
The storage room of your 'power station' thus has to meet one important condition. Outside your 'power station' one should receive no radiation from the radioactive stuff stored inside.

Devise a building plan for the storage room in your 'nuclear power station.' Make sure that your plan can actually be carried out.
Write down your plan below.

It is expected that in devising a building plan for their 'nuclear power station,' the groups will be guided by what they know about how for real power stations it is taken care that no radiation is measured outside, namely by applying some kind of resistance (e.g. lead, stones). Because of the preparation in chapter 1 it also is expected that after having carried out a building plan, they will use a Geiger counter to check whether one receives radiation outside the build 'storage room.'

The expected result of this activity is that, by using suggestions of the various groups, the class will eventually manage to build a 'storage room' that satisfactorily meets the requirement that outside no radiation can be measured and so is, in this respect, relevantly similar to a real power station (cf section 7.4.2). Another expected result is that among the conclusions they formulate (in task 3) will be the following: if radioactive material is appropriately built in, a Geiger counter does no longer tick near it. Another, perhaps surprising, conclusion may e.g. be that radiation partly does go through lead.

Coming to recognize the problem by acting in the classroom-situation
Next pupils' attention is focused on 'accidents with nuclear power plants' (which is also the title of section 2-3). The teacher could link up with the global introduction to the series of lessons, if some pupils then mentioned the Chernobyl accident. With an eye on present generations of pupils, task 4 (a reading task, cf appendix 2) gives some information about the accident by means of a map of Europe and some headlines of newspapers from around the time of the accident (e.g.: 'Disaster in nuclear power station near Kiev in Soviet Union;' 'Chemical explosion lead to nuclear disaster;' 'Population of fifty villages in Byelorussia evacuated').

Subsequently the groups are going to work on tasks 5 and 6.[10] These two tasks have the same structure as task 1 and 2 above. In task 5 the groups have to think about how some consequences of the Chernobyl accident have come about, and in task 6 they subsequently have to think about how they can bring about similar such consequences with the material present in the classroom (in particular, 'their power station').

5 Also in the Netherlands the consequences were noticeable

Not just for the surroundings of Chernobyl did the accident have consequences. In the Netherlands too we got some problems, whereas Chernobyl is more than 1500 km away from the Netherlands.

[The headings translate into things like 'Radiation levels rise to more than three times the usual values' and 'Substantial increase of radioactivity in IJsselmeer and big rivers.']

a After the accident more radiation than normal was measured in the Netherlands. How could that have come about?

10. The tasks are part of an attempt to merge sections 2-3 and 3-2 of the first version of the didactical structure into a for pupils coherent whole (cf the remarks towards the end of section 7.4.3).

[Picture of a greengrocer's, with the letterpress: 'Fresh vegetables are hardly sold any longer.' Picture of someone measuring with a Geiger counter near a crate of spinach, with the letterpress: 'Homegrown spinach is being checked for radioactivity.' A heading that reads 'Consumption of fresh spinach not advisable.']

b In the Netherlands people were also advised against eating fresh vegetables. And the spinach that was harvested around that time had to be withdrawn from the market. It was also not allowed to sell fresh milk. All those fresh things were too radioactive.
How could those fresh things have become radioactive?

6 Imitations of the Chernobyl accident

a After task 2 you have built a 'nuclear power station.' Let us call the place where it is standing 'Chernobyl.' And let us call some place at the opposite side of the classroom 'the Netherlands.'
How can it be brought about that radiation is measured in 'the Netherlands?' What would have to happen for the latter to be the case?
Write down below a plan to make it the case that radiation is measured in 'the Netherlands.' Or several such plans if you can think of more than one. (Make sure that all your plans can actually be carried out.)

b Would you be able to make e.g. an apple radioactive with the things in your classroom? Write down below a plan. Or more plans if you think it can be done in more ways. (Again your plans must be performable.)

It is expected that in devising plans to imitate those consequences of the Chernobyl accident, the groups will be guided by what they know about the Chernobyl accident: that because of the explosion in the power station some radiation* escaped, that the wind carried some of the radiation* towards the Netherlands, that the fresh vegetables came to contain radiation*, etc (cf chapter 2 of this thesis). They may thus want to break their 'power station,' cause a draught from 'Chernobyl' towards 'the Netherlands,' make the apple stand in the radiation emitted by some radioactive object, etc. Again it is expected that they will use a Geiger counter to check whether their plans do indeed bring about what they were asked to bring about -whether as a result of their actions it does start ticking at a more than normal rate in 'the Netherlands' or near the apple.

After the plans of the several groups have been listed, the different plans are carried out at class level (each plan by a group that has proposed it). The teacher chooses some appropriate order in the plans, e.g.: first the plan to break the 'power plant' and then the plan to also use a fan. The pupils are asked to briefly note down in task 7 all the plans that are carried out and their conclusions concerning each of the plans. Given the expectations about the sort of experiments they will carry out, it is expected that among those conclusions there will be ones like:

- breaking the 'power station' made the Geiger counter start ticking in 'Chernobyl,' but not in 'the Netherlands;'
- the Geiger also did not start ticking when there was a draught towards 'the Netherlands;'
- placing the apple next to one of the radioactive stones for a while did not make it radioactive.

Such conclusions may also make the pupils propose new plans that according to them will lead to the desired result and that they want to carry out for the reason that thus they will be proved right (cf section 6.3.3). E.g.: to not just cause a draught from 'Chernobyl' towards 'the Netherlands,' but to also make it 'rain' above 'the Netherlands;' to not just place the apple near one of the stones, but to put it in the much stronger X-ray machine.

It is expected that somewhere in the above process the pupils will come to appreciate the central problem how an object can be made radioactive and how not, and that they then appreciate it in the right way. That is, that they then understand it in accordance with the agreements made earlier and see it as a real problem which is worth a further investigation. Although they may not yet see the solution to the problem, they must somehow have got the idea that solving it is not beyond their reach. Perhaps they have got some faint ideas about how to tackle it. They may also, perhaps by sheer luck, already have proposed plans that after having appreciated the problem they now come to recognize as (partial) contributions to its solution, e.g.: to put one of the radioactive stones inside the apple. In any case it is expected that the pupils will have an open eye and mind for possible contributions to the solution of their problem and do have the 'equipment' to recognize contributions to its solution as such.

The teacher's role in the above process is essentially one of complimenting, structuring and providing an outlook of what is to come. E.g.: noting that the problem they have hit on is a good and, indeed, a serious one that deserves to be stored in the summary under the heading 'Questions we still have to find an answer to;' promising that they themselves will come to solve the problem within one or two lessons; emphasizing that while they do not yet know the solution, they still have learned quite a lot, namely what they have concluded from carrying out the plans, etc.

8.4 From ground level to qualitative descriptive level

This section concerns the second period, in which pupils come to solve the general problem how things can be made radioactive and how not, by arriving at a qualitative descriptive level: a set of general statements that are formulated in such terms as 'is radioactive,' 'is irradiated by' and 'is contaminated.' A first step concerns the 'how not' part of the problem. It consists in letting pupils make explicit, consolidate and generalize some of the conclusions that have already implicitly been established in the process that lead to the formulation of the problem, namely by stimulating them to note *similarities* between the actions they have performed and appropriately chosen new situations, and to frame these similarities in the terms that are prepared in the preceding. In particular, it is expected that pupils will thus arrive at the following general statement: an object does not become radioactive by irradiation.[11)]

11. It may be argued that, since the problem had come about as a result of their failure to make something radioactive, after this first step the problem will still have kept much of its force for the pupils, and that therefore the first step ought not to be included in the second period but rather in an intermediate stage between their formulating the problem and their solving the problem. Well, that's all right by me. I have already noted

A second step concerns the 'how' part of the problem, and uses a procedure similar to the above one: stimulating pupils to note *differences* between the actions they have performed and appropriately chosen new situations. It is expected that in this second step they come to see the point of paying special attention to processes in which something comes to contain radioactive material, and thus also the point of having available a term to refer to such processes: contamination.

In the above steps pupils are challenged to play an active part in the establishment of a system of generalizations that is appropriate to answer their problem, in order that they best come to appreciate how, when, and when not to apply those (and perhaps also to make them appreciate the limitations of those, i.e., to induce some theoretical need in them). In a third step it is tried to make them feel better at home in the established system of generalizations by challenging them to use it for explanations and predictions in situations that do not concern their own actions but are still of some practical interest, in particular to evaluate the use of safety measures.

8.4.1 Finding some general statements by looking back at how the problem has come about

After the problem has come forward, the teacher proposes to first give the pupils a chance to apply what they have already learned in some new situations, before they will return to the problem. The new situations are three applications of radiation, some of which may be new to the pupils: food irradiation (treated in section 3-2 of the textbook), sterilization of syringes (section 3-3), and radiation treatment of cancer (section 3-4).

In each of the mentioned sections, an application is briefly introduced by some information on what is done and why it is done. Food irradiation, for instance, is introduced by saying that some food easily goes off because it is easily effected by bacteria or mould, that radioactive radiation kills the bacteria and mould, so that after irradiation the food can then keep longer. Two pictures are contrasted: one of strawberries that are irradiated and one of strawberries that are not. Some information is given (both verbally and pictorially) about a room in which food is being irradiated: in the middle is a source containing radioactive material; around it rotate crates of food. The other two applications are similarly introduced. The introduction to an application is followed by some questions about it (see below).

The pupils are to work through the three sections in small groups, that is: study the given information and answer the questions. They are also invited to carry out experiments if they find that might help them in answering the questions.

1 The sale of irradiated food

a What is the aim of food irradiation?

b Irradiated food is simply sold in shops. In some countries it should say on the packing that it is irradiated. In the Netherlands this is not compulsory.
Now suppose that in the Netherlands too it is made compulsory. And you had to indicate on the packing that the contained food is irradiated.

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that I do not see any worth in trying to draw sharp lines where there are none -drawing sharp lines should not become an end in itself.

[Picture of the 'radioactivity-sign.']

Would you use the above sticker for that purpose?
This sticker *should* / *should not* be used on irradiated food, because...

2 The use of irradiated syringes

a What is the aim of irradiating syringes?

b Joke[12] says: "I simply do not understand that they irradiate syringes. It may well be that a patient does not get infections since the bacteria are killed. But the patient does get irradiated a bit by the syringe. And that too isn't really healthy, is it?"

We *do* / *do not* agree with Joke, because..

3 The care of irradiated cancer patients

a What is the aim of irradiating cancer patients?

b After cancer patients have been irradiated, they go back to the ward. There they are taken care of by nurses.
Do the nurses receive any radiation from the irradiated patients? Do the nurses have to protect themselves, e.g. by wearing lead aprons?

When taking care of the patients lead aprons *are* / *are not* needed, because...

I think that someone who knows the following general statements will recognize that those statements have application in the three above applications: by means of irradiation organisms or cells can be killed; an object does not become radioactive by irradiation. The point of sections 3-2 to 3-4 is, conversely, that the groups come to explicitly formulate such general statements, by recognizing similarities between some of the experiments they have just done and each of the three applications, and between the applications among themselves. It is also expected that they will be able to recognize those similarities (see below). The point of trying to make them arrive at *both* general statements more or less simultaneously (or: of asking both the a-parts and the b-parts), is to prevent a conclusion that some of the pupils who worked with the first version of the textbook believed was forced on them, namely that irradiation is not dangerous (cf section 7.4.1). It is prevented, first of all, by not using the unspecific term 'dangerous' (as was done in the tasks of first version, e.g.: is it dangerous to eat irradiated food?) and, secondly, because the two general statements together allow a better way to formulate the state of affairs: by means of irradiation damage can be done to an organism (in this sense the process of irradiation can be said to be dangerous), but an object does not become radioactive in the process of irradiation (in this sense an irradiated object can be said to present no danger to its surroundings).

Their explicit formulation of the general statement that organisms or cells can be killed by means of irradiation is most likely not problematic at all. The fact that radiation does have damaging effects is already well-known to pupils (cf chapter 2 of this thesis). Moreover,

12. An ordinary Dutch girl's name -no jokes please!

all three applications are introduced in the context of killing unwanted elements. The similarity in the a-parts of the above questions, finally, may also stimulate similar answers.

It is also expected that their coming to explicitly formulate the general statement that an object does not become radioactive by irradiation is sufficiently prepared by the preceding and that, moreover, the information given about the applications and the b-parts of the questions will further drive them in that direction. For in the course of carrying out their plans to make an apple radioactive they may already have noted that several actions did not result in that outcome. They may e.g. not only have placed the apple near a radioactive stone for a while but also for a rather long period, or they may have put the apple in the much stronger X-ray machine. And if they have performed the latter two actions, they will probably have done so for the reason to make the apple stand longer in radiation or in the radiation of a 'stronger' source. They will thus be aware that all three actions are cases of making the apple stand in radiation (i.e.: cases of irradiation). Furthermore, if they think of ways to imitate the applications, as they are suggested to do when working on the questions 1 to 3 above, they may find that those imitations will be rather similar to what they have done when trying to make the apple radioactive: it is only that the apple will have to be replaced by something else. This may even be more evident in the first application they encounter (food irradiation). Also the teacher's introduction of the applications in terms of trying to apply what they have just learned in some new situations, may stimulate them to search for similarities. Finally, it is expected that they will understand each of the b-parts of the three above questions as a variation on the question whether something has become radioactive: that they know the 'radioactivity-sign' should only be stuck on objects in the vicinity of which a Geiger counter ticks; that they know one only stands in the radiation of an object (is irradiated by it, receives radiation from it), if a Geiger counter that one holds in one's hands is ticking.

When discussing the questions after the group work, the teacher's participation will have to consist in trying to make the pupils explicitly formulate the sort of general statements mentioned above. Since it is expected, on the above grounds, that the pupils will already have noticed the relevant similarities,[13)] it is also expected that the pupils will be able to formulate the similarities because the vocabulary to do so has already been prepared in the preceding.

The general statements can be written down in the summary, under the heading 'Important to remember.' Perhaps some pupils will wonder why it is that an object does not become radioactive by irradiation: what, then, happens to the radiation? In that case the teacher notes that this is, again, an important and good question, but that it will take some time before it can be properly answered. In order that it will not be forgotten it is therefore best to store it in the summary, under the heading 'Questions we still have to find an answer to.'

8.4.2 Solving the problem by finding more general statements

Tackling the problem

13. If necessary the teacher may make them explicitly think about similarities by questions and remarks such as: have you noticed anything similar in the a-parts, both in the questions and the answers?; it is just like when you tried to make an apple radioactive by placing it next to a radioactive stone for a while, etc.

After the discussion of the sections 3-2 to 3-4 of the textbook, the teacher notes that from the detour along chapter 3 they do know now that objects do not become radioactive by irradiation, and draws their attention to the problem they have formulated in chapter 2. For this problem still stands: how can an object be made radioactive? How is it that because of the Chernobyl accident fresh vegetables had become radioactive or that more than normal radiation could be measured in the Netherlands? Why is it that their attempts to make a Geiger counter tick at a more than normal rate in 'the Netherlands' or near the apple did not succeed?

The teacher proposes to go back to the point where they have left chapter 2, namely section 2-4 (Radioactive waste). This section consists of the below task, and the teacher sets the groups to work on this task while noting that it may help them in solving the problem.

8 Radioactive waste in the Irish Sea

Nuclear power plants produce radioactive waste. That is, waste consisting of radioactive material.

Radioactive waste is sometimes dumped in sea. That is very controversial, as you may gather from the below articles.

[A headline saying: "British factory dumps too much nuclear waste." A newspaper cutting in which it is said that an advisory committee of the British government has established that the plant in Sellafield still dumps needlessly much radioactive waste in the Irish Sea. A map of Great Britain and the Republic of Ireland in which the Irish Sea and Sellafield are indicated.]

a Some fish from the Irish Sea are radioactive.
How could they have become radioactive?

[A newspaper cutting that reads (in translation): "For a long time past the safety norms that are applied in Sellafield are being criticized. Environmental organizations have repeatedly insisted on the termination of the dumping of radioactive waste in sea. November last year the government had to close beaches near the plant because too high levels of radiation were measured there."]

b Some beaches at the Irish Sea had to be closed. Too much radiation was measured there.
How could that have come about?

It is expected that this task may indeed, as the teacher has said when introducing it, help the groups in solving the problem. First of all it is expected that, because of the preceding treatment of sections 3-2 to 3-4, the suggestion that the fishes have become radioactive by having been irradiated will be blocked. Furthermore, the groups are expected to notice the similarity between the type of questions asked here and in tasks 5 and 6 above: how something could have become or could be made radioactive; how it can be or be brought about that at some place more radiation than normal is measured because of something that happened elsewhere. A new element in the situation of task 8, however, is that what has become radioactive (a fish) is itself able to move around. This circumstance is supposed to provide a clue to the groups. For it is easy to imagine that when a fish swims too close to the dumped radioactive waste some of the radioactive material may stick to its skin, or that a fish that swims along the radioactive waste may in passing eat bits of the waste. And it also seems evident that a Geiger counter will start ticking near a fish that has radioactive material on or in it. But once the step has been taken that an object becomes radioactive by e.g. taking in radioactive material, it can also easily be seen that it is not essential that the object to become radioactive is itself able to move: all that is needed is that it somehow comes to contain radioactive material. It may also be, for instance, that some of the dumped radioactive waste itself has been displaced by the tide, and has thus been washed up against the shore. This would explain why on some beaches too much radiation was measured. By comparing this explanation to their attempts to make it the case that more radiation is measured in 'the Netherlands,' the groups may then also appreciate why those attempts were doomed to fail. For what they failed to do in those attempts was transport the radioactive material itself towards 'the Netherlands' in one way or another. If all this happens, the pupils can be said to have solved their problem. Implicitly they will moreover also have used the generalization that an object becomes radioactive by putting radioactive material in or on it.

In the subsequent class discussion of task 8, the teacher's participation will have to be directed at bringing forward the main points: check whether the pupils find they have solved their problem (and compliment them for that if they do); make the pupils explicitly formulate their general conclusions (among which the above mentioned generalization), as well as newly risen questions; make them note down these main points in the summary. Once it seems clear enough that the pupils already use the concept 'contaminated' in the sense that they see the point of paying special attention to objects that have come to contain radioactive material (cf section 7.4.4), the teacher introduces the word 'contaminated:' from now on we call an object contaminated if it has radioactive material on or in it. The teacher may at the end of the discussion also ask the pupils to have a second look at tasks 5 and 6: how it has come about that after the accident more radiation than normal was measured in the Netherlands, or how they could have brought it about that in 'the Netherlands' more radiation than normal is measured; how fresh vegetables had become radioactive after the accident and why it was then advised against eating fresh vegetables, or how they could have brought it about that the apple is radioactive. The teacher may also hollow out an apple, put one of the radioactive stones inside and close the apple again: then outside the apple a Geiger counter will tick. Some pupils may protest that thus it is not really the apple that is radioactive. For the counter simply measures the radiation emitted by the radioactive stone that has been put inside the apple. The teacher may then note that it is just a matter of sticking to earlier agreements to call the apple with the stone inside radioactive (since a Geiger counter ticks near it), but at the same time concede that by this move the source of the protest does not really seem to have been touched. For although according to the earlier agreements the apple with stone is rightly called radioactive, it seems clear that it is only the stone that is, what might be called, genuinely radioactive. Or perhaps the stone itself too is not genuinely radioactive but rather contaminated. Since it seems intuitively clear that there cannot be an infinite regress here, the question seems to be how it is that some material is genuinely radioactive -i.e. radioactive without being contaminated? This would be a question to store in the summary, under the heading 'Questions we still have to find an answer to.'

Explicit formulation of generalizations

The summary of chapter 3 contains, apart from the usual 'Important to remember' and 'Questions we still have to find an answer to,' two other parts: 'Important statements to remember' and 'A story containing the important terms.' In both parts the pupils are presented with five important terms they have got acquainted with: radiation, irradiated, radioactive material, contaminated, and irradiated. In the first part the pupils are asked to form true statements in which each time two of these terms occur: as an example they are first given a statement in which the terms 'radioactive material' and 'radiation' occur (Radioactive material emits radiation); then they are asked to make true statements contain ing 'irradiated' and 'radiation,' 'radioactive material' and 'contaminated,' 'contaminated' and 'radiation,' 'irradiated' and 'radioactive,' 'contaminated' and 'radioactive;' finally they are asked to make true statements with other pairs out of the five mentioned terms. In the second part they are asked to think of a situation in which all five terms have application, and to write a short piece (if needed, with illustrations) or a comic about that situation. The only condition is that all five terms do occur in their story.

It is expected that the first part will challenge the pupils to explicitly state general statements and that they will be able to do so, aided by what they have learned before. The teacher may also involve the pupils in several ways in judging such statements: first of all by letting them think of such statements themselves, and then also by letting them read the statements that some other pupils have thought of. On the statements that are judged as unclear or false there can then be a further discussion in which the teacher's principal role is to prevent talk at cross purposes: by letting them make disciplined use of the agreements made earlier, or by letting them think of and, if still needed, carry out experiments to settle disagreements, etc. The sort of situations that the pupils will think of in the second part are expected to be closely related to one of the situations they have met before. The challenge for them will then consist in trying to apply all of the terms in such a situation in a correct way, and it is expected that they will be able to do so. From the stories themselves the teacher can infer a global idea of the way in which the pupils understand the situations they have written about and of the way in which they have applied the relevant terms. Lacks of clarity and putative errors can again be discussed.

8.4.3 Getting at home in the established system of generalizations

The aim, i.e. the curriculum deviser's and teacher's aim, of chapter 4 of the textbook is to make the pupils feel better at home in and add to the sorts of generalizations they have k arrived at and explicitly formulated.[14] In order to achieve this aim the pupils are to give explanations or to make predictions concerning some new situations. In order to challenge them to apply the relevant generalizations, the descriptions of the situations and the formulations of the questions in the earlier tasks of chapter 4 are put in the relevant terms ('contaminated,' 'irradiated,' etc; cf section 7.4.1). In the later tasks the situations and questions are more loosely framed, so that the pupils will then first have to reframe them

14. Of course all that follows from now on, and not just chapter 4, can be seen as a contribution to pupils' getting better at home in and adding to the system of generalizations. By relating the aim exclusively to chapter 4 (and to some extent to chapter 5), however, I mean to explicitly acknowledge that the pupils do indeed need some time to get at home in it. In later chapters it will be assumed that they will more or less self-evidently make use of it.

in the relevant terms before the relevant generalizations can be used to give an explanation or make a prediction (cf section 6.3.4).

For the pupils themselves the aim of chapter 4 is supposed to derive from its title: How to protect oneself? The teacher introduces the chapter by noting that radiation can do damage, as the pupils probably already know and moreover have also concluded in chapter 3; that it is therefore best to receive as less as possible radiation, unless of course there is e.g. a medical necessity; that it is the topic of this chapter to discuss ways to prevent that someone receives (too much) radiation. It is then also natural to make a link with the topic of chapter 5: the possible effects in case someone nevertheless has received (too much) radiation. It is expected that this introduction sets the main themes of the next two chapters sufficiently clear for the pupils, that their existing interest in these themes will moreover give them a sense of purpose and motivation for further discussing these themes, and that they already know quite a lot about safety measures and effects that can be further built on. It is also expected that in the course of working on chapters 4 and 5, the pupils themselves too will notice that they get better at home in the use of the relevant concepts and generalizations, e.g. by better appreciating their relevance. The distinction between contamination and irradiation, for instance, not only is relevant because, as they have appreciated in section 2-4, in such terms and with the use of appropriate generalizations it can be explained why in some situation an object had or had not become radioactive, but also because, as they will come to appreciate in chapter 4, the prevention of getting contaminated demands other measures than the prevention of getting irradiated. Below I outline and comment on the tasks of chapters 4 and 5.

Section 4-2 (Measures against receiving radiation) consists of tasks 1 to 5 below. Tasks 1, 2, 4 and 5 have a rather uniform form in order to focus pupils' attention as well as possible on the relevant concepts: 'irradiated' and 'contaminated.'

1 Prevention of contamination

Think of some measures to prevent that someone gets *contaminated*. Note those measures down in the below table. Also write down why they are a good measures.

[Frame of a table with two columns, headed 'Measure:' and 'With this measure *contamination* is prevented, because:'.]

Task 2 is the same as task 1, with 'contaminate' replaced by 'irradiate.' Task 3 is not formulated in terms of 'contaminate' and irradiate.' Instead it contains some newspaper headings in which it is said that after the accident sand, lead and concrete were poured on the exploded power station in Chernobyl, and the question is why this was done. It is expected that after tasks 1 and 2 they will think about these measures in terms of prevention of contamination and prevention of irradiation.

4 Measures after someone is contaminated

a Someone has got *contaminated* and is hospitalized. Does one receive radiation when sitting next to that person?

Yes / *no*, because...

Answer part b only when your answer to part a is "yes."

b You think one receives radiation from a contaminated person. But then that person him- or herself will also receive radiation from him- or herself.

Is there still something that can be done about that? That is, are there still measures that take care that the person him- or herself receives less radiation?
Note down in the below table such measures. Also write down why according to you those measures are helpful.

[Frame of a table with two columns, headed 'Measure:' and 'By this measure a *contaminated* person him- or herself receives less radiation, because:'.]

Task 5 is the same as task 4, with 'contaminate' replaced by 'irradiate.'

Section 4-3 (Protection with lead) consists of tasks 6 and 7 below. In the tasks some situations are described and the problem is whether in those situations the pupils would apply the safety measure that is best known to them: protection with lead. The situations and problems themselves are based on 'real life' situations and problems as some radiation experts have encountered them (cf Eijkelhof, 1990, p.61-3; see also section 2.5). The tasks are not formulated in terms of 'contaminate' and irradiate.' It is up to the pupils to analyze the situations in these terms and to base their judgement as to whether or not protection with lead is necessary on that analysis. It is expected that after the previous tasks they will be able to do so.

6 Lead aprons for the cleaning personnel of an X-ray department, or not?

Almost every hospital nowadays has an X-ray department. In such a department there are X-ray machines, with which X-rays are taken.

[Photograph of a nurse who takes an X-ray of a child and on which the X-ray machine is also seen. Picture of an X-ray.]

Of course an X-ray department regularly has to be cleaned. That happens in the evening, when no X-rays are taken.
In one hospital the cleaners once demanded lead aprons. They wanted to wear lead aprons when cleaning the X-ray department. Just like the nurses that work there during the day. The management of the hospital told the cleaners that they do not need lead aprons.

Would you give lead aprons to the cleaners?
Yes / no, because...

7 X-raying animals

Animals too are sometimes X-rayed. When they have broken a bone, for example. The pictures are taken by X-ray assistants. Of course animals do not simply lie still. The X-ray assistants have to hold them when taking an X-ray.
After the X-ray has been taken, the animals are taken back to their pens. There they are looked after and fed by animal caretakers.

Whom would you give lead gloves?

a *The X-ray assistants that take the X-ray.*
b *The animal caretakers that afterwards look after and feed the animals.*
c *Both.*
d *Neither.*

Our answer is ..., because...

In section 5-2 (Effects of radiation) the pupils can bring forward what they already know about the effects of receiving radiation. They are asked to think of situations in which something or someone has received radiation, and of some negative and positive effects of receiving radiation, e.g. in the situations they have just thought of; furthermore, they are asked how people have found out about the effects of receiving radiation; finally they are asked what the seriousness of the effects depends on.

Depending on what they bring forward, the teacher adds one thing or another to prepare some of the following activities. If the pupils themselves have not already done so, the teacher notes that it is somehow strange that on the one hand radiation can induce cancer while on the other it is used to treat cancer. If the teacher has a portable X-ray machine and a matching screen that lightens when exposed to X rays at his or her disposal, he or she may pay special attention to that as a preparation for a later task (see task 5 below). The effect of the X rays on the screen is the lightening of the latter. By turning on and off the X-ray machine it can be noticed that the screen only lightens when, and for as long as, the X-ray machine is on. So not only has the screen not become radioactive because of the irradiation (as has already been established some time ago), but moreover the screen is just effected by the radiation as long as it is being irradiated. Perhaps some pupils will wonder why this is so: what, then, happens to the radiation? Again this would be an example of a problem that is worth being stored in the summary, under the heading 'Questions we still have to find an answer to.'

Section 5-3 (Damage to cells) begins with some information that is meant to refine the general statement that has already been established before, namely that organisms or cells can be killed by radiation. The following is a piece of the information.

X rays and radioactive radiation can damage cells. There are three kinds of damage to cells.

1 A cell is just lightly damaged. The cell is able to fully recover after a while.
2 A cell is so much damaged that it is no longer able to carry out its specific task. Or that its division goes out of control.
3 A cell is so badly damaged that it dies.

The point of this information is to provide the pupils with a clue to solve the problem that on the one hand radiation can induce cancer while on the other it is used to treat cancer. In fact, this problem is treated in a task in which the pupils are asked to say by which kind of damage to cells cancer is induced, on which kind of damage to cells radiation treatment of cancer depends, and why a cancerous tumour is irradiated from different angles.

The point of the final task of chapter 5 is to make the pupils see that while cells are only damaged when, and for as long as, they are being irradiated, it may take years before the cells whose division as a result of the irradiation has gone out of control have developed into tumours that give trouble to the person involved. It is expected that as a result of what the pupils have learned before, the suggestions that the radiation lingers or somehow keeps on doing damage will be blocked (the pupils may have to be reminded of the screen in the X-ray machine here).

5 Only years later it may give trouble

When someone receives radiation that may lead to cancer. But it is only years later that the cancer will show up and give that person trouble.
Tom says: "That is because it is only then that the radiation begins to do damage."

a Do you agree with Tom?
Yes / no, because...

Answer part b only when your answer to part a is "no."

b Why do you think that it is only years later that the cancer will show up and give the person trouble?

8.5 Extension of the descriptive level in quantitative direction

The descriptive level that has been established in the preceding can be thought of as a way of describing and a system of generalizations such that, if appropriately described, the occurrence of a range of events can be predicted and explained by means of the generalizations. It is, however, of a purely qualitative nature. An object has the property 'is radioactive,' for instance, if a Geiger counter starts ticking at a more than normal rate in its vicinity, but the rate at which the counter ticks in its vicinity has not yet been taken into account. The same applies to the other basic properties and thus also to the generalizations in which such properties are in one way or another connected. Consequently, the predictions and explanations that can be produced by means of the generalizations are also of a qualitative nature, e.g. whether or not an object will become radioactive as a result of a particular action.

It is the aim of chapter 6 of the textbook (Still more applications) that by working it through pupils come to extend the previously established descriptive level in a more quantitative direction, in which in particular aspects like the penetrating power of radiation and the strength and half-life of radioactive substances will play a role. For the pupils themselves the aim of chapter 6 is, as its title suggests, to learn more about applications of radiation. It is expected that what may be called a global interest in applications will provide them with a sufficient initial sense of purpose and motivation for further learning about applications of radiation. It is also expected that in the course of working on chapter 6, the pupils themselves too will notice the relevance of extending what they already know in a more quantitative direction, e.g. because they learn that it is only by doing so that they are able to understand some of the applications at all (or at any rate to understand most of the applications better). From the curriculum deviser's and teacher's point of view it can thus be said that applications of radiation form the context in which the pupils are supposed to extend the qualitative descriptive level to what may be called a quantitative descriptive level.

There is not much new in chapter 6. Aspects like penetrating power and half-life are treated in most courses on radioactivity. Moreover, the idea to treat these aspects in the context of applications, in particular in the context of choosing an appropriate radioactive substance for a given application, is also not new: I have 'stolen' it from SATIS 14-16 Unit 204 (Using radioactivity). This is why below I just briefly sketch the main steps of the extension in quantitative direction, dwelling only upon the points where I may have laid the emphasis somewhat differently than is usually done.

8.5.1 Inducing a need for something more quantitative

The teacher briefly introduces chapter 6, by noting that the pupils already know quite a lot about radioactivity, that they already have got acquainted with some applications of radioactivity (in particular in chapter 3), that in this chapter they are going to study more applications, and that some of those applications may be new to them, as perhaps the ones in section 6-2 are. The teacher subsequently sets the groups to study section 6-2 (Some new applications), which contains descriptions of three new applications and some questions about them. The applications are: (1) investigation of a patient of whom it is suspected that a blood vessel supplying the heart muscle is blocked; a radioactive substance is introduced to the patient's bloodstream; a photographic film is held near the heart region and on the resulting 'photograph' it can be seen whether there is a blockage and where it is; (2) the production of sheets of metal; metal is squeezed between rollers; the bigger the pressure of the rollers, the thinner the metal; in order to keep the sheets of metal of the same thickness all the time, a radioactive source and Geiger counter are used to control the pressure of the rollers; the source is held at one side of the sheets, the Geiger counter on the other side measures the amount of radiation that passes through the sheet; if the sheet gets thicker, the counter will measure less radiation; (3) idem for the production of sheets of paper.

The point of some of the questions on the applications is to make the pupils wonder things like: It is kind of strange that radioactive substances are used here, for what about...? The pupils will e.g. note that the heart patient is in fact contaminated, and even though they will see the advantage that the patient need not be cut open in this way, they may wonder whether the patient will remain contaminated for the rest of his or her life or whether the contamination will decrease. And while it is expected that the pupils will not find the idea behind controlling the thickness of sheets of metal very strange, i.e. the idea that the emitted radiation is partly stopped by metal, they may wonder why the same procedure can also be applied to control the thickness of paper: radioactive radiation is very penetrating, isn't it? In the discussion of the tasks the teacher tries to amplify such statements of wonder, in order to give a preview of what will also be treated in this chapter: the question whether something remains equally radioactive or contaminated and the question how far radioactive radiation penetrates into something. It is expected that thus the pupils will be sufficiently open to also find answers to such questions, and that they perhaps already have some ideas about the answers.

8.5.2 Extension towards a quantitative descriptive level

Penetrating power of radiation

In section 6-3 (Penetrating power) there follows first some information on the question how far radioactive radiation penetrates into something: some radioactive substances emit radiation that has a rather low penetrating power (and is called α-radiation); other radioactive substances emit radiation with a medium penetrating power (called β-radiation); yet others radiation with a rather high penetrating power (called γ-radiation); the penetrating power of the X rays that an X-ray machine emits is situated between that of β-radiation and γ-radiation; it is indicated how far α-radiation, β-radiation, γ-radiation and X rays penetrate into some materials (flesh, bones, air, metals, etc). Note that the terms α-, β- and γ-radiation are thus introduced as nothing more than shorthand for radiation with low, medium and high penetrating power, respectively. No mention is made of their nature or of the fact that α-, β- and γ-radiation are different types of radiation. In fact, they are, together with X rays, treated as being of the same kind in the sense that they all make a Geiger counter tick. Of course the pupils may ask such things as why it is that some radioactive substances emit radiation with a higher penetrating power than the radiation that other radioactive substances emit, or why it is that the radiation that some radioactive substance emits penetrates further into some materials than into others. Such questions can again be stored in the summary, under the heading 'Questions we still have to find an answer to.'

In section 6-3 there are also some tasks to go with the presented information. An X-ray of a hand is shown and the pupils are asked to draw what the photograph would have looked like if, instead of X rays, α-radiation was used, or β-radiation, or γ-radiation. Furthermore they are asked to say of some of the applications they have already got acquainted with (sterilizing syringes; investigating whether a blood vessel of a heart patient is blocked; controlling the thickness of sheets of metal, and of sheets of paper) whether they would for that application use a substance that emits α-radiation, β-radiation or γ-radiation.

Strength of radioactive sources

In section 6-4 (The strength of radioactive materials) a begin is made with tackling the question whether something remains equally radioactive or contaminated, by first coming to agree on a measure to express how radioactive something is. This is done by putting e.g. two radioactive stones in the classroom and asking the pupils to find out whether they are equally radioactive and, if not, which one is most radioactive. It is expected that the notion 'being more radioactive than' is intuitively clear to the pupils (in fact, that they will already have said of the X-ray machine that it is stronger than e.g. the stones), and that they are at least able to aurally determine which of the stones is most radioactive. They are thus expected to intuitively take the ticking rate of a counter as a measure for how radioactive an object is. It is also expected that, perhaps with a little guidance from the teacher, the pupils are able to see something like the number of ticks per second as an appropriate unit to express the strength of a radioactive object. If necessary some modifications can be made, such as that to properly measure the total strength of an object one should somehow measure all round it. Next the pupils do some exercises of the type: this number of ticks is measured in that period of time, what is the strength?

Since by now two notions of 'strongness' are introduced, penetrating power and strength, there follows the below task to clearly separate them.

9 Controlling the thickness of sheets of lead

In a factory one wants to control the thickness of the sheets of lead that are produced there. The first attempt is to hold a source containing the radioactive substance strontium-90 at one side of the sheets. It turns out, however, that the Geiger counter on the other side then measures no radiation at all. So another source will have to be tried.

a One will have to increase the strength of the source by putting more strontium-90 inside it. This is *correct / incorrect*, because...

b One will have to put another substance in the source. That other substance must emit radiation with a higher penetrating power.
This is *correct / incorrect*, because...

In the discussion of this task the teacher points at the importance of a precise use of the terms 'penetrating power' and 'strength.' In fact, since the latter indicates a property of the source and the former of the emitted radiation, it is best to always speak more fully of the 'strength of a radioactive source' and the 'penetrating power of radiation.' In the sequel the teacher will have to encourage such a disciplined use of these terms by the pupils.

Half-life of radioactive substances
In section 6-5 (Does the strength of radioactive material change?) the question whether something remains equally radioactive or contaminated is addressed in terms of the just agreed on measure to express how radioactive something is. To investigate the question quantitatively, the pupils are not given the task to themselves perform experiments but to analyze experiments that were performed by pupils in some other class. They are presented with the rough data of those other pupils: the date of measurement; the number of ticks; the measuring time (e.g.: March 8, 590 ticks; 15 seconds). The pupils are asked to calculate the strength at the various dates and to plot the strength against the date. Then they are given a graph that has resulted from similar measurements at a source containing the radioactive substance natrium-24, and which looks just like the one they themselves have just plotted except that the numbers along the axes are somewhat different. By a series of questions (the strength has decreased to half its initial value after ... hours; this value is again halved after ... hours, etc), the pupils are supposed to note that after every such and such period of time the strength of natrium-24 is once more halved. The notion 'half-life of a radioactive substance' is introduced by noting that the 'such and such period of time' just found is called the half-life of natrium-24. The pupils are subsequently asked to find the half-life of the substance for which they themselves have just plotted a graph, and of some other substance for which a graph is given.

Section 6-5 closes with some straightforward exercises concerning half-life. Furthermore the pupils are asked to say whether in controlling the thickness of sheets of paper a radioactive substance with a short or with a long half-life has to be used.

8.5.3 Application of the quantitative descriptive level

In the preceding the pupils are expected to have extended the qualitative descriptive level by an addition of the notions 'strength of a radioactive source' and 'penetrating power of radiation.' Moreover, the need for some such extension initially derived from an induced demand to better understand some applications, and the added notions are to some extent already related back to applications by the pupils (when they were asked to say whether e.g. in controlling the thickness of sheets of paper a radioactive substance that emits α-radiation, β-radiation or γ-radiation, or with a short or long half-life, has to be used). In the final sections of chapter 6, the extension is in two steps more explicitly related to applications. In section 6-6 (Got it?), the pupils are asked to give the reasons why in a given application a radioactive substance with a particular half-life and emitting radiation with a particular penetrating power is used. In section 6-7 (Exercises), the pupils themselves are, for a given application, to choose an appropriate radioactive substance from a list.

The application that is presented in section 6-6 is of the same kind as the first application of section 6-2. Again, an organ that is suspected to malfunction (in this case a liver) is investigated, not by cutting the body open but by introducing a radioactive substance to the body and by monitoring from outside whether and where it has gone in the relevant organ. The pupils are asked to explain why in this investigation a radioactive substance is introduced with a relatively short instead of a rather long half-life, and emitting γ-radiation instead of α- or β-radiation. The applications presented in section 6-7 are: finding a suspected blockage in an air passage in a lung; controlling the thickness of polythene sheeting; sterilizing Petri dishes; detecting smoke; checking welds of pipelines for faults; reducing a too large thyroid gland. For these applications the pupils are to choose an appropriate radioactive substance (and to argue for that choice) from a table of 18 substances, in which it is indicated whether a substance emits α-radiation, β-radiation or γ-radiation (six of each), and what its half-life is (varying from relatively short to rather long).

8.6 From descriptive level to theoretical level

It is expected that in the preceding the pupils have arrived at and come to value a way of describing and a system of generalizations, in terms of which they can predict and explain the occurrence or non-occurrence of types of event that have some practical interest, in situations that have some practical interest, and to an extent that is quite sufficient for practical purposes. An event of interest is e.g. receiving radiation (because of its possible effects, especially for people), situations of interest are e.g. real life situations (such as the Chernobyl accident and its consequences) and real-life applications of radioactive substances. It is also expected, however, that in the course of arriving at the descriptive level the pupils have posed and stored in the summaries some questions that not so much cast doubt on the usefulness of the descriptive level but rather demand a deeper understanding and further clarification of it, and may thus be understood as reflecting some kind of theoretical need. In section 6.3.5 and the preceding sections of this chapter I have already given possible examples of such questions: why is it that the gas mantle is radioactive?; why is it that some material is genuinely radioactive -i.e. radioactive without being contaminated?; why do we not seem to be able to make an apple radioactive, while after the Chernobyl accident fresh vegetables had become radioactive?; why is it that an object does not become radioactive by irradiation and is only effected for as long as it is being irradiated: what, then, happens to the radiation?; why is it that radiation penetrates further into some materials than into others?; what is radiation anyway?

The idea behind chapter 7 is to make the pupils reflect on what has already been established and especially on what has still been left open. Pupils' entrance to chapter 7 is thus what its title is: looking back and rounding off. A further aim of the curriculum deviser and the teacher is that in the 'looking back'-part some kind of theoretical need is brought to the fore, while in the 'rounding off'-part it is to some extent met by trying to answer some of the questions that have arisen in the preceding. This is tried by a shift to a different vocabulary, in particular by making some hypotheses about micro-structure (cf section 6.3.5). The emphasis should thereby not so much be on the *content* of some particular hypothesis, but rather on its *function* in better understanding some of the facts that have already been established. In section 3.3 I have already given an example of an hypothesis that might be useful: radiation is nothing but very fast moving particles. That is, radiation consists of particles, but those particles as such are not radiation. They are only radiation, and are only able to do damage, as long as they are moving. And the fact, e.g., that radiation seems to disappear, in the sense that an object does not become radioactive by irradiation and is only effected for as long as it is being irradiated, might eventually be explained by a micro-level account of what happens with the fast moving particles when they get into an object. E.g.: the particles of the radiation collide with the particles that the irradiated object consists of. It is because of those collisions that the particles of the radiation on the one hand may do damage to the object, while on the other they themselves lose speed. Then either a particle of the radiation gets, perhaps after having done some damage, through the object, or it comes to a stop inside the object. So after the irradiation has stopped, i.e. after the bombardment with the fast moving particles has stopped, neither do there escape fast moving particles out of the irradiated object any longer nor is there still any damage done by fast moving particles. Some particles of the radiation may indeed have remained in the irradiated object, but they are standing still and thus no longer cause any damage. If in such a way it enables them to answer some of their questions, the pupils are expected to come to see some value in the suggested hypothesis, and the more so the more questions it enables them to tackle.

I am very modest concerning the extent of what can be achieved in this way, however. As I already noted in section 6.3.5, I would be quite satisfied if the pupils just got a flavour of how a shift to a different vocabulary might enable a deeper understanding. I expect, moreover, that their theoretical need asks for not much more than just that. Even though most of their questions will still not be answered and even though some of the answers may in turn have given rise to new questions, I think that the unit could be satisfactorily rounded off now that the pupils know that there is still much more to be said and explored concerning radioactive phenomena and have seen a glimpse of the direction of such a further exploration. After all, they already have learned quite a lot about radioactivity and, if I am right concerning my expectations, they have learned it in such a way that all along they knew what it was all about.

I have just sketched how I would round off the topic if things were entirely up to me. But they are not. In particular, I felt obliged to meet the demands of the examination syllabus. And the syllabus demands that pupils know about protons, electrons, neutrons, unstable nuclei, isotopes, etc, know that α-radiation consists of helium nuclei, β-radiation of electrons, etc. I think that these demands reflect the tendency that I have pointed at in chapter 3, namely to self-evidently associate the topic of radioactivity with 'abstract,' 'theoretical' and 'nuclear model:' to take it as self-evident that to meaningfully teach the topic of radioactivity, even if one aims at 'contextual physics' or 'physics in contexts,' one will have to first teach about atoms, nuclei, etc. In chapter 3 I have already argued against the obviousness of this tendency and, moreover, the didactical structure outlined above can also be seen as making a case for the possibility of meaningfully teaching the topic of radioactivity without teaching about atoms, nuclei, etc. But nevertheless, the examination syllabus being what it is, there is of course the responsibility to prepare the pupils for it.

Chapter 7 as it is written, and briefly outlined below, is some sort of hybrid product that has arisen out of the tension between rounding off the topic as I would have liked and meeting the demands of the examination syllabus. It has been tried to merge the two by also presenting the facts that pupils have to know according to the examination syllabus in the context of answering the questions that have emerged in the preceding. I was fully aware, however, that this is an uneasy compromise -to say the least. For the questions that have emerged in the preceding surely do not justify in any way the introduction of a fairly detailed nuclear model or, to put it another way, the presented nuclear model does not match in any way the theoretical need that may have emerged. It is like giving them a sledgehammer they cannot really bear, and then asking them to just crack a nut with it. Nevertheless, even though I was not very satisfied about chapter 7, it was decided to try it out at least once.

8.6.1 Inducing a theoretical need by looking back

The teacher begins with noting that the pupils already have learned quite a lot about radioactivity, and introduces the theme of chapter 7: rounding off by looking back on what has been established in the preceding, in particular on the questions that have arisen in the preceding, for some of which it will be tried to find an answer.

Section 7-2 (Questions we still need to find an answer to) contains two tasks. In the first one the pupils are challenged to look back on what has been established in the preceding and to collect some questions on it. They are given the hints to look at the summaries, and in particular at the 'questions we still have to find an answer to.' But they may also have some questions concerning the 'important things to remember.' And perhaps they have cut some articles on which they have questions. In the second task the pupils are asked whether they can already answer some of the questions they have just collected.

In the discussion of the tasks the teacher may first of all have the opportunity to point out that the pupils have indeed learned something. For they may have found that they can now answer some of the questions they once had, e.g. why initially they were not able to make an apple radioactive, while after the Chernobyl accident fresh vegetables had become radioactive. The teacher then focuses on the questions that still remain unanswered, and tries to bring out their 'why-character:' we do already know that such and such is the case, but why is that? E.g.: we do know that an object does not become radioactive by irradiation, but why is that so? Depending on what they themselves have already brought forward, the teacher may ask the pupils if they do know more such 'why-questions.' If needed, the teacher him- or herself may also add some, e.g.: why is the penetrating power of β-radiation higher than that of α-radiation?; why does the strength of a radioactive substance decrease with time?; why do the half-lives of different radioactive substances differ (so considerably in some cases)?

8.6.2 Trying to meet the theoretical need by a shift to a different vocabulary

An hypothesis about the nature of radiation

In section 7-3 (How can we conceive of radiation?) a beginning is made with tackling some of these questions. On the basis of some of the 'why-questions' that are expected to have come forward, the teacher first of all works towards the question: what is radiation anyway? The teacher then tells that physicists too have posed the sort of questions that the pupils have, and that in order to answer them have had the idea to think of radiation as consisting of particles -very small particles that are moving very fast. According to that idea a radioactive substance shoots away particles, which can encounter all sorts of things on their way: a Geiger counter, a human body, etc. The counter ticks each time a particle enters it. In a human body a particle may collide with cells and thus do damage to cells.

Trying to answer some questions by using that hypothesis

The teacher also notes that the idea that radiation is nothing but very fast moving particles may sound very strange. Still, physicists have come to appreciate the idea as useful, because it has enabled them to answer a lot of their questions. Perhaps it will also enable the pupils to do so. The teacher then sets the pupils to work on the below task, in which they are to answer some questions by using the idea that radiation consists of very fast moving particles. (Of course they are also free to try to answer some other questions by using that idea.)

3 Answering unanswered questions

a Beta-radiation does not penetrate a plate of lead. Why?
(Hints: * Beta-radiation consists of particles.
* Lead consists of molecules.)

b Alpha-radiation penetrates just a few centimetres into air.
Why is that?
(Hint: * Air too consists of molecules.)

c Beta-radiation only partly passes through a plate of aluminium. But beta-radiation does not pass through a plate of lead at all.
Why not through lead and partly through aluminium?

d Alpha-radiation does not pass through a sheet of paper. Beta-radiation does so partly.
That is, the penetrating power of beta-radiation is higher.
Think of some explanations for that.

e While somebody is being irradiated the radiation can do damage. After the irradiation there is no damage done any longer.
Why is that?
(Hints: * Radiation consists of particles.
* Those particles can do damage by collisions.)

f Irradiated food is not radioactive.
Why is it that the food itself does not emit radiation after having been irradiated?

It is expected that the pupils will be able to think of ways to use the suggested idea in order to answer these questions, and that in doing so they will make additional assumptions about, e.g., the size and speed of the particles, or about the density of the molecules of the object they collide with. In the discussion of pupils' explanations the teacher's focus should not so much be on the content of some particular explanation, but rather on whether the suggested idea is soundly used in it to answer a question. Thus the pupils may come to appreciate the idea as useful (at least to some extent).

Some more hypotheses: about the nature of (radioactive) substances

The structure of section 7-4 (How can we conceive of (radioactive) substances?) is in a way the same as that of section 7-3. Firstly, the teacher works towards a question (in this case: why is it that a radioactive substance is radioactive?). Secondly, some hypotheses are presented (in this case: concerning the nature of substances in general, and of radioactive substances in particular). Thirdly, some questions are being answered by using these hypotheses (in this case in particular the hypothesis that the particles of radiation are emitted by unstable nuclei). The difference with section 7.3, however, is that this time some artillery is developed in the second step that is far too heavy for the use it is put to in the third step. The reason is that it is in this second step that I felt obliged to meet the demands of the examination syllabus.

Anyhow, the teacher links up with section 7-3 by noting that the pupils may have begun to see some use of the idea presented there for answering some questions. But it does not answer all questions and, in turn, itself evokes some new questions. For according to that idea a radioactive substance shoots away particles. But where do those particles come from? And why is it that some substances emit such particles while others do not? Why exactly is it that a radioactive substance is radioactive?

The teacher then tells that in order to answer such questions physicists have put forward some ideas concerning the nature of radioactive substances. These ideas have in turn come forward out of ideas concerning the nature of substances in general, as physicists and chemists have developed them throughout the ages. In chemistry class, the pupils may already have come across some such ideas, e.g., the idea that substances consist of molecules, and that molecules consist of atoms. Such ideas may again sound strange, but chemists have come to appreciate them as useful since such ideas have enabled them to explain and predict how substances will react with each other and which new substances emerge in such reactions. Some further ideas concerning the nature of substances have proved useful to better understand why some substances are radioactive.

The further ideas about substances that are (both verbally and pictorially) presented in the text are: atoms consist of protons, neutrons and electrons; the number of protons in an atom equals the number of electrons in an atom (and is called the atomic number); the protons and neutrons sit close to each other in a small clod, which is called the nucleus of the atom; the electrons circle around the nucleus. As further ideas about radioactive substances in particular the following are presented: what is special about radioactive substances is that the nuclei of the atoms they consist of are unstable, i.e., inclined to change; unstable nuclei change by shooting away a particle; some unstable nuclei shoot away alpha-particles, which are clods of two neutrons and two protons; radioactive substances whose unstable nuclei change by shooting away alpha-particles emit alpha-radiation, i.e. the fast moving particles that alpha-radiation consists of are alpha-particles; the activity of a radioactive substance (with the becquerel as unit) is the number of its unstable nuclei that per second change or, equivalently, the number of particles that per second are shot away by its unstable nuclei. Alongside this presentation the textbook also contains a lot of tasks whose main function is to let the pupils practice with the multitude of presented ideas (i.e. with the facts that pupils have to know according to the examination syllabus). There is also a task in which the pupils are asked to relate the notion 'activity of a radioactive substance' as it is defined here to the notion 'strength of a radioactive substance' as they have defined it in chapter 6.

Trying to answer some questions by using the hypotheses

At the end of section 7-4 the leading thread is taken up again in a task that is given below, and which is similar to task 3 given above. (I hope to have made clear that I have my doubts about whether also for the pupils the leading thread is still visible or whether, instead, they have lost their thread altogether.)

14 Answering unanswered questions

You now know how physicists think that substances are build up. And why according to them it is that some substances are radioactive. With those ideas they can answer a lot of questions.
Can you too?

> *Answer the below questions. Use in your answers the idea that radiation is emitted by unstable nuclei.*

a Some pupils measure near two stones. Near the one stone they do not measure radiation, near the other they do.
Why is that?

b Why can't one simply switch off radioactive material? Just like a lamp or an X-ray machine.

c Why does a radioactive source emit less radiation in the course of time?

d Some pupils measure near two radioactive stones. They find that the strength of the one stone is much greater than that of the other.
Try to think of what might be the cause of that.

e Some radioactive substances have a half-life of a couple of billion years. The half-life of other radioactive substances is just a few tenths of a second.
Try to think of what might be the cause of that.

In this task too, the pupils are free to also try to answer some other questions by using the presented ideas. It is expected that the pupils will be able to think of ways to use the suggested idea in order to answer the questions, and that in doing so they will make additional assumptions, e.g., that the more unstable nuclei will change per second the more unstable nuclei a radioactive substance contains, or that the unstable nuclei of the one radioactive substance are more unstable (more inclined to change) than those of other radioactive substances. In the discussion of pupils' explanations the teacher should again not so much focus on the content of some particular explanation, but rather on whether the suggested ideas are soundly used in it to answer a question. In this way the maximum is done to make the pupils appreciate the usefulness of some of the presented ideas. (It will be clear that I have no high expectations concerning the degree of this appreciation.)

8.6.3 Rounding off

In section 7-5 (Have all questions been answered?) the unit is rounded off. It contains one task, in which the pupils are asked to look back on the unanswered questions they had noted down at the beginning of the chapter and to check which ones have been or can now be answered and which ones still cannot be answered. The attention of the pupils is thus once more explicitly focused on the theme of chapter 7.

In the discussion of the task the teacher builds on what the pupils bring forward and tries to bring out such things as: indeed, some of the questions have been answered by using some new ideas; but on the other hand some questions have not been answered, or some new questions have in turn emerged. The teacher may add to this that physicists have found that the fast moving particles of which beta-radiation consists are electrons. That is, radioactive substances that emit beta-radiation contain unstable nuclei that change by shooting away electrons. But how on earth can electrons be shot away from nuclei, which do not contain electrons?

To close the topic the teacher may draw the following moral. It is absolutely no shame that some of pupils' questions have remained unanswered or that some of their answers have in turn generated new questions. The same goes for physicists. In fact, while physicists may have found answers to some of the questions that for the pupils still remain unanswered, on some other such questions they are still doing research today. And although the pupils will not further study the fruits of physicists' further research, they may at least have got some idea about the way that physicists try to tackle the further questions concerning radioactivity. Isn't that enough?

8.7 Status of the didactical structure

When I had written the above didactical structure, I believed that it would come near to 'good enough' (cf section 7.3). That is, although I had the idea that it could be approved if only I had had some more time, I also believed that it would serve as a valuable guideline in the coming series of lessons, in the sense that these series would not deviate much from it though they would of course meander somewhat around its main path. My main reason for believing this was that I had quite explicitly constructed the didactical structure as a detailed process of rational accommodation that pupils themselves, guided by teacher and teaching materials, would be able to establish and give shape. So if I was asked why I expected that in the coming series of lessons the actual process would not deviate essentially from the one predicted by the didactical structure, I could have done no better than refer to the didactical structure itself and indicate that there it says why. Of course, it only says why there in a pragmatic and intuitive manner, by an implicit appeal to fundamental norms of rationality that pupils share with me, e.g.: if I were to believe and want what I assume pupils to believe and want at that stage, I would find it reasonable to do such and such; therefore I expect pupils to do such and such. A further reason for my belief that the didactical structure would come near to 'good enough' was that in its construction I had taken into account the critical remarks and other comments of several other people. The expectation that in the coming series of lessons the actual process would not deviate essentially from the one predicted by the didactical structure, was therefore one that, on the same pragmatic and intuitive level, was shared by several people, and in this sense strengthened. A final reason was that in its construction I had tried to avoid the mistakes (e.g. with respect to the wording of tasks) that became apparent in the try-out of the first version of the didactical structure (cf section 7.4). In this weak sense, the didactical structure could be said to be empirically supported.

This is the status of the didactical structure before it was tried.[15] I think two comments are in place concerning its status, in particular concerning the pragmatic and intuitive nature of its justification. A first comment is that a further worked out version of Davidson's theory of interpretation (cf appendix 1) promises the possibility of a more explicit justification of a didactical structure as a dynamic process of rational accommodation than one that implicitly

15. In the next chapter I will discuss its status after it was tried, and in particular address the question whether it did indeed come out as near 'good enough.'

appeals to fundamental norms of rationality. For such a theory tries to make explicit the norms that underlie an understanding of one another as rational creatures (and thus also our intuitive and pragmatic understanding of one another), and the evidential base that is required in order to reach such an understanding (which must be of a kind that in daily life we base our intuitive and pragmatic understanding of one another on, i.e., public and, in principle, observable behaviour), and an indication of the way in which such an understanding on the basis of this evidential base can be reached (by rational creatures like ourselves).

A second comment is that, even it was possible to produce such an explicit justification, a presentation of a didactical structure as the one of this chapter would still be of value, precisely because its implicit appeal to fundamental norms of rationality challenges one to think through the didactical structure for oneself and to judge it on an intuitive and pragmatic level. I hope the reader has experienced this in reading the above didactical structure, and has reached a pragmatic and intuitive judgement as to whether my expectations make sense to him or her. I expect, moreover, that the reader who has, will have found him- or herself largely in agreement with me, simply because if I, e.g., expect pupils to do such and such, given that they believe and want this and that (because I myself would then do such and such), I expect the reader to expect the same. Of course I do not mean to suggest that there is something wrong with the reader if he or she doubts parts of my account. On the contrary, it would provide a starting point for a discussion that aims at an improvement of the didactical structure.

9 Evaluation of the didactical structure of the topic of radioactivity

9.1 Introduction

This chapter and the preceding one are two companion chapters in the sense that in this chapter the didactical structure that has been presented in the previous one is evaluated in the light of what happened during a couple of series of lessons in which it served as a guideline.

This evaluation of the didactical structure has been of a pragmatic and intuitive nature, like its construction and its presentation in the form of a scenario have been (cf section 8.7). Like a further worked out version of Davidson's theory of interpretation (cf appendix 1) promises the possibility of a more explicit justification of a didactical structure (cf section 8.7), it also promises the possibility of a more explicit evaluation of an educational process. So if this possibility was realized, I think this would constitute a progress of educational research methods (or, more generally, of the research methods in the social sciences). While evaluating an educational process it would enable researchers to state as explicitly as possible what each of them takes as evidence for, e.g., a particular interpretation of what happens in the educational process, and especially so in cases where interpretations diverge. Accordingly, the evaluation would clearly pinpoint both the points where interpretations diverge and the sources of those divergences. Moreover, the subsequent process of weighing the pro's and con's of the various interpretations, in order to reach a shared interpretation or, at least, a meaningful disagreement on the appropriate interpretation, would then also gain in clarity.

Having said this, let me now also stress the value of presenting a more intuitive and pragmatic evaluation, as in this chapter. If anything is to stimulate teachers to work with some didactical structure, for instance, it must be because a presentation of it and/or how it works in practice appeals to them on an intuitive and pragmatic level. An evaluation on an explicit level will hardly be of use to them, because that is not the level on which they will be going to work with it. But also for people who are in principle interested in an explicit evaluation, and those people are most likely to be found amongst researchers, it will be useful to first form a prima-facie judgement on the basis of an evaluation of an intuitive and pragmatic nature. For it is this prima-facie judgement that largely determines whether or not it makes sense to also study an explicit evaluation: someone who is not convinced on an intuitive and pragmatic level most likely will no longer be interested in an explicit evaluation.

In section 9.2 I outline the procedure that has been followed, both with respect to the evaluation and with respect to its presentation that is to follow in sections 9.3 to 9.6. In section 9.7 I close the chapter with a reflection on the outcomes of the evaluation.

9.2 Procedure of the evaluation and its presentation

9.2.1 Procedure of the class observations

The observed classes

The second version of the didactical structure was tried in two classes of pupils from the middle-ability bands (the so-called MAVO-stream) at the end of the school year '90-'91. In figure 9.1 a simplified diagram of the Dutch school system is presented (or at least, as it was at the time) in order to locate the MAVO type of education.

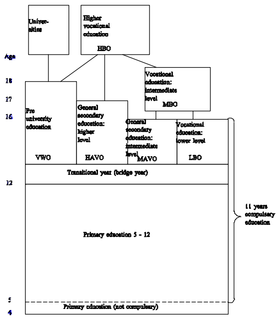

Figure 9.1 Simplified diagram of the Dutch school system

The MAVO-stream takes four years (including the bridge year), is of a general (non-vocational) kind and of an intermediate ability level. About 40% of Dutch children enter the MAVO-stream (about 15% the VWO-stream, about 15% the HAVO-stream, and about 30% the LBO-stream).

The school in which the lessons were followed is a medium-sized school (about one thousand pupils) for MAVO, HAVO and VWO in the city of Utrecht. Both observed classes were of form 3, which consisted of pupils of about 15 years of age who had chosen physics as a subject. One class contained 8 pupils, all boys; the other 4 girls and 13 boys. The relatively small size of both classes was rather exceptional. The percentage of girls who had chosen physics that year was also exceptionally low.

In the school, the PLON-curriculum is used for physics education. Without going into the details of the PLON-curriculum (see e.g. Eijkelhof & Kortland, 1988, for more), I just want to point at two of its features that may have prevented that the series of lessons on radioactivity were too far out of line with what the pupils were used to. The first feature concerns the STS-approach of the PLON-curriculum. This means that the pupils are used to work with units in which physics is related to everyday life -earlier in the third form they had e.g. worked on the units "Bridges," "Energy at home," "Seeing," and "Dealing with electricity." The second feature concerns the variety in classroom activities that the PLON-curriculum aims to promote. In particular this means that the pupils are used to working in small groups. In fact, in the series of lessons on radioactivity they do not work as much in small groups as they were used to. This is because in the other units experiments are normally carried out as group work, whereas in the series of lessons on radioactivity for safety reasons all the experiments are carried out (by pupils) as a classical activity. For it is only then that the teacher can supervise what is going on and, if needed, take immediate action.

The teacher

Each class had three 50-minute lessons of physics per week. The total series of lessons took 13 periods. Both classes were taught by the same teacher. In fact, by the same teacher who had also worked with the first version, had been involved in the evaluation of the first version, and in the construction of the second version. By this close and quite intensive cooperation with the teacher (on which I will say more in chapter 10), it was tried to secure as well as possible that the teacher had made himself so familiar with the second version of the didactical structure -with why, partly on the basis of experiences with the first version, it was as it was, with the role he had to play in it (and believed he was able to play), etc- that he would not deviate essentially from it. For only then could the try-out properly be called an evaluation of the devised didactical structure. The relatively small size of both classes was also useful in this respect. It allowed the teacher to concentrate better on the essence of the didactical structure and his role in it, because he only had to deal with management problems at a fairly small scale. It may alternatively be said that the small classes provided a good environment for the teacher to learn to work with the didactical structure.

Activities during the lessons

I was present in both classes throughout the series of lessons. I was not just a passive spectator, however. I tried to understand what was going on as well as possible, and made notes of things that struck me or deserved a closer look.

Furthermore, I tried to be of as much assistance to the teacher as I could. In some cases I was of assistance because I acted like a second teacher. When the pupils were working in groups I would, like the teacher, walk around, see how they were doing, help them if they had some problem, etc. This also had the advantage that I got a fair idea about how things were going. During class discussions too I tried to understand as well as possible what was going on, and especially pupils' contributions. Perhaps I was even better able to do so than the teacher himself, because I did not have to participate in the discussion and did not have to manage the process. A second way in which I tried to be of assistance, was by briefly informing the teacher at appropriate times during the lesson (e.g., when the pupils were working in groups) how things were going according to me. I would then usually also briefly remind the teacher of things that still needed to be done, or make some suggestions about how in the following class discussion he could build on what the pupils were doing in groups, etc. In all this I tried to be as positive as possible.

I also took care that in both classes the whole series of lessons was recorded, in the one class on audiotape and in the other on videotape. The advantage of an audio-recording is that it lends itself more easily for transcription. The advantage of a video-recording is that it lends itself for a more accurate transcription because also the non-verbal aspects can be taken into account. In the class in which audio-recordings were made, I would for instance have to make additional notes when experiments were performed. Another advantage of a video-recording is, of course, that it gives a direct and lively impression of what happened and, as such, is suited to use at e.g. teacher conferences for illustrative purposes. I tried to let the recordings be as less intrusive as possible. The camera remained at a fixed position at the back of the classroom, I did not stand behind the camera for long periods of time, tried to handle the camera as casually as possible, reduced the camera-handling to a minimum, etc. By keeping a low profile with respect to my recording activities I hoped, at the one hand, to distract the pupils as less as possible, while on the other it enabled me to more devote myself to assisting the teacher in the above senses.

Another recording activity was that at appropriate times I collected the pupils' textbooks in order to copy them.

Activities in between the lessons

My activities in between lessons were also directed at being of as much assistance to the teacher as I could, namely by helping him prepare the next lesson. Part of this assistance was rather straightforward: I took care that all the material that might be needed the next lesson would stand ready. This had the advantage that I had to think through what had to be done the next lesson. I also tried to be of assistance by improving my understanding of what happened in the lesson just given, in as far as it seemed relevant for the preparation of the next lesson in the same class or the matching lesson in the other class. To this end I would, after a lesson was over, look back on it in somewhat more detail by playing (fragments of) the tape or reading (parts of) the textbook of some pupils. Again I was in a better position than the teacher to do all this -I simply had more time for it. On the basis of my looking back on the previous lesson in somewhat more detail, I would then usually write, and verbally explain, a short piece that the teacher would use for his further preparation of the next lesson. If the next lesson was one matching an already given lesson in the other class, I would sometimes indicate some, usually minor, points where the teacher's role could have been more in line with the didactical structure. If possible I would illustrate these points by referring to the already given lesson (e.g., by using a transcript of some fragment), point out why I thought that, for instance, some feedback of the teacher was not entirely adequate, and discuss with him how it could have been better (e.g., by using a transcript of some other fragment). I did not discuss such cases for their own sake, for it was unlikely that identical cases would occur in the parallel class. I rather used them as concrete cases to further illustrate the spirit of the didactical structure at. In my short piece for the teacher I would usually make some suggestions about the way the next lesson might build on what happened in the previous lesson in the same class (e.g. by using some fragments of pupils' textbooks), and briefly indicate, as a sort of reminder, the main points of the piece of the didactical structure that was relevant for the next lesson. My assisting the teacher in this way in his preparation of the next lesson can thus also be seen as creating an optimum[1)] environment for the teacher to work with the didactical structure as intended, or as creating optimum conditions for the didactical structure to be carried out as intended and thus for it to be evaluated as it is.

In order to maximally exploit the facts that the series of lessons was given in two classes and that the experiences in the one class could be positively used to improve the matching lesson in the other class, the teacher and I had planned the starts of the two series of lesson in such a way that in the one class a given lesson would always be given before the matching lesson in the other class.[2)] Though the teacher would of course do his very best in the former class, it was expected that in the latter class he would deviate less from the didactical structure. We selected the smaller-sized class as the one in which the lessons would be given first. The lessons in this class were recorded on audiotape, so that I was able to play and, if needed, relatively quickly transcribe fragments of a lesson, and on that basis to think of some improvements for the matching lesson in the larger class, wherever I was and whenever I had the time. Given the intended illustrative use of the video-recordings at e.g. teacher conferences, it seemed best to record those lessons on video which were expected to best illustrate the didactical structure and which took place in what comes closest to an average class. For these reasons the lessons in the larger (though, in fact, still relatively small and not quite average) class were recorded on videotape.

9.2.2 Procedure of the evaluation

First impressions, gathered during the series of lessons

My starting point for the evaluation of the didactical structure has been that it was near

1. Of course 'optimum' does not necessarily mean 'good.' The time-table or the hectic school environment sometimes forced the teacher and me to have our preparatory talks during e.g. lunch breaks.
2. Owing to circumstances beyond our control, as they happen in schools, things did not work out entirely as planned: in three lessons the order was reversed.

'good enough' (for the reasons outlined in section 8.7). Taking this as a null hypothesis, so to say, has had two consequences for my activities during the series of lessons. The first one has been, as already noted, that I tried to secure that in both classes, but at least in one class, the teacher would not deviate essentially from the didactical structure. Furthermore, if in some lesson the teacher deviated essentially from the order in activities suggested by the didactical structure or if his contributions were not quite in the spirit of the didactical structure, I would talk this over with him as part of the preparation of the matching lesson in the other class. The second consequence has been that during the series of lessons I tried to understand what was going on in terms of the didactical structure. That is, if the order in the tasks was more or less followed as suggested by the didactical structure and the teacher's contributions were of the sort suggested by the didactical structure, I would try to interpret what the pupils did say and do as more or less in line with the sort of things they were, according to the didactical structure, expected to say and do: the sort of experiments they were expected to think of, the sort of conclusions they were expected to draw, the sort of questions for further investigation they were expected to formulate, etc. This also means that already during the series of lessons I got some fair idea as to whether the sort of things the pupils did say and do could indeed be interpreted as more or less in line with what they were, according to the didactical structure, expected to say and do. Since during the series of lessons I did not have the time or opportunity to intensively study the tapes and pupils' textbooks, this fair idea could of course not be much more than a first global impression. But this first global impression was that on the whole the didactical structure seemed good enough, though there were of course passages where what the pupils did say and do seemed too far out of line with the sort of things they were expected to say and do.

Further evaluation of the didactical structure
Given that the first impression largely justified the assumption that the didactical structure was on the whole good enough, the further evaluation, which took place after the series of lessons, was also based on it. Again this had two consequences. The first one was that the didactical structure was taken as a mould for the description of the lessons. That is, to put it schematically: the scenario presented in the preceding chapter was copied, while the sort of things the pupils were expected to say and do were replaced by what they actually did say and do (in the form of a literal transcript, a summarizing paraphrase, or an overview of fragments of pupils' textbooks). The evaluation then consisted in the pragmatic and intuitive judgement whether the resulting description made sense. As long as it did, i.e., as long as there were no strong reasons to doubt an interpretation of what actually happened as more or less in line with the scenario, the didactical structure was judged 'good enough.' The second consequence was that also in the cases where the resulting description did not make sense, i.e., where what the pupils did say and do seemed too far out of line with the sort of things they were expected to say and do, it was assumed, on the basis of the first impression that such deviations were not too serious or did not occur too frequent, that there is no reason to question the main line of the didactical structure. So if e.g. the experiments the pupils did think of deviated too much from the sort of experiments they were

expected to think of, it was assumed that, for the reasons given in the didactical structure, it would still be a proper preparation for the sequel that they carried out the sort of experiments they were expected to think of (but did not). The evaluation then consisted in an attempt, on the one hand, to account for the deviation in terms of pupils' not understanding some task or teacher intervention as intended and, on the other, to make such adjustments to the didactical structure (e.g. by adding, deleting or reformulating tasks) that with the adjustments the pupils are expected to think of the sort of experiments that without the adjustments they did not think of. That is, the evaluation then consisted in a revision of (fragments of) the didactical structure -in an account of why the revised version would come out as 'good enough' if it were tried. So throughout the evaluation of the didactical structure, the didactical structure itself served as an important tool.

Wouter Moerman and I made the descriptions of the lessons in the way outlined above. Usually I would produce the skeleton for the description of a lesson, and put what happened in the smaller class as flesh on it. Moerman would then make a similar description of what happened in the larger class, based on the same skeleton, my way of putting flesh on it (with respect to e.g. the form and elaborateness of presenting what happened), and my instructions to pay special attention to particular passages (e.g. activities in which, on the basis of preparatory talks during the series of lessons, the teacher participated somewhat differently than in the smaller class). We would then discuss these descriptions and, together with the teacher, reach a judgement as to whether they made sense and, if they did not, think about adjustments to the didactical structure. I would then usually further think about and work out the adjustments.[3)]

As we had done in its construction, also in the evaluation of the didactical structure we mainly focused on the first two periods: the preparatory period in which a ground level for the following descriptive level emerges and the transition from this ground level to a qualitative descriptive level, each of which took about three and a half 50-minute periods. The extension of the descriptive level in quantitative direction and the transition from descriptive level to theoretical level, each of which took about three 50-minute periods, were evaluated more loosely.

Global evaluation: pupils' comments on the series of lessons

One of the major points of constructing a didactical structure as a detailed process of rational accommodation that pupils themselves, guided by teacher and teaching materials, are expected to establish and give shape, is to bring about an educational process that pupils themselves will experience as an internally coherent one with a certain direction, which in important respects is being driven by their own questions and over whose progress with respect to content they have some control. So the first impression that on the whole what happened in the actual process was more or less in line with the expectations of the didactical structure, also gives rise to the tentative conclusion

3. Some of this further thinking and working out took place much later and, to some extent, is still going on today.

that the pupils will thus have experienced their learning process. And the further, more detailed, evaluation along the above lines is expected to further substantiate that conclusion.

In order to get some additional information on how the pupils had experienced their own learning process, they were asked, after the series of lessons was over, to give their impression of it.

> **What I think about this unit**
> Only a few pupils have worked with this unit. We are therefore very curious about your experiences.
> So tell us something about working with this unit. What did you like and what not? What was good about it and what bad? What would according to you have to be improved or changed? Did you learn a lot or not that much? What is the most important thing you have learnt? What did you find unimportant?
> Note down below your views about this unit. We will use your comments to improve it.

This formulation is expected to be broad and open-ended enough to challenge the pupils to give their general views about working with the unit. If it is, pupils' comments will serve as part of the global evaluation of the didactical structure.

9.2.3 Procedure of the following report of the evaluation

One way of presenting our evaluation would be to follow a procedure similar to the one of the previous chapter: to challenge the reader to reach a pragmatic and intuitive judgement concerning our evaluation, simply by providing the descriptions on which we have based our evaluation (i.e., the descriptions in which the didactical structure was taken as a mould). If this procedure was followed here, my expectations about it would have been similar to what I expected concerning its application in the preceding chapter: that the reader would have found him- or herself largely in agreement with our evaluation, simply because if we, e.g., had no strong reasons to doubt an interpretation of what actually happened as more or less in line with the didactical structure, the reader would not be expected to find such reasons.[4]

I have not chosen for this way of presenting, however, for two reasons. First of all, the presentation would be too extensive, given that a description of one lesson in one class along the above lines is about 10 to 15 pages. Secondly, there would be too much overlap with the preceding chapter, given that the descriptions use the didactical structure outlined there as a mould.

Instead I have chosen for a presentation of the evaluation of the didactical structure that, on the whole, is of a global nature and, at some points, is worked out in more detail in order to illustrate some aspects of the procedure of the evaluation. The global presentation is some sort of stripped version of the descriptions mentioned above. It also takes the didactical structure as a skeleton, but does not put much flesh on it. It confines itself to an anecdotal description of what pupils did say and do. Given my expectation

4. The same comment as in section 8.7 applies here. Cases in which the reader disagreed with us would provide a starting point for a further discussion towards an improved evaluation.

that, when reading the didactical structure as presented in the previous chapter, the reader has found him- or herself largely in agreement with me (cf section 8.7), I also expect that just this anecdotal description will suffice to make it plausible for the reader that there are no strong reasons to doubt an interpretation more or less in line with the expectations of the didactical structure (and even more so because I have also taken into account the comments of the people who have read the previous chapter and earlier versions of this chapter). But a reader who has judged the presentation of the didactical structure in the previous chapter as not very convincing, will certainly not get convinced by the global presentation of its evaluation in this chapter. So be it.

An aspect of the procedure of the evaluation that at some points is worked out in more detail, concerns the evaluation of cases where what the pupils did say and do seemed too far out of line with the sort of things they were expected to say and do. I have already mentioned that in such cases the evaluation consisted, on the one hand, in an account of the deviation in terms of pupils' not understanding some task or teacher intervention as intended and, on the other, in a revision of (fragments of) the didactical structure and an account of why the revised version would come out as 'good enough' if it were tried. Some examples are given of such revisions. If possible, I will also briefly indicate whether the revised fragments did indeed seem to come out as 'good enough.' For some of the revisions were incorporated before the series of lessons were given in the subsequent school year ('91-'92). I also attended those series of lessons. Although I did not follow them that closely (I just made notes during the lessons and copied some fragments of pupils' textbooks), I did pay special attention to the revised parts.

In order to clearly bring forward that the below presentation of the evaluation of the didactical structure takes the didactical structure as a skeleton, the below division in (sub)sections corresponds to the one of the preceding chapter. Section 9.3 concerns the evaluation of the preparatory period and corresponds to section 8.3. Section 9.4 concerns the evaluation of the transition from ground level to qualitative descriptive level and corresponds to section 8.4. I have tried to reduce an overlap with the preceding chapter as much as possible, which implies, I think, that sections 9.3 and 9.4 cannot be read without the corresponding sections in chapter 8. In section 9.5 I briefly go into the extension of the descriptive level in quantitative direction and the transition from descriptive level to theoretical level, but mainly to say why I have not felt a need for a further evaluation of these parts. In section 9.6 I report pupils' general views about the unit.

9.3 The emergence of a ground level

9.3.1 A global outlook

Some of the things the pupils had written down as, according to them, having got to do with radioactivity were: X-ray apparatus; nuclear power station; Chernobyl; radiation of negative atoms; radiation treatment; radioactive waste; nuclear weapons; poisoned vegetables; lead; radiation danger. This selection may serve to illustrate that their answers indeed enabled the teacher to give a global outlook on the sort of subjects that would be treated further on in the series of lessons. Furthermore, given also that on average each pupil had noted down about four things in just a couple of minutes, it may be concluded that the concept 'has got to do with radioactivity' served well as a lead to get them thinking about the topic and to bring forward a rich enough variety.

9.3.2 Coming to agree on a specific use of the term 'is radioactive'

Coming to feel a need for a criterion of being radioactive

In the next task the groups were asked to decide of some objects that the teacher brought into the classroom whether or not it has got to do with radioactivity. Let me now first give an example of a change that, on the basis of experiences in the smaller class, I proposed as part of the preparation of the matching lesson in the larger class -in this case, a minor change concerning the organization of the task just mentioned. It turned out that in the smaller class, partly because of its small size but also because the objects were placed close together, the pupils went up to all the objects more or less as one group. As a result the class discussion which was to follow the group work partly coincided with the group work, and this in turn made it difficult for the teacher to start the discussion as something new and to give it its own point. Furthermore, the teacher was in too much a hurry in that he started the discussion before the pupils had properly finished the group work.

So I proposed to scatter the objects more evenly along the sides of the classroom in order to prevent too much interaction between the groups during the group work. This would then also more clearly separate the group work from the following class discussion. Furthermore, I proposed to not begin the class discussion before the pupils had finished the group work, if only because the discussion would not make much sense if they had not. Finally, the fact that the group work took more time than the teacher had expected was not due to fooling around of the groups or something like that. It simply takes quite some time (about a quarter of an hour) for the groups to go up to all ten objects, to get to know some of them a bit better (e.g. the X-ray machine by X-raying a wallet), discuss whether they have got to do with radioactivity, to fill in the table, etc. So they should be given that time.

I will now give an overview of the group work on the above mentioned task, partly on the basis of fragments of discussions during the group work but mostly on the basis of what the pupils had written down in their textbooks.

All groups were able to reach agreement on most of the objects. Some groups were not able to do so on one or two objects. One group, for instance, had already agreed that the laser has got to do with radioactivity because a laser beam is very strong, but it remained divided on the remote control. There was agreement on the fact that it emits infrared rays, but disagreement over the issue whether those rays are strong enough. When the group called in the teacher for help, his feedback was appropriate. For he did not try to settle the disagreement, but simply informed whether the group was in agreement on the other objects. And since it was, the teacher said that for the time being he did not mind that for one item different group members would note down different answers. The laser or the battery were also objects on which there was disagreement within some groups.

During the group work some pupils explicitly stated that they had difficulties with saying why an object does or does not have got to do with radioactivity, e.g.: "X-ray machine, yes. But how to say… I just don't know what to write down." The same difficulty may also be the source of some rather superficial exchanges of 'argument,' in which the power of persuasion derived from the force of the used words rather than from the cogency of some argument, as e.g. in the following brief exchange: "The answer is 'yes,' of course. Really, a lot of radiation does get out of it." "No way." "No?" The difficulty is very likely also the cause of the fact that some entries in the third column (the 'because'-column) of the table were left blank. In about one third of the cases in which a 'no'-answer was given, for instance, this answer was no further explained.

I hope this makes sufficiently plausible that during the group work on this task the sort of things did happen that according to the didactical structure were expected to happen and that would make for a proper preparation of the following group discussion. But before going into that group discussion, I first give some examples of 'because'-answers in which terms like 'radiation,' 'radioactivity,' 'contamination,' etc are used, if only to illustrate that indeed they are used. Some 'because'-answers are of a 'radiation* is (is not) released'-type, e.g.: "radiation is released;" "infrared rays come out of it;" "it doesn't radiate anything;" "radioactivity is released;" "irradiated, and because of that it radiates a radiation;" "if it falls to pieces, radiation will be released." Others are of a 'has (has not) stood in radiation*'-type, e.g.: "is radioactively irradiated;" "is not irradiated;" "a radioactively irradiated person has worn it"; "it has been exposed to radiation." Still others are of a 'does (does not) contain radiation*'-type, e.g.: "there is no radioactivity inside it;" "it has sucked up radioactivity;" "it most likely is radioactively contaminated;" "it is full of radioactivity;" "it has no radiation;" "is radioactive." Together these types of 'because'-answers make up about half of the explanatory remarks.

Let me briefly mention that the discussion of the task in which, among other things, the pupils were asked to name two objects that both have got to do with radioactivity but have got to do so in a different way, as expected allowed the teacher to point at the use of a more specialized concept than 'has got to do with radioactivity' and to propose to express that concept by means of the term 'is radioactive.' Some of pupils' answers on which the teacher could build were as expected, e.g.: "articles and stones, because the one has radiation and the other not." But the difference between the two concepts sometimes also came forward in unexpected (though equally useful) ways. One group e.g. found that the bathroom tile, though not itself radioactive, still has got to do with radioactivity because it could be used as a shield "against radiation."

The discussion then preceded with a blackboard inventory of the number of 'yes'-, 'no'- and 'don't know'-answers, not to an objects's having got to do with radioactivity, but to its being radioactive. The below table is a result of such a stock-taking (a number represents the number of groups that has given a particular answer).

	is radioactive		
	yes	no	don't know
Chernobyl shoe	7	0	0
jar with stones	7	0	0
X-ray machine	7	0	0
light bulb	0	7	0
articles	0	7	0
battery	0	7	0
bathroom tile	0	7	0
gas mantle	0	6	1
laser	4	3	0
remote control	3	3	1

Of course this table is just the result of a stock-taking in one class. In other classes the result was somewhat different. But also in the other classes the result was such that it properly set the stage for the sequel: there was (almost) complete agreement on the majority of objects; on two or three objects the groups were divided.

The agreement on the majority of objects enabled the teacher to compliment the pupils; the division on some of the objects set the stage to go into some arguments (also concerning the objects on which there was agreement). Below are examples of that. The first one concerns the remote control.

Jeremy: Well, a ray of infrared comes out there, doesn't it. Well, there most likely is radiation inside.
Iris: Yes, so what?
Teacher: Radiation comes off. You find that important, don't you. Then you surely will have filled in 'yes' for the laser too?
Jeremy: Yes.
Teacher: And for the lamp too?
Jeremy: No, not for that.
Several pupils: But there also comes radiation out of that.

The next example concerns the stones in the jar, of which some pupils said that they are radioactive: "you can read that, can't you;" "there is a sticker with that sign on it."

Teacher: So we think they are, because there is a sticker on the jar?
Melvin: Yes, but a sticker like that can be stuck on everything.
[…]
Lawrence: Yes, but there a great dose can be… there is a lot of radiation on them.
Melvin: Can you tell that?
Lawrence: What?
Melvin: That it is like that.
Lawrence: Otherwise they wouldn't be in a glass jar.
Melvin: But it does go right through, doesn't it, through glass.
Several pupils: Yes.

As expected, such going into the arguments did never lead to mutual agreement on the objects on which the groups were divided, while it did lead to situations like the ones exemplified above, in which, guided by the teacher, pupils began to question each other's arguments. So what was to provide the pupils with a sensible reason for wanting an objective and verifiable criterion to determine whether or not an object is radioactive did indeed happen: they were in agreement concerning the majority of objects, and although it should be possible to reach agreement on all objects, they did not manage to do so and did not really have the proper arguments to do so.[5)] Before going into the indications whether indeed the pupils were open for such a criterion, I want to link up with the latter fragment in order to indicate how the 'questions we still have to find an answer to' may naturally be brought into play. For the discussion in that fragment boiled down to the question whether or not it (which the pupils later specified to 'radioactive radiation') does go right through glass. Since the pupils disagreed on the issue, and since the question could not be meaningfully answered at the time, storing the question in, as the teacher had called it, "the memory of the textbook" was the appropriate way to close the discussion in a meaningful way: the issue would be treated further on. In the other class a similar kind of question was noted down in the 'questions we still have to find an answer to'-part of the summary, when some pupils could not believe that the shoe was really worn by someone who had been near Chernobyl at the time of the accident because the shoe was only covered by a plastic bag and "it would go right through that, wouldn't it."

In the account of the didactical structure I have noted that a minimal form of pupils' being open for an objective and verifiable criterion to determine whether or not an object is radioactive would be their seeing the point of, and therefore being prepared to work on, the next task, in which they are asked to find out of some meters whether these provide the desired criterion. On this minimal form I will come back presently. In both classes, however, pupils' being open, or at least some pupils' being open, also took the form of their bringing forward, with some help of the teacher, the idea of a meter. During the exchange of arguments the teacher, at first rather casually but towards the end more persistently, said things like "I really think it's a nuisance that we can't come to an agreement" and "Don't you think there must be a method by means of which we can reach an agreement?" At first the pupils would not react or just make a brief suggestion, e.g.: "Investigate." Later on they would then bring forward the idea of a meter, e.g.:

Teacher:	On a couple of things we do now fully agree. And with these I heard again and again: ah, there is a sticker on it. So one could say: when there is a sticker on it, it is radioactive. Is it true what I'm saying now?
?:	Yes.
Lawrence:	If there is a sticker like that on it.
Melvin:	If you have to believe the sticker.
Teacher:	If you have to believe the sticker and if there is a sticker like that on it […], then it is radioactive. Yes. Is there another way in which we could find out whether it is radioactive?

5. It can thus also be said that there was sufficient variation among the objects that were present in the classroom, in the sense explicated in section 8.3.2.

Lawrence: Yes, with such a device.
Melvin: You can measure it, can't you.
Lawrence: Yeah, such a measuring device.

In the other class too several pupils suggested the idea of a meter, e.g.: "with that thing, with a meter that squeaks, I really don't know how such a thing is called." Also some other suggestions were, half-jokingly, put forward: "look it up in an encyclopedia;" "send it to a laboratory." Such responses allow a straightforward response, of course: how have the people who have written the encyclopedia found out or how would the people in the laboratory find out?

Coming to find a criterion of being radioactive

The pupils were, without any noticeable unwillingness but rather with some enthusiasm, prepared to work on the task in which they were asked to find out of some meters whether these provide the desired criterion. I have already noted that their being prepared, without reluctance, to work on the task is prepared by the preceding, in which the point of the task has, at least implicitly, emerged: there is a need for an objective and verifiable criterion, because their own 'criteria' were not very convincing and at any rate did not enable them to reach agreement on all objects; some sort of device promises to yield the desired criterion. In both classes these reasons for doing the task remained implicit. In the smaller class, the task was done towards the end of the first lesson. Therefore I think it was quite alright that no attempt was made to let the pupils, before going to work on the task, explicitly bring forward their reasons for going to work on it: it simply would have taken the momentum out of the lesson. In the larger class, however, the first lesson ended, after pupils' suggestion that some sort of device might be of help to decide whether something is radioactive or not, with the teacher's concluding remark that the next lesson this suggestion would be followed by letting them check of some meters whether these are radioactivity-meters. So the beginning of the second lesson in the larger class would have been an appropriate time for the teacher to challenge the pupils to bring forward their reasons for the next task, e.g.: I have already noted that next you are going to check of some meters whether these are radioactivity-meters, but why is it that you are going to do this? This was not done, however. In fact, I now take it as a shortcoming of the didactical structure that it does not point out that, apart from the end of a chapter, there are other appropriate stages (e.g. the beginning or end of a lesson) to let pupils globally look back on what has happened and, on the basis of that, explicitly state the reasons for what is going to happen next.

Let me return to the task itself. I guess that some of the groups' enthusiasm derives from the puzzle-character of the task. Furthermore, the groups had no difficulties in finding out which meters will do as radioactivity-meters and they did find that out in the expected ways: hold a meter near objects that almost certainly are radioactive (e.g.: "it did not react in the X-ray machine"), or almost certainly are not radioactive (e.g.: "it reacts if you hold your hand against it"); simply note that a meter seems to react to something else (e.g.: "when we got the meter in our hands we at once saw that it reacted only to light; just to be sure we also held the meter near radioactive objects and it did not react at all to them"). Since one of the Geiger counters produced rather sharp squeaks, it was also unavoidable that there were interactions between groups. So when one group held this counter near e.g. the jar with stones, there would usually be several reactions from pupils of other groups, e.g.: "That's the one, no doubt;" "Hey, that surely is one;" "Hey, put it in the X-ray machine." There would also be several wows and supers (the native speaker of English may replace them by their modern equivalents), especially when a Geiger counter was put in the X-ray machine and the machine switched on: the counter then not just ticked or squeaked, but rather whistled. Furthermore, there were already some signs that the meters identified as radioactivity-meters were accepted as such. When in one group the pupils had found out that the meter they were carrying was a radioactivity-meter, the meter was e.g. held near a pupil who had taken the jar with stones in his hands. When the meter did not squeak, it was concluded: "it has already come off."

In the next task the pupils again had to fill in a table, which differs from the earlier one in the sense that it uses the more specialized concept 'is radioactive' and demands for a way of telling whether or not something is radioactive that is guaranteed to lead to the desired mutual agreement. This task too did not pose great difficulties to the pupils. When the teacher e.g. reminded the pupils that they also had to do this task, some pupils immediately said: "But then we will have to use a meter." Furthermore, all the groups did indeed use a meter that had just been identified as a radioactivity-meter. And the 'because-answers' in the third column were all of the 'it does (does not) squeak'-type. In one group the pupils did not go round to all the objects together but let one pupil do it, who afterwards had to report the results to the rest of the group. When this pupil reported that the bathroom tile was radioactive, the rest found this hard to believe: "No? That tile?" The issue was immediately settled by the reporter, however: "Oh yes, that tile. Went really ee-ee-ee. [Imitates one of the counters, and then calls a pupil who at the time carries a radioactivity-meter.] Aaron, have you already got round to that tile or not? Where's that tile? Yeah, try the tile, will you. [Aaron holds the meter near the tile, and the meter squeaks.]" The acceptance of the radioactivity-meters can further be illustrated by the fact that in both classes several pupils asked (expected) questions such as: "Why is it that the gas mantle is radioactive?", which were stored in the summary.

In the class discussion of the preceding tasks, the pupils were indeed able to bring forward the main points. When discussing the table, for instance, the teacher acted more and more enthusiastically ("Up to now we are well on our way to… and again we are in agreement… great"), and then closed as follows:

Teacher:	We are agreed. That's fantastic. But *why* are we now in agreement? Why?
Peter:	Because we have measured it. Because of the fact.
Several pupils:	Yeah.
?:	Yes, you measure it.
Teacher:	So, something is radioactive… what could follow that? Something is radioactive if…?
Peter:	It is measured.

Melvin:	If it reacts near it, a Geiger counter.

Somewhere in the discussion the teacher also managed to make the pupils bring forward the special position of the X-ray machine, in the sense that it can be switched on and off. In both classes also some additional questions concerning the X-ray machine came forward (some of which were stored in the summary), e.g.: "If you had held your hand inside, then you would have to be radioactive, wouldn't you" (and another pupils added: "Yes, that's why they wear those protective clothes"); "Can you get something from it?"

A slight modification

Concerning the modification of the agreement to something like 'we call an object radioactive if in its vicinity a Geiger counters starts ticking *at a more than normal rate*,' I just want to remark that it is essential, or at least very handy, to take care that during the above discussion it is indeed established that a Geiger counter has a 'normal' (background) ticking rate. For in the smaller class the teacher had forgotten to do so, and consequently had to do so when in the next task the pupils measured nearby and some distance away from a radioactive object. For the pupils this was an inconvenient and rather *ad hoc* interruption of the task, which lead to some confusion. In the larger class the fact that Geiger counters have a normal background ticking rate had already been established before they were going to work on the task. When in that class the pupils measured some distance away from a radioactive object they concluded that one no longer notices anything from it. In fact, when the teacher objected that the counter still ticked, the immediate answer was: "Yes, but that is normal."

9.3.3 Standing in the radiation that is emitted by a radioactive object

In the next task it was tried to make the pupils measure with a Geiger counter nearby and some distance away from a radioactive object, by asking them whether the radioactive things in the classroom are giving trouble to the pupils sitting nearby and some distance away. In section 8.3.3 I have already expressed my doubts as to whether this question, given its rather unspecific formulation, will indeed make them measure nearby and some distance away from a radioactive object. It turned out that in both classes my grounds for the doubts were justified. The following fragment may illustrate this.

Teacher:	Have we got it? Melvin too?
Melvin:	Yeah, but still… I think it's a stupid question. You may very well measure whether someone… whether it will squeak or not, but then you still won't know whether it's giving you trouble.
?:	Yes, you still don't know whether it makes you ill.
Melvin:	Yes, then you would have to lock up someone for three months near… make a lot of those pictures and then see whether all at once he gets green hair. [Laughter]

Several groups had also proposed an experiment of the following kind: "You put 1 person some distance away and 1 person nearby an irradiated object and ask how they feel." The result was that in both classes the teacher had to go through the unnecessary trouble of bending such proposals to the proposal to measure nearby and some distance away from a radioactive object, which was of course unsatisfactory for the groups who had made such proposals.

In order to prevent this it seemed useful to adjust the didactical structure and, according to the strategy outlined in section 9.2.2, to do so on the assumption that for the reasons given in the didactical structure it would still be a proper preparation for the sequel that the pupils measured nearby and some distance away from a radioactive object. In fact, what this measurement had to prepare was, on the one hand, that pupils explicitly linked radioactive objects to the radiation they emit and, on the other, brought forward that a Geiger counter measures the emitted radiation. The adjustment that was made consists in the deletion of section 1-3 (Does it bother you that there are radioactive things in the classroom?), and its replacement by the below task (as part of section 1-2 of the textbook).

Nearby and some distance away

Last year Lara walked away from a gas mantle with a radioactivity-meter in her hand.

a Do as Lara did. That is, walk away from a gas mantle with a radioactivity-meter.
Note down below what happens.

b Lara's conclusion was: "If you are far enough away from it, the gas mantle is no longer radioactive."
Do you agree with Lara? *Yes* / *no*

Answer part c only when your answer is "no."

c You do not agree with Lara. What is your conclusion?

Since in this formulation it is rather straightforwardly asked to measure nearby and some distance away from a radioactive object, the sort of problems mentioned above are not expected. Furthermore, it is, as it was, expected to be intuitively clear to the pupils that the objects's being radioactive cannot be affected by walking away from it.

These expectations did indeed come out the next year, when the textbook contained this new task. Some answers that were then given to the a-part are: "the farther away you go from it, the less the counter ticks;" "nearby it does tick, far away it ticks once in a while as it normally does." Furthermore, none of the groups agreed with Lara: "the meter is simply too far away from it in order to be able to measure something (the remote control does not work either if you stand too far away from the tv), but the gas mantle simply is still radioactive;" "the radiation fades after such and such meter;" "the farther away you walk from the object the less rays you catch;" "the gas mantle remains radioactive, it's just that the radiation becomes less the farther you move away from the radioactive source."

In the two classes that were observed in more detail, the teacher eventually managed to lead the discussion towards such conclusions. But the road towards it had lots of unnecessary bends and was, for the pupils, initially just a sidetrack -i.e., it took the teacher quite some time to make it clear to the pupils that what they thought of as a distracting sidetrack was indeed the main road he wanted to be on.

9.3.4 Coming to recognize a problem in a particular way

Creating a classroom-situation in which pupils can act guided by what they already know

A first thing to note is that in the discussion of the previous task (the last task of chapter 1 of pupils' textbook) quite unexpectedly one pupil made a link with what was going to happen in the course of chapter 2. To be more precise, after in the smaller class it was eventually concluded that "radiation does not reach far enough to measure it at a large distance," one pupil proposed a kind of experiment that later in chapter 2, after they had build their 'nuclear power station,' the pupils were expected to carry out: "Yes, but sir, if for instance… well, if we rather had taken that shoe and had taken off that plastic bag and then… for instance wind machine, then that radioactive radiation would in fact have reached that device." Now, indeed, there is this link, but I simply had not expected that pupils themselves would bring it forward at this stage -as, in fact, most pupils did not. But the fact that it was brought forward, if only by one pupil, was of course just the better. It will have contributed to an increased appreciation of the coherence between the various activities by the pupils -not only by the one pupil who had made the remark, but also by all his classmates who saw the point of his remark. At any rate it allowed the teacher to point at the coherence: "I think you are so… he is so eager to know it… You know what? We are going to talk about it today." In the larger class, the teacher had to introduce the topic of chapter 2 by linking up with the preceding in a more global way: in the global outlook nuclear power stations and accidents with them had been mentioned by the pupils.

The building of the small scale 'nuclear power station' proceeded more or less as expected. In both classes the analogy between the classroom situation and a real nuclear power station was accepted in the sense that in both situations there is radioactive material that has to be insulated (which is the word that most groups used) in such a way that outside no radiation is measured. Lead was mentioned most often as an insulation material that is used in real nuclear power stations. Some pupils, however, also kept an open eye for the purpose of real power stations and noted that lead should not be applied too close to the radioactive material, because "an enormous amount of heat is released, isn't it" and "lead has a low melting point." Other materials that were mentioned are concrete and graphite (of which some pupils knew that it was dumped on the power station in Chernobyl after the accident). The fact that a few groups also mentioned materials like polystyrene foam and foam rubber seems to be triggered by their knowledge about insulation materials in general.

In their building plans all groups wanted to insulate the stones. Again, lead was mentioned most often, but also bricks and, again, polystyrene foam and foam rubber. Some groups had also written in their plan to measure with a Geiger counter. But also the other groups must have had this in mind. For when the plans were carried out, a Geiger counter was always used, without further comment by anyone (this is again a clue that the pupils accepted the agreed criterion to establish whether or not something stands in the radiation emitted by some radioactive object). When the plans were carried out, a little figure was used to represent the people living in the neighbourhood of the 'power station.'

By carrying out the various building plans, testing the various suggested materials etc, both classes managed to build a 'nuclear power station' that satisfactorily met the requirement that outside no radiation could be measured, e.g.: a 'power station' in which the radioactive stones were first shielded by some layers of lead which in turn were surrounded by some bricks. The conclusions were accordingly, e.g.: "the thicker you wrap it up with the right materials, the less radiation gets through;" "lead and stone break down radioactive radiation."

Coming to recognize the problem by acting in the classroom-situation

Subsequently the teacher focused pupils' attention on the theme of section 2-3 of the textbook (Accidents with nuclear power plants), usually by pointing out that while they now have built a 'power station' such that outside no radiation is measured, there have occurred accidents with nuclear power stations such that quite some distance away radiation could be measured. If possible, the teacher also linked up with earlier remarks of pupils, e.g. the one that "if we rather had taken that shoe and had taken off that plastic bag and then… for instance wind machine, then that radioactive radiation would in fact have reached that device," or the remark that a pupils made towards the end of the 'building'-task: "Does that radiation… all that radiation, does it have a velocity or something like that? Just like… when that nuclear power station in Chernobyl exploded, it took some time before it was in the Netherlands."

After reading some further information on the Chernobyl accident, the groups were then set to work on tasks 5 and 6, in which they were asked to say how it could have come about that after the accident more radiation than normal was measured in the Netherlands and that some fresh products had become radioactive (tasks 5a and 5b, respectively), and to devise plans to bring about similar such consequences with the material present in the classroom (tasks 6a and 6b). In devising such plans, the groups indeed seemed to be guided by what they knew about the Chernobyl accident (as the below examples may illustrate). Furthermore, most answers could be interpreted as being of the following kind: because of the explosion in the power station some radiation* escaped; the wind carried some of the radiation* towards the Netherlands; the fresh vegetables came to contain radiation*, etc. An example of an answer that may be thus interpreted is the next one (of Julius' group).

5a: the wind and the rain had carried the radioactive radiation along
5b: the radioactive radiation was inside the rain, which came on the vegetables and on the grass
6a: then the reactor would have to be open and there would have to be wind towards that direction
6b: lay the apple up against it, or spray radioactive water into the apple

I thus take the proposal to "lay the apple up against it [one of the radioactive stones]" as one to make the apple contain radiation*. I feel strengthened in this because later on one of the pupils in this group added: "I've got something else: in that X-ray machine." In line with this interpretation I understand the group's "radioactive water" as 'water containing radiation*,' just like there was "radioactive radiation inside the rain." When asked how to make "radioactive water," I thus expected that the group's answer would be to lay a radioactive stone up against a beaker of water or to place the beaker in the X-ray machine.[6)] Some answers, however, seem to require a different interpretation, as e.g. the next one (of Luke's group).

5a: the ~~radiation~~ dust particles is carried along with the wind and towards the Netherlands. or with water. (the dust particles are radioactive)
5b: because the wind has been in the vegetables and grass. the cows eat grass so radioactive milk and radioactive vegetables
6a: make a considerable hole in the wall that is close enough to the radioactive source and then produce a strong wind towards the Netherlands
6b: cut the apple in two and make a hollow and close it. (put the source inside)

As the deletion in the first answer may illustrate, this group had actually discussed whether it is radiation or something else that is blown towards the Netherlands by the wind. The result of this discussion was that, since the wind had played an important role and radiation, like light, cannot be blown, it must have been "dust particles [that] are radioactive" that were carried along. So I take this group's proposal to "make a considerable hole in the wall" and to "produce a strong wind towards the Netherlands" as different from Julius' group's proposal that "the reactor would have to be open and there would have to be wind towards that direction." I expected that, whereas for Julius' group it would be sufficient to make a hole and produce some wind, for Luke's group it would also be necessary that particles of the radioactive source itself are able to escape (and that it is for this reason that the group wants a hole in the wall that is "close enough to the radioactive source").

The above already illustrates that it is not always clear, from the groups' written proposals, precisely what experiments they want to carry out, and perhaps the groups themselves were not always clear about that either. How, for instance, does Julius' group think to come by "radioactive water?"; is there indeed any special reason why Luke's group wants the hole in the wall to be "close enough to the radioactive source?"; and how does the group that proposed to "contaminate chalk dust with radioactivity and blow that towards the other side of the classroom with a wind machine" think to "contaminate chalk dust with radioactivity?"

For the time being (i.e., while the groups are working on tasks 5 and 6) such unclarities do not matter very much because, and this brings forward the importance of letting the groups both devise and carry out their own experiments: they will naturally get resolved when the groups are going to carry out their proposals. For then it is in doing what it is doing that e.g. Julius' group will make clear how to come by "radioactive water," or at any rate the group will then be forced to further think about how "radioactive water" can be come by. All that matters for the time being is that from the groups' written proposals the teacher, despite some uncertainties with respect to the

6. If this interpretation is correct, it once more shows that both the a- and b-part of task 6 are required in order that the groups in carrying out their proposals come to appreciate the central problem in the right way (cf sections 7.4.3 and 8.3.4).

details, gets a fair idea about the sort of experiments that the groups want to carry out and about ways to deal with the remaining unclarities. As it was part of my activities during and in between lessons to help the teacher get this fair idea, I can tell that pupils' written proposals indeed served well to get it. At an appropriate time (sometimes during a lesson, sometimes as part of the preparation of the next lesson) the teacher and I took stock of the sorts of proposed experiments, discussed an appropriate order to carry them out, thought about additions that might be suggested by some groups, etc. I then also pointed at cases where tolerance with respect to pupils' use of expressions would be required and cases where the teacher might demand some discipline in their use of expressions. Tolerance is e.g. required concerning the use of the expression 'to contaminate' by the group that wanted to "contaminate chalk dust with radioactivity" -in particular, it should not be assumed that the group uses the expression as a physicist does. The tolerance may, as already noted above, take the form of simply letting the pupils act, i.e., letting them do something that for them is an instance of 'contaminating chalk dust with radioactivity' or letting them say in somewhat more detail what action would for them be an instance of 'contaminating chalk dust with radioactivity.' Discipline may be demanded with respect to expressions on the shared use of which the pupils have already agreed, in particular the expression 'is radioactive.' So if e.g. Julius' group has done what it thinks had to be done to make some water radioactive, the teacher may, if the pupils themselves have not already done so, very well ask to check whether the water has indeed become radioactive in the agreed sense.

Concerning the carrying out of the proposals, I first want to make the general note that it had struck both the teacher and me how very involved most pupils were (and other people also got this impression from watching the videotape). Not only had the groups together produced a rich variety of proposals, but they also followed the various experiments intensively (and not just the ones they themselves had proposed). The group that was carrying out an experiment was sometimes literally directed by the spectators to try this or that. Lots of suggestions for additional experiments were made -some groups were in fact still busy trying out all sorts of things well after the lesson was over. Pupils quieted each other down to be able to listen whether the counter would tick, etc.

All this was very positive, of course, but at the same time it raised a management problem for the teacher: how to deal with it all, how to put and keep the whole thing on the right lines? In the smaller class the teacher did not properly handle this management problem. What went wrong, paradoxically as it may sound, is that the teacher was too involved and got too much carried away by it all. For what happened after the various proposals were listed, was that the list was hardly given attention (and as a consequence several proposals were not carried out). Rather almost every additional proposal that the pupils made was instantly followed, sometimes even before the original proposal was thoroughly carried out. As a consequence hardly any conclusions were explicitly drawn. In particular, conclusions that according to the didactical structure would serve as intermediate steps in pupils' coming to appreciate in the intended way the general problem under which conditions an action does or does not lead to an object's becoming radioactive (cf section 8.4.1) remained implicit, and thus also the problem itself. I might say that the teacher's emphasis was not so much on problem-posing but rather, and more and more so, on problem-solving. Instead of first taking care that the general problem clearly came forward, he rather wanted to pull the specific solutions to tasks 6a and 6b out of the pupils. As a consequence the teacher more and more took over and even began to propose and direct some experiments himself. After the lesson the teacher himself indicated to be dissatisfied over this, when he said that he had tried to pull too much out of the pupils too soon (in ten Voorde's terms: his anticipation tension had been too high; cf section 7.4.3).

As part of the preparation of the matching lesson in the larger class the teacher and I talked over possible means to properly handle the management problem in the spirit of the didactical structure. The main point was that the teacher's control should be of a procedural nature: he should not so much make contributions with respect to content, but provide the opportunities for an ordered process in which the groups can do what they want to do as long as it is clear to everybody what is going to be done. Some concrete points the teacher and I agreed on were:

- list all the proposals (on the blackboard);
- think of an appropriate order to let them be carried out;
- stick to this list;
- make sure everybody knows which experiment is carried out and why (let, if necessary, the group that is going to carry out give a further explanation to the rest);
- try to so arrange it such that most groups get to carry out an experiment;
- take notice of suggestions for additional experiments, but do not instantly follow them (think of an appropriate time to let them be carried out; if necessary, add them to the list on the blackboard; when it is going to be carried out, make sure that everybody knows why; etc);
- build in a break at the end of each performed experiment, during which the pupils are to briefly note down what experiment has just been performed and what has happened.

In the larger class the teacher managed (as he himself said after the lesson: by making a very conscious effort) to keep a low profile with respect to content and to mainly focus on procedural control along the above lines.

I have already mentioned that in all observed classes the groups had together produced a rich variety of proposals: break their 'power station;' cause a draught from 'Chernobyl' towards 'the Netherlands;' make it 'rain' above 'the Netherlands;' lay the apple up against a radioactive stone for a while; put the apple in the X-ray machine; put one of the stones inside the apple, etc. Furthermore, a Geiger counter was always self-evidently used to check whether their plans did indeed bring about what they were asked to bring about -whether as a result of their actions it did start ticking at a more than normal rate in 'the Netherlands' or near the apple. Moreover, the Geiger counter was accepted as an arbitrator: if it clearly did not start ticking at a more than normal rate near e.g. the apple, the apple had not become radioactive.

Usually also several suggestions for additional experiments were made, which were triggered by the results of those experiments. In fact, in some classes some of the above mentioned proposals were only brought forward after earlier proposals had not lead to the desired outcome. In one class, for instance, after an experiment had been performed that pupils described as something like "power station broken, fan on" and on whose result they noted down something like "nothing happened at all" or "nothing happened to the amount of radiation in the Netherlands," it was then proposed to also make it 'rain' (by sprinkling some water) above 'the Netherlands.' And sometimes the experiment that was concluded with something like "put the apple near a radioactive stone → it doesn't work, it doesn't become radioactive," was then followed by a suggestion to put the apple in the X-ray machine. But also some new suggestions were made. After the brief reflection on the previous experiment (e.g.: "apple in X-ray, not radioactive"), in one class it was proposed to first cut the apple in two and then put it in the X-ray machine. Probably all such additions were made for the reason to now bring about the desired outcome, which the previous proposals had not produced.

In some classes even more experiments could have been done than actually had been done. After several experiments on the apple had been performed, which were all of the 'making an apple stand in radiation'-kind, one pupil e.g. concluded that "an apple is a kind of fruit that cannot become radioactive." If this conclusion had not been passed, it would quite naturally have given rise to the proposal to find out whether, by applying the same sorts of method that did not make the apple radioactive, other kinds of fruit or, more generally, other objects than apples can in fact be made radioactive. It might have been useful that this proposal had actually been carried out. For it would then have been found that also the other objects cannot be made radioactive by applying the same sorts of method. And since it obviously is absurd to conclude that no objects can be made radioactive, it would then have been natural to try to account for the failures in terms of something in the applied methods and to look for something that the applied methods have in common. The following might thus more easily have come forward: the recognition that the applied methods were all of the type 'making an object stand in radiation,' and the formulation of the general statement that something cannot be made radioactive by making it stand in radiation. The latter generalization, moreover, once established, would then at the same time have been established more firmly because by then it could be seen as supported by more instances.

The strategy just mentioned, of letting pupils actually carry out several experiments that are all of the same type, is not only useful for the just given reasons: that thus they will more easily be able to conjecture an appropriate generalization, and conjecture it more confidently. The strategy is also useful to make the pupils note down what actually happened in an experiment when what happened was not in line with their expectations. For sometimes, and especially after the first experiment was performed, some pupils noted down that in the experiment the Geiger counter had "reacted a little bit" or "ticked a little bit more [than it normally does]." After additional experiments such conclusions usually were implicitly rectified, e.g.: after the experiment "power station broken, fan on" it was noted down that "he reacted a little bit", after the additional experiment "exactly the same set-up, with rain" that "it doesn't work either," in which it is implicitly acknowledged that the first proposal too had in fact not worked. So letting the pupils carry out several experiments that are all of the same kind and all lead to the same unwanted and initially unexpected result, is also of use to help the pupils in facing, and stating, the facts as they are.

I hope that from the above it has become sufficiently clear that what pupils noted down concerning the performed experiments are indeed the sorts of thing that according to the didactical structure would serve as intermediate steps in their coming to appreciate in the intended way the general problem which kinds of action lead to an object's becoming radioactive and which do not.

In the classes in which the teacher's emphasis was on problem-posing, this kind of general problem did indeed come forward. The way in which, and the stage at which, it did come forward, however, varied from class to class and also within one class there were differences between (groups of) pupils. In one class the pupils were asked to formulate a kind of overall-conclusion after all the experiments had been carried out. And in the discussion of those conclusions -e.g.: "The stone cannot make the apple radioactive, but Chernobyl can. How's that?;" "If Chernobyl can actually make the shoe radioactive, why can't we make the apple radioactive with the stone or the X-ray machine?"- the general question how things can be made radioactive came forward, which was then asked open-mindedly and in accordance with the agreements made earlier. In this class most proposals seemed to have been carried out with the intention to show that they would lead to the desired result. In another class some pupils already quite early, after just a few experiments had not lead to the desired result, took on an hypothetical attitude and open-mindedly suggested some kind of systematic investigation in something like[7)] the following terms: well, I really wouldn't bet my life on any of those [proposals] any longer; let's just try them all out and see what will make that thing tick. In yet another class some pupils, who already in devising their proposals had discussed such things as whether it was radiation or something else that was blown, consequently looked upon the experiments as means to get answers to general questions like 'Can radiation be blown by the wind?' and 'Can something be made radioactive with radiation?'

It does not matter that the way in which, and the stage at which, the appropriate kind of general problem comes forward will differ from class to class and, within one class, from group to group. I would e.g. not call one of the above ways better or more suitable than the others: it's just that in this class or for this group of pupils it did come forward in this way or at this stage and in that class or for that group in that way or at that stage. All that matters is that it does come forward in one way or another, and not just for one or two pupils. And for that to happen, the activity in the course of which the problem is to come forward must be such that, if appropriately guided by the teacher (i.e., in a problem-posing manner), it is not very sensitive to exactly what is done in the course of it (e.g. exactly which experiments are being carried out), as long as what is done in the course of it is sufficiently rich (as long as e.g. a rich enough variety of experiments is being carried out). Furthermore the activity must not be very sensitive to exactly when (groups of) pupils come to formulate the problem. So in case some pupils quite early

7. The following is not a literal quote. It is based on a note I made in one of the classes in which no recordings were made.

take on an hypothetical attitude, the sequel of the activity must still be worthwhile for them (and the pupils they have 'infected' with their hypothetical attitude) as well as for the other pupils. I hope to have made clear that the activity discussed above sufficiently met these requirements. Both for the pupils who had not (yet) taken on an hypothetical attitude and for those who had it was e.g. worthwhile to do more experiments: for the former to show that the new experiments will lead to the desired result; for the latter to open-mindedly and somewhat systematically find answers to the general problem.

Apart from the way in which the problem did come forward, the final results of the above activity also differed in the different classes. In one class it ended with the formulation of the general problem. Another class already arrived at substantial contributions to its solution. There the experiment in which a radioactive stone was put into an apple that had been hollowed out gave rise to the suggestion that something similar might have happened in the Chernobyl-case: (parts of) the source might have arrived on or in the fresh products in the Netherlands.[8)] It was not always the case, however, that possible contributions to the solution of the problem were recognized as such. In yet another class, for instance, after several experiments on their 'power station' had been performed, none of which had lead to the counter's ticking at a higher rate in 'the Netherlands,' one pupil, as if to relieve his frustration by means of a joke, picked up the piece of cardboard with the radioactive stone on it, carried it along and put it down in 'the Netherlands.' Even though this made the Geiger counter tick, it did not ring a bell for the pupils.

Again, the fact that the final results of the above activity differed in the different classes does not matter. For in each class the final result was such that it could be meaningfully further built on in the sequel, though in each class in a somewhat different way, of course.

9.4 From ground level to qualitative descriptive level

9.4.1 Finding some general statements by looking back at how the problem has come about

The point of chapter 3 of the textbook was that, by studying the three applications treated in there (food irradiation, sterilization of syringes, radiation treatment of cancer), answering the questions about them and, if they thought that might help them in answering the questions, carrying out experiments, the groups would come to explicitly formulate the following general statements:

- by means of irradiation organisms or cells can be killed;
- an object does not become radioactive by irradiation.

It was expected, moreover, that their explicit formulation of the first general statement would not be problematic at all. The discussion of the a-parts of the questions (What is

8. It also gave rise to an agreement concerning the term 'is contaminated,' and, as expected, to the protest that "then you can make everything radioactive: hollow them all out" and the question "how then has the stone become radioactive?"

the aim of …?) indeed came up to this expectation. After the discussion of task 1, for instance, in one class the teacher began the discussion of task 2 as follows.

> Teacher: If you now once more look at those a-questions, right, that 1a, 2a and 3a…
> Aaron: That are really all the same…
> Teacher: Yes. Why, then, are it all the same things?
> Aaron: Because the point is always… will kill bacteria… so to…
> Teacher: So the point is always to kill… bacteria, mould, cells, isn't it. We have got that right, haven't we, because I do not know much about it. But to kill mould, bacteria, cells, that's what the point always is. Shall we from now on just skip question a? For it is always the same.
> [The pupils agreed. Almost all of them had indeed already written down uniform answers to the a-parts of questions 2 and 3. That is, answers that were all of the kind "to kill …," "to counteract …," or "to make disappear …," and that differed only with respect to what replaced the dots.]

Concerning the second general statement above it was expected that the groups' coming to explicitly formulate it would be guided by the order in and the formulation of the tasks. First of all, it was expected that they would, for each application, understand the b-part of the question as a variation on the question whether or not something has become radioactive. Furthermore it was expected that, since the first application (irradiation of food) is so similar to some of the things they had done in the preceding to make the apple radioactive, the pupils would be strongly tempted to use here what they had found there, and that, once this generalizing step was taken concerning the first application, they would also be more inclined to do the same concerning the other two applications. The temptation and inclination, finally, were expected to be further triggered when, in thinking of ways to imitate the applications, they would notice that those imitations (and, again, especially the one corresponding to irradiation of food) are rather similar to some of the things they had done when trying to make the apple radioactive.

Below I try to say why the evaluation concerning pupils' arrival at an explicit formulation of the second general statement above amounted to a modification of the didactical structure. And in line with the procedure outlined in 9.2.2, also in this case the main line of the didactical structure was not questioned: it was still assumed that it would be desirable that the pupils would come to explicitly formulate the general statement. Rather it was tried to reformulate the tasks and to give an account why it is reasonable to expect that the reformulated tasks will not give rise to the problems that made the modification necessary. The need for the modification clearly came forward in the larger class.

But before discussing the problems in the larger class that gave rise to the modification, I first briefly discuss what happened in the smaller one. None of the groups wanted to stick the radioactivity-sign on irradiated food, because "that sticker means that the food is radioactively contaminated" and "the food is not radioactive." None of the groups agreed with the statement that a patient gets irradiated a bit by an irradiated hypodermic needle. Some groups already explicitly used the general statement in their answers, e.g.:

"the needles are being irradiated and if something is irradiated it is not radioactive." Only one group found that, when taking care of irradiated patients, the nurses need to wear lead aprons, because "the tumour has absorbed radiation, and emits that." In the discussion of the task, however, this answer was immediately withdrawn.

Teacher:	But now b. Does that nurse […], does she have to wear a lead apron because she's standing near that bed all the time, near that irradiated patient?
Peter:	Yes.
?:	No.
Peter:	[As if suddenly struck:] What?! No. Oh! No, no, no, no, no.
Teacher:	What? Peter, read aloud…
Peter:	No.
Teacher:	…for now you are just saying something. Read aloud.
Peter:	[As if ashamed:] Are needed, because the tumour has absorbed radiation and emits that. But…
Teacher:	But are you going to cross that out now?
Peter:	Yes, because…
Teacher:	What are you going to write down? Luke, what do you think is Peter going to write down there?
Luke:	That it is not needed and… because he is not radioactive.
Julius:	[Julius is a group mate of Peter.] If he is irradiated, he is not radioactive.

I now address the problems in the larger class, and argue why it is reasonable to assume that it were unclarities in the formulations of the tasks that delayed pupils' arrival at the second general statement above. In this class the tasks of chapter 3 of the textbook were given as homework. I now first summarize the answers. Fifteen pupils had answered the question whether or not a sticker with the 'radioactivity-sign' should be used on irradiated food. Ten pupils had answered that the sticker should not be stuck on irradiated food. Four of them for the reason that the sticker doesn't clearly show that the food is irradiated, e.g.: "such a thing doesn't attract attention and besides nobody knows what a sign like that means." The other six indicate that "people" will draw all sorts of conclusions from the sticker, e.g.: "it will deter people and then they won't buy it." Four pupils had answered that the sticker should be stuck on irradiated food in order to indicate that the food is irradiated, because "people may want to eat food that is not irradiated" or because "that is the sign of radiation and then one knows that it is irradiated to make it keep longer." One pupil, finally, indicates that with some imagination one could see the sign as a representation of the room in which the irradiation of food takes place (and of which the textbook contains a drawing): "the circle the source, the things around it the food." So many pupils had not used in their answer that the sign stands for 'is radioactive.' Rather some of them had seen it as some sort of dummy symbol that is therefore not useful because it does not give any information. Others seem to have plainly accepted it as a sign for 'is irradiated,' and have thus found it useful.

The important thing, however, is that none of the pupils seems to have understood this question as a variation on the question whether or not irradiated food is radioactive. The question had thus not challenged the pupils to think about the question whether irradiated food is radioactive. Consequently it cannot be said whether, if they had thought about it, they would have used here what they had found in the preceding, when they tried to make the apple radioactive.

With regards to the question on the hypodermic needles, there was the same sort of problem: the task had not challenged the pupils to think about the question whether or not irradiated hypodermic needles are radioactive. Let me first of all repeat the task.

> Joke says: "I simply do not understand that they irradiate syringes. It may well be that a patient does not get infections since the bacteria are killed. But the patient does get irradiated a bit by the syringe. And that too isn't really healthy, is it?"
> We *do* / *do not* agree with Joke, because..

Fourteen pupils had answered this question, ten of them did not agree with Joke, two of them did agree with her and two pupils took up some sort of intermediate position. But no matter whether or not they did agree with Joke, I think all of them really agreed with each other, namely on something like: receiving just a little bit of radiation will not do much harm, but receiving much may. The pupils who did not agree with Joke focused on the first part, e.g.: "a human being can surely stand such a little bit of radiation;" those who disagreed with Joke focused on the second part, e.g.: "if every day you have 3 injections (the rest of your life) you get additional symptoms;" those who took up an intermediate position disagreed with Joke "as long as it does not happen too often." So the task was unclear as to what pupils were to agree or disagree on. They seem to have reacted to the last sentence of what Joke said (And that too isn't really healthy, is it?), and not, as intended, to the sentence before the last one (But the patient does get irradiated a bit by the syringe). They simply seem to have taken for granted that the patient does get irradiated a bit by the syringe, and have thought about whether that will do much harm. Now, of course, someone who is in command of the second general statement above cannot take for granted that a patient gets irradiated by an irradiated syringe. In fact, not taking that for granted is a sign of being in command of the general statement. The above question, however, was not directed at someone who is well in command of the general statement but was, conversely, meant as a contribution to pupils' arrival at the general statement. And viewed in that light it did not clearly enough direct pupils' attention to what they were to agree or disagree with.

Again it cannot be said whether, if they had thought about the question whether or not irradiated hypodermic needles are radioactive, the pupils would have used here what they had found in the preceding, when they tried to make the apple radioactive. I do think, however, that the inclination to take this generalizing step would then still have been decreased by the fact that concerning the first application (irradiation of food) they had not already taken a similar step. If such a step had been taken there, that might perhaps also have contributed to their understanding the task, despite its unclarity, as asking whether or not irradiated hypodermic needles are radioactive. That is, that might have helped them in appreciating that the needles too, like the apple in some of their own experiments and the food in the first application, are only irradiated. It might have made the information that the needles were irradiated a relevant piece of information (as it probably had been for the pupils in the smaller class). In fact, viewing that piece of information as a relevant piece of information is part of the generalizing step that the pupils were expected to take. But given that their thinking about the previous application had not resulted in such a step, it will then also not have made them appreciate the relevance of a piece of information of that kind. And consequently it will also not have made them more inclined to take a generalizing step now.

With regards to the question on the irradiated patients the situation was somewhat different. This question actually seems to have challenged four pupils to think about the question whether or not the patients are radioactive (emit radiation) -i.e., about the question whether or not patients *who are only irradiated* emit radiation. They did not find that lead aprons are needed when taking care of irradiated patients, e.g. because "you no longer can get irradiated" or because "they absorb the radiation, but do not give it off." For the other nine pupils who had answered the question, however, it seems that the same sort of comments can be made as above (concerning the irradiated syringes). I believe they had not actually thought about the question whether or not patients *who are only irradiated* emit radiation, but rather had simply taken for granted that the patients do emit a bit of radiation. What they had thought about was whether that will do much harm to the nurses. Their conclusion was that it might (e.g.: "if they are standing in the ward the whole day they will catch much too much radiation;" "too much radiation is not good (from several patients)"), and that therefore lead aprons are needed. For them the information that the patients were irradiated had not served as a relevant piece of information.

Finally, I think it is reasonable to assume that the pupils had not thought of ways to imitate the applications, which was expected to further trigger the temptation and inclination to take generalizing steps. First of all, the pupils were not asked to think of imitations in the tasks on the applications themselves. Rather, at the end of the introduction to chapter 3 (section 3-1 of the textbook), they were invited to carry out experiments:

> Read the next sections and do the exercises.
> If you find it necessary to perform experiments, you can do so. But do consult the teacher before you start.

Secondly, because the pupils worked on the exercises of the next sections (in which the three applications were successively treated) at home, there was not much to experiment.

I hope the above suffices to illustrate the problems in the larger class, and that these problems prevented that the pupils took the required generalizing steps. This is also how I analyzed the situation when, at the beginning of the lesson, the pupils had to gear their answers to those of their group mates, and from walking around I got an impression of the sorts of answers they had given. In order to set the required process of generalization in motion, I then advised the teacher to begin the discussion on the task whether or not the radioactivity-sign should be used on irradiated food with the question what that sign really stands for, as a means to get them thinking about the question whether irradiated food is radioactive. It could then be seen whether they would then use what they had found when they tried to make the apple radioactive, i.e. whether they would take the first generalizing step, and whether, once this first step had been taken concerning the application in which it was most likely that they would take it, they would take similar steps concerning the other two applications. It turned out that by this move the process was indeed set in motion.

The experiences in the larger class have lead us to the following suggestions for adjustments to the didactical structure:
- better challenge the pupils to think about the question whether or not irradiated food is radioactive, for this is to trigger the whole generalizing process;
- challenge them more directly to think of ways to imitate the applications, for this may further trigger the temptation and inclination to take generalizing steps;
- replace the formulations that, because of their ambiguity, hindered pupils' arrival at the general statement by formulations that more clearly focus pupils' attention in the desired direction.

The first suggestion was further worked out by adding a task in chapter 1 of the textbook and adjusting the task on irradiation of food. The point of the additional task, to be fitted in after task 6 of chapter 1 (cf section 8.3.2), is to explicitly focus pupils' attention on the radioactivity-sign. The task reads as follows.

> **A sign to indicate whether something is radioactive**
> On objects that are radioactive this has to be indicated.
> All countries have agreed to use a sign for that. (See alongside.)
> So that sign has to be used on radioactive objects.
> But it is not allowed on objects that are not radioactive.
> a Which of the objects in the classroom carry that sign?
> b Which of them carry it rightly?
> c Which of the objects really ought to carry the sign too?

In order to challenge the pupils to actually think about the question whether or not irradiated food is radioactive, in the task on irradiation of food the following question was added (with a reference back to the above task of chapter 1): On what kind of objects must a sticker with that sign be stuck?

In order to challenge them more directly to think of ways to imitate the applications, the following was simply added to the tasks on each of the applications: Note down an experiment that can be carried out in the classroom and that imitates this application. Carry the experiment out if you think that will help you to answer the below questions. But do consult the teacher first.

Concerning the reformulations of the tasks I just give one example. In order to more clearly direct pupils' attention to what they were to agree or disagree on, the old formulation of the task on the hypodermic needles (We *do* / *do not* agree with Joke, because…) was replaced by: Joke says that a patient gets irradiated by an irradiated needle. We *do* / *do not* agree with that, because…

With these adjustments, the problems that occurred in the larger class did not return the next year. Rather things then went as they had gone in the smaller class. The required generalizing steps were then taken by nearly all groups, and some of them already used the general statement in their answers quite explicitly. And the solitary group, or pupil within a group, that had not taken the generalizing step concerning some application, needed just one or two words to take it (like Peter in the smaller class).

9.4.2 Solving the problem by finding more general statements

Tackling the problem

Since the final result of the activity in which the problem had come forward varied from class to class, the starting point for the present activity varied accordingly. Whereas in some classes the problem was already nearly solved, in other classes or for some groups of pupils within a class it still stood open. In the former cases the task how some fishes in the Irish Sea could have become radioactive (cf section 8.4.2) was rather an easy exercise. But the main point is that in the latter cases the task turned out to be very useful. In fact, most groups almost immediately saw their answer to this task (e.g.: "the fishes have eaten the radioactive waste;" "the bits stick to the fishes") also as a contribution to the question how e.g. the 'Chernobyl-shoe' might have become radioactive. For some groups, however, it was really a two-step process. They could understand how the fishes might have become radioactive: they might have eaten (bits of) the radioactive material. But then, so they would begin the second step, what about the shoe: it cannot eat, can it? It would then usually not take a long time before they finished the second step by noting that the 'eating-part' of the story is not very essential: all that matters is that the shoe had somehow got (bits of) radioactive material on or in it. In order to let the pupils, at least implicitly, use the generalization that an object becomes radioactive by putting radioactive material in or on it, and in order to make them explicitly realize that they have solved their problem, the teacher usually also asked them to have a second look at task 5 and/or task 6. The pupils then were indeed able to say, e.g., why their attempts to make it the case that more radiation is measured in 'the Netherlands' had not worked.

Explicit formulation of generalizations

The task in which the pupils were asked to form true statements containing two of the terms 'radiation,' 'radioactive,' 'radioactive material,' 'contaminated' or 'irradiated' did indeed challenge them to explicitly state the sorts of general statement they had, at least implicitly, used in the preceding.

What I think is still lacking here, and what I now[9] propose as an addition to the didactical structure, is a task in which the pupils come to explicitly recognize that their use of words like 'radioactive,' 'contaminated' and 'irradiated' has changed as compared to the beginning of the series of lessons, and once more come to explicitly state the agreements that have been made concerning the use of such words. In the present didactical structure these things remain pretty much implicit. Given that at the

9. As I have already noted, thinking about improvements of the didactical structure is still going on today.

beginning of the series of lessons pupils already used words like 'radioactive,' 'contaminated' and 'irradiated' (as I have illustrated towards the beginning of section 9.3.2), a task that might lead to the desired explicit recognition and statements suggests itself: make the pupils compare their then use of such words with their present use.

9.4.3 Getting at home in the established system of generalizations

The aim of chapters 4 and 5 of the textbook was to gradually make the groups feel even better at home in the system of generalizations and, to some extent, add to it. This was tried by challenging them, and more and more indirectly so, to apply the relevant generalizations in order to give explanations or to make predictions concerning some new situations. From the fact that they were e.g. largely able to base their judgement as to whether and which protection measures are needed in a particular situation on a sound analysis of that situation in the relevant terms ('contaminate,' 'irradiate,' etc), even when the situations themselves were not formulated in these terms, it can be concluded that indeed they did begin to get rather well at home in the system of generalizations. Sometimes this was also indicated somewhat more explicitly. Some groups, for instance, had in the summary of chapter 4, under the heading 'Important to remember,' noted down something like "What the difference is between contaminated and irradiated." At least for these groups the difference must have become clearer or more relevant than at the end of chapter 3 of the textbook.

Instead of discussing in more detail the groups' answers to the tasks of chapters 4 and 5, I will now rather give some other examples from which it may become clear that the pupils began to feel at home in the system of generalizations. The examples concern new situations that were not brought up by the textbook, but were brought up by a pupil in the form of a question. In the discussion of that question it can be noticed that pupils - some of them immediately, others after some hesitation and with some guidance by the teacher- begin to apply what they have learnt before to the new situation in order to answer the question. Both of the examples took place during the discussion of the tasks of chapter 3 and the last task of chapter 2 (i.e., before the task in which the pupils were challenged to explicitly state generalizations).

The first example relates to a story that a pupil (Aaron) had read in Reader's Digest. The story was about a Soviet pilot that "had flown about six times over the nuclear core [of the exploded power station in Chernobyl]" and "later died of leukaemia." (Recall that the pupils were asked to collect articles on the topic of radioactivity. The teacher would then usually ask a pupil who had found such an article to tell something about it.) While telling the rest of the class about this pilot, Aaron had said, among other things: "First they wanted with military airplanes to just pour sand on it, on the core, but that did not work because… They wanted to smother that thing, that core, but that didn't work because nucl… radioactive substances kept coming out, or something like that." Later on, another pupil came back on this:

Melvin:	Why did it say there a while ago… that there… with sand, or something like that, that they wanted to let it smother, or so, that core… in that book [points to Aaron's Reader's Digest].
Teacher:	Yes.

Melvin: Well, how can that be?
?: Yes, we just have…
Lawrence: Yes, it will no longer blow away then, that…
Teacher: Yeah. Why was that? Do you [Aaron] still know? In order to let it smother? Is it to make that hot core…
Aaron: Yes, for what else?
Teacher: …smother?
Lawrence: No.
Peter: Because there [unintelligible] no longer goes through.
Melvin: No, because you can never put it out.
[There follows a brief exchange, the conclusion of which is that the sand was not poured on the core to put the fire out.]
Teacher: But why then do we still pour sand on it? And I believe I have already heard the answer.
Peter: In order that the radiation… [in his hurry to correct himself, he begins to stutter] radioactive-ive…
Melvin: [joking] Radioactive-ive-ive…
Teacher: [to Peter] Yes. [to Melvin] No.
Peter: …substance no longer can… let escape from it.
[The teacher and several pupils are speaking at the same time.]
Teacher: That the substance can no longer get out, that the particles… that the substance can no longer get out. And for the people living nearby. Would that make some difference?
?: No.
?: Yes.
?: Less radiation gets through it.
[Several pupils are speaking at the same time. The teacher interrupts them. He reminds the pupils of the experiments they performed when they tried to build their own 'nuclear power station.' The conclusion is that radiation goes through sand.]
Teacher: Now, does it make sense to pour something on it or does it *not* make sense to pour something on it?
[Several pupils are speaking at the same time.]
Julius: If you do it with lead, it does.
Lawrence: But if you pour sand on it, it does not make that much sense. It just has the advantage that there is no further contamination.
Melvin: And why then didn't it work?
Luke: Too little sand.
?: Yes, then you would have to have another helicopter pilot that did not die.
Teacher: I thought there was also a little story in… Page 32. Why do I want you to cast a glance at page 32? […] I look at the biggest letters on 32.
?: Bombardment with sand and lead on power station in Chernobyl.
Teacher: We are still going to talk about it. Agreed?

The discussion thus also allowed the teacher to give a preview at chapter 4. Again it is likely that this will have contributed to pupils' increased appreciation of the coherence in the series of lessons.

Although the teacher had not done so explicitly, also at the end of the discussion given in the next example there was the opportunity to give a preview at chapter 4 of the textbook. The example begins with a pupil (Peter) who had watched and videotaped a documentary on the Chernobyl accident. (The class watched the videotape at the end of the series of lessons.)

Peter:	But what in that film they also did with those people, right, they did push such a stick in their stomach, then they did some measuring, didn't they.
Teacher:	Right.
Peter:	Now what are they doing that for?
Lawrence:	In their stomach?
Peter:	Yes. Well, they had to… here… such a thing… then they had to sit right like this [he gestures how "such a thing" was held near the gastric region of "those people"].
Lawrence:	Oh, yes. Yes, I see. I see, I see.
Teacher:	And then they did some measuring with that thing [points at a Geiger counter]?
Peter:	A thing like that, right, but much bigger.
Teacher:	And what did they measure then?
Lawrence:	Well, that they don't…
Teacher:	What does that thing measure?
Peter:	Well, the radioactivity.
Teacher:	Right. So what do they measure?
Peter:	Whether they are radioactive.
Teacher:	Right. And where in the body would that pile up? Look, because…
Peter:	Oh, it is inside the stomach…
[The teacher and several pupils are speaking at the same time.]	
Peter:	…because maybe they eat radioactively contaminated food.

The teacher might have given a preview by noting that in chapter 4 the question will be treated whether there is still something that can be done when someone has got contaminated.

9.5 The extension in quantitative direction and the transition to theoretical level

I have already said that the extension of the descriptive level in quantitative direction and the transition from descriptive level to theoretical level were evaluated more loosely. In fact, the evaluation of these parts did not go much beyond the global impression I gathered during the series of lessons as to whether the sort of things the pupils did say and do could indeed be interpreted as more or less in line with what they were, according to the didactical structure, expected to say and do. And this global impression was, as I have already noted as well, that the didactical structure concerning these parts did indeed serve as a valuable guideline and on the whole seemed good enough.

Below I mainly indicate why I have not felt the need to also further evaluate these parts in somewhat more detail, as had been done for the preparatory period and the transition from ground level to qualitative descriptive level.

I do not see much worth in a detailed evaluation of the extension of the descriptive level in quantitative direction, precisely for the reason that indeed it is an extension -a rather straightforward continuation of the process that had already been set on the right tracks in the preceding. This 'setting on the right tracks' deserves most attention, because it is the hardest and most interesting part of the educational challenge. It is harder and more interesting anyway than keeping the process on the right tracks, once it has been properly set in motion. Indeed, the parts of the didactical structure that correspond to the later stages of the transition from ground level to qualitative descriptive and to the extension of the descriptive level in quantitative direction had been relatively easy to construct (given that we also wanted to treat protection measures, effects, and further applications).

If a further evaluation of the extension in quantitative direction had been carried out, it would without doubt have lead to e.g. somewhat better formulations of some tasks. I think, however, that such modifications would have been rather minor and thus not worth all the trouble. But of course I may be wrong.

I do not see much worth in a detailed evaluation of the transition from descriptive level to theoretical level either. The main reason is, in line with the expectations presented in section 8.6, that there really was not much to evaluate. Of course I could further evaluate pupils' difficulties with mastering the nuclear model that, according to the examination syllabus, they had to know. I could also mention that initially it was very confusing for them that all at once everything was 'particles:' radiation consists of particles, which are shot away by a particle that in turn consists of particles and around which circle yet other particles, and so on. But the most important thing to note is that pupils' mastery of the nuclear model was and remained pretty much an activity in itself, which, on the one hand, demanded pretty much of them but which, on the other, most of them also seemed to like. The link with the preceding, the model's function in answering unanswered questions, did not really come forward, probably because of the mismatch between that model and the theoretical need induced by the unanswered questions (cf section 8.6). So there was not really a transition, but rather an isolated activity.

On the basis of such experiences, the teacher has decided for a different way to round off the series of lessons. What has remained the same is that the pupils are given the task to collect all the questions that have arisen in the preceding. Below I have listed examples of such questions.

> Why is there a bag around the shoe?
> Does the meter in the great hall tick as fast as in the classroom?
> Do the rays break down cells?
> Can radioactive radiation glance off at some particular material?
> Does the temperature have got something to do with contamination?
> Does radioactive radiation penetrate glass?
> Is a part of the body radioactive if it has been in an X-ray machine?

Can radiation be inside rain?
How can materials get radioactive?
Why is lead a stopper?
Why does iodine help in case of contamination?
Where have the X rays gone to?
Why is the gas mantle radioactive?
Does radiation get broken down?
Why is it that radioactive particles are radioactive?
Is there a radiation magnet?
Do the cells in the body break down radioactive particles?
Why are there so many cancer patients in Chernobyl?

What has also remained the same is that the pupils are asked whether they can now answer some of the questions and that, if they can, the teacher once more points out that they already have learnt quite a lot about the topic. Concerning the questions that still remain unanswered, however, the teacher's present strategy is different. Depending on what those questions are, the teacher will e.g. go a bit further into one or two of them (in relation to the question 'Why does iodine help in case of contamination?' the teacher may e.g. explain in what way non-radioactive iodine does prevent contamination with radioactive iodine), or may perhaps still find it useful to introduce the 'radiation is nothing but very fast moving particles'-hypothesis in order to answer some of the questions. After a while the teacher then rounds off with the moral that, although they have learnt quite a lot about radioactivity, there still is a lot more to be found out about it: but that is the way things go, physicists too are never finished.

The teacher pushes the treatment of the facts about the nuclear model forward to the training for the examination. Thus it is quite clearly separated from the rest of the series of lessons on radioactivity -as, in fact, it really already was when it was still part of it.

9.6 Pupils' comments on the series of lessons

Below I discuss what 24 pupils (of the smaller and larger class, one pupil was ill at the time) had written in response to the below question(s) after the series of lessons was over.

What I think about this unit

Only a few pupils have worked with this unit. We are therefore very curious about your experiences.

So tell us something about working with this unit. What did you like and what not? What was good about it and what bad? What would according to you have to be improved or changed? Did you learn a lot or not that much? What is the most important thing you have learnt? What did you find unimportant?

Note down below your views about this unit. We will use your comments to improve it.

Global overview

In their response, 13 pupils used the word 'nice' or indicated to have enjoyed it, 9 used the word 'instructive' or indicated to have learnt a lot, 8 used the word 'interesting.' Some pupils did so in the form of a comparison, e.g.: "It does work nicer than an ordinary school book I think;" I think this was a nicer unit than normal." Of the 24 pupils, 21 used at least one of the three key words 'nice,' 'instructive' or 'interesting,' of which 7 pupils used at least two, of which, finally, 2 pupils used all three (e.g.: "On the whole I think was a nice interesting and instructive unit."). Two pupils indicated how their finding it nice, instructive and/or interesting had had a positive influence on their (and other pupils') attitude: "[The unit] simply is terribly nice very interesting you could also tell that by the other boys [this pupil was in the small, all-boy class, KK] we all took part and listened very concentratedly;" "I've got the feeling that with this subject I paid more attention than with other units." Four pupils noted that, as far as they were concerned, there was no need for improvements, e.g.: "I really would not know what had to be changed."

The responses of the 3 pupils who did not use any of the three key words are as follows:

> I think it was important to discuss in a group what we thought and did not have to do this individually. It would have been handier if these tasks that are now in a ring binder had been in a smaller exercise book because such a big ring binder is awkward. I've had enough of it!!! (Dennis)
>
> Too tedious. Sometimes you get fed up with it. I do think it was well done so I do not know many bad things. (Michael)
>
> I sometimes did like working with the class but in a small group it is nicer because then you can better consult. I think the subject matter we have treated was a bit tedious and I don't think much of those postponed questions at all. Nuclei atoms and so on at the end of the unit I did again enjoy. Because then you've got somewhat more to do. (Frank)

Dennis' practical point about the awkwardness of the ring binder, which was also mentioned by two other pupils, has been taken care of: the textbook now has a handier cover. Although Frank would have liked more small group discussions, both he and Dennis make the point that "it was important to discuss in a group." Since also many other pupils made this point, and often did so in relation to why they thought it was nice, instructive and/or interesting, I will come back on it presently. Both Michael and Frank thought it was tedious. An indication of why they thought so might be contained in what the one pupil who wrote that it was not tedious crossed out: "The lessons were not tedious, ~~but if you are going to talk about one small subject too long then it gets boring.~~" So although it is nice to talk about something for a while, if it takes too long you may "get fed up with it," as was the case for Dennis and Michael. Frank did enjoy the end of the unit about "nuclei atoms and so on," probably because that part was more difficult and so gave him "somewhat more to do." Several other pupils also commented on the difficulty of the unit. There were also other pupils who commented on the post-poned questions, which Frank did not think much of at all. On both these points I will come back presently, as well as on the remarks that were made on the textbook itself and on what was the most important thing they have learnt.

Why it was nice, instructive and/or interesting

About half of the pupils wrote, more or less elaborately, that working/discussing in a group was an important feature of the series of lessons that contributed to their finding it nice, instructive and/or interesting, e.g.:

> "You have to kind of find it out yourself with your group, but once you understand it you ever want to find out newer things."
>
> "I find it good to discuss things in a group, you learn a lot from it."
>
> "I think this was a nice unit because you worked a lot with the whole group [probably means: class, KK] and thus different and/or new ideas were suggested."
>
> "I think the disc. were interesting and instructive and also the going more deeply into."
>
> "It was nice to have lessons in this way because it was pleasant to discuss and things like that. You go more deeply into some things until you really knew everything. You noted things down that you did not know and on which you yourself can then later give an answer on the basis of more information. Otherwise you worked more on your own now in a pair or with the whole group that was always pleasant and instructive."
>
> "It was a terribly nice experience because you discuss about something you at first knew nothing or little about and now know quite a lot about. if you had a question you could discuss it with your classmates. sometimes there were several answers and then you answered it when everybody agreed. [...] You could also learn a whole lot from each other. if the one (e. Melvin) knows very much about something and I don't he can explain it and if Melvin didn't know anything about something you can also do it the other way round. so in a group you can put forward your opinions but also your knowledge and thus you learn much more."

So these pupils not only experienced working/discussing in a group as pleasant in itself but also as instructive, probably because it provides the opportunity to learn from each other and to go more deeply into things.

As the pupil that is quoted last, two other pupils claim something like: "I think the unit was interesting, because you find out something about radioactivity, about which before you knew <u>nothing</u> at all." For those three pupils their finding it interesting or nice was stimulated by the fact that they thought they had learnt a lot, which for them was clearly visible because before they "knew almost nothing about it." Another pupil gave another (or additional) reason why it is clearly visible that "from this unit you learn something," namely: "because you don't have as much to do with it as with those things from the other units." So the fact that the topic of radioactivity is somewhat remote, in the sense that you do not have that much to do with it and thus know little or nothing about it, may have made it more easily visible for the pupils that they had learnt something.

Apart from this peculiarity relating to the topic of radioactivity itself and the working/discussing in a group, just a few scattered remarks were made that might count as further explanations of why some pupils thought it was nice, instructive and/or interesting, e.g.: "It was also nice that pupils were allowed to carry out experiments in front of the class;" "At least it is something else than all those experiments with metals and things like that;" "it was a nice subject to close the year with;" "It was also not too difficult."

Difficulty of the unit
Apart from this "It was also not too difficult" several other general remarks were made concerning difficulty: "it was an interesting but difficult subject it also was an extensive subject, lot of work;" "[The unit] is well built up from easy to difficult." One pupil made a comparison with the PLON-material, which contains a unit on radioactivity with the common structure that has been set forth in chapter 3 of this thesis: "I think this was a much better made unit, because I recently had a look at our other physics book and that I found far more difficult."

The other remarks on difficulty concerned specific things that one pupil or another found difficult, e.g.: "some things I did find difficult like: when you have to know a certain substance for a patient;" "I only find that they about those protons neutrons isotope electrons not so clear. It was too difficult to read."

Postponed questions
Six pupils wrote something on the postponed questions (the ones that were stored in the summary under the heading 'Questions we still have to find an answer to'):

> I don't think much of those postponed questions at all. (Frank)
>
> What I did regret is that you have to wait too long for an answer to some questions. Then it is like: just note it down on the yellow page [the summaries were printed on yellow paper] and later on you yourself give a vague answer to it of which in fact you do not really know whether or not it is right. (Iris)
>
> It's just that at the beginning you've got many unanswered questions that only much later get answered, that just makes it hard at the beginning, because you do not know whether your answer is correct. (Mervyn)
>
> You noted things down that you did not know and on which you yourself can then later give an answer on the basis of more information [...] It's just that sometimes I did not quite like it if a question was asked that could not yet be answered. (Melvin)
>
> It was useful to yourself ask your questions and later solve those yourself. (Peter)
>
> It was also nice that you yourself found the answers by thinking logically. (Lawrence)

Mervyn and Melvin brought forward that sometimes it is not nice for pupils, and especially at the beginning may even make it hard for them, that some questions are not immediately answered. This is a point we had not taken into account. It did even more clearly come forward the subsequent year, when in one class the pupils seemed sort of reluctant to ask questions. The teacher had the impression that this was due to the fact that too often when a pupil had asked a question his reaction had been something like: that's a good question, let's all note it down on the yellow page. This might indeed explain the reluctant attitude of the pupils: let's not ask any questions, otherwise we only have to note them down.

Anything that makes pupils reluctant to ask questions should of course be seriously reconsidered, given that it is an essential ingredient of the didactical structure that pupils are challenged to ask questions. In fact, the reason why many tasks also have the function to make pupils ask questions is that this will help them in appreciating the coherence between the various activities. They may e.g. appreciate the coherence between subsequent activities if a question they ask during a particular activity more or less coincides with one of the next tasks or at least makes clear the point of one of the next tasks. In the evaluation of the didactical structure I have given some examples of questions that are likely to have contributed to pupils' appreciation of such a 'local coherence.' The postponed questions, on the other hand, are supposed to give some sort of 'global coherence' -a coherence between activities that are separated much wider (with respect to time, subject, etc). The fact that the above pupils (except Frank and Iris) indicated that the initially postponed question did eventually (be it "only much later") get answered, thus is a sign for their appreciation of the global coherence. Melvin and Lawrence can then be taken to have explicitly stated the coherence, by having noted that the questions got answered "on the basis of more information" and "by thinking logically."

But since storing questions in the summary is not something that pupils really seem to like and may even result in an attitude to no longer ask questions, we have been forced to rethink the activity of postponing questions. As before, in rethinking this we have not cast any doubt on the usefulness (for the above reasons) of postponing some questions. Below I indicate how the teacher nowadays tries to deal with questions.

For one thing, the teacher tries to better explain why, even though they may not like it, it is still inevitable that some questions cannot immediately be answered, and why this is most likely to happen at the beginning: those questions can only be satisfactorily answered once you have learnt enough about the topic. Furthermore, the teacher also tries to postpone questions in other units. Indeed, pupils may thus get used to the phenomenon, and also find out that postponing questions is not an end in itself or a form of parrying questions, when in fact later on they manage to answer (at least some of) those questions. All this may help, of course, and the teacher claims it does. But it is not sufficient. The most important change that the teacher has made, is that he now tries to make a more balanced use of the possibility to postpone questions. First of all, only those questions that can indeed be better dealt with once the pupils have learnt more are candidates of questions to be stored in the summary. The teacher tries, in one way or another, to immediately deal with other questions, e.g.: is uranium expensive? (yes); how does a Geiger counter work? (no idea, but I do not know that of a great many things). Furthermore, the teacher does not actually let store all the candidates. He may also use another method to point at the coherence between various activities, e.g. by concretely showing that a question will be treated further on. And if the teacher thinks it is best to actually store a question, he does not let it automatically store by all pupils. In this way the questions that are actually stored will be more surveyable, not only for the pupils but also for the teacher. The teacher tries to make use of that overview by coming back on a question whenever the time is ripe, in order to prevent Iris' complaint that "you have to wait too long for an answer to some questions." Of course, the question should then also be dealt with satisfactorily and the result should not be "a vague answer to it of which in fact you do not really know whether or not it is right." Only then can pupils, like Peter and Lawrence, come to find it useful or nice "to yourself ask your questions and later solve those yourself."

By finding the right sort of balance along the above lines, the teacher now claims that in recent years the pupils have hardly complained about the usefulness of postponed questions (and certainly have not showed an attitude of no longer asking questions), even though through the years he has grown ever more sensitive to such complaints.

The textbook

Seven pupils made a comment on the textbook itself, or on working with the textbook. Some did so in quite general terms, e.g.: "The textbook was quite nice;" "Everything was well and clearly explained." Some made more specific remarks, e.g. concerning the fact that the textbook mainly consists of tasks: "In some parts of the text were more questions than answer;" "Things are clearly described in the textbook and you can easily look up again the exercises, the answer is there;" "I think it was good that you write it yourself because you can then write in your own words so is easier for yourself." Concerning the tasks themselves, finally, one pupil remarked that they "were easy to understand."

The most important thing

For the sake of completeness I finally mention that two pupils indicated what for them was the most important thing they had learnt. For the one it was "the difference between contaminating and irradiating;" for the other "what radiation really is." The latter pupil also wrote: "I myself wanted to go somewhat more deeply into what β and what γ radiation was (but otherwise you very likely are occupied with this subject for a full year and that's not really necessary either)."

9.7 Conclusions

Let me now summarize what I take to be the major outcomes of the evaluation. I think that on the whole the didactical structure (at least up to and including the extension of the descriptive level in quantitative direction) can be judged as 'good enough.' Concerning the few cases in which what pupils did say and do seemed too far out of line with the sort of things they were expected to say and do, moreover, it was possible to account for the deviation in terms of pupils' not understanding some task or teacher intervention as intended. It was then also possible, on the basis of that account, to so adjust the didactical structure that its main line was not touched and the adjusted didactical structure could reasonably be expected to come out as 'good enough' if it were tried.

Apart from these rather local adjustments, I have also suggested a few improvements that relate to the major aim of a problem-posing approach: to enable pupils to themselves perceive their process of learning science as an internally coherent one with a certain direction, which in important respects is being driven by their own questions and over which they have some control.

It is part of meeting this aim that pupils are provided sufficient opportunities, at appropriate times, for reflection: on what has been done, on what has been established, on the reasons for what is going to happen next, etc. I think that in some respects insufficient opportunities for reflection were built into the didactical structure. What remained very much implicit, for instance, is that pupils' use of words like 'radioactive,' 'contaminated,' and 'irradiated' had undergone a change. Therefore, I have suggested the addition of a reflective activity in which pupils come to explicitly recognize that their use of those words has changed as compared to the beginning of the lesson series. I have also suggested that the beginning and end of a lesson provide suitable opportunities for reflective activities of the kind: what have we done, and why, and what are we going to do next, and why?

I have also noted that a reflective activity should not follow too closely after what is to be reflected upon. In order that pupils come to explicitly recognize that their use of some words has changed, for instance, a reflective activity in which they are to compare their present use of those words with how they used to use them, should be built in when they are already somewhat at home in the new use. Or, to take another example, if the reasons for doing a given task (e.g., select radioactivity-meters out of a collection of measuring devices) are properly prepared by preceding activities (pupils want to reach agreement on whether or not something is radioactive and believe this must be possible; they do not seem to be able to reach it without additional help; they know that some sort of device might provide the desired help), it would be silly to let the pupils, before going to work on the task, explicitly bring forward their reasons for going to work on it. It simply would take the momentum out of the lesson.

It is also in line with the above mentioned general aim of a problem-posing approach, that pupils' questions contribute to it. Recall, for instance, that many tasks had the function to make pupils ask a question that more or less coincides with one of the subsequent tasks or at least makes clear the point of one of the subsequent tasks. Such tasks often functioned as intended, i.e., the intended 'local questions' were indeed often asked by pupils, which will have contributed to their appreciation of a 'local coherence' between subsequent tasks.

It was also expected that pupils would ask questions that cannot appropriately be answered at the time they are asked and also cannot be used to make clear the point of one of the subsequent tasks, but that could be answered further on in the process or make clear the point of tasks far further on in the process. Such questions were expected to contribute to pupils' appreciation of some sort of 'global coherence,' i.e., a coherence between activities that are separated rather widely. It turned out that pupils did indeed ask such questions and that that did indeed contribute to pupils' appreciation of a global coherence. Pupils indicated, for instance, that such questions eventually (be it much later) got answered on the basis of more information. It also turned out, however, that the procedure that was built into the didactical structure in order to deal with such questions, namely to 'postpone' them (to let pupils note them down for the moment in order to later come back on them), was not very stimulating. Pupils indicated, for instance, that it is not nice that they did not always get an answer, especially at the beginning of the series of lessons, when they had quite a lot of questions. In some cases the procedure was even counter-productive, in the sense that pupils were reluctant to ask questions.

So with respect to the procedure of postponing questions a similar remark has to be made as concerning the use of reflective activities: in order that the procedure functions as intended, a balanced use will have to be made of it. I have suggested that the following points are useful for a teacher to bear in mind, in order to find the right sort of balance. First of all, to only take questions that can indeed be answered once the pupils have learnt more as candidates of questions to be stored, and to deal immediately with other questions. Secondly, to not actually let store all the candidates, and to also use other methods to point at the coherence between various activities, e.g.: to concretely show that a question will be treated further on. Thirdly, to not automatically let all pupils note down a question that is worth being stored. In this way the questions that are actually stored will be more surveyable for the pupils. But also for the teacher it will then be easier to keep track of the stored questions and to come back on them whenever the time is ripe.

What has also come forward from the evaluation, I think, is that it would be good to not just plan and evaluate a didactical structure as a class process (as I have done). Indeed, if it is to be expected that the process will proceed somewhat differently for different (groups of) pupils, one will have to appropriately take that into account in the construction of a didactical structure and have to pay special attention to that in its evaluation. As already indicated, I have not systematically done so. Nevertheless it turned out that in some cases the didactical structure appropriately supported a process that proceeded somewhat differently for different (groups of) pupils. So let me now review one of these cases in order to find some clues about how to appropriately anticipate, in the construction of a didactical structure, that the process will proceed somewhat differently for different (groups of) pupils.

The case I have in mind relates to the activity in which pupils were asked to make an apple radioactive. Recall that the point of this activity was that pupils came to see something like the following as a problem worth a further systematic investigation: how things can be made radioactive (and how not). As illustrated in section 9.4.1, this kind of general problem did indeed come forward. The way in which, and the stage at which, it did come forward, however, varied from class to class, and also within one class there were differences between (groups of) pupils. In one class most groups, even though all their proposals to make the apple radioactive failed, seemed to have carried out those proposals to the very end with the intention to bring about the desired result (a radioactive apple). In another class some pupils already quite early, after just a few proposals had not lead to the desired result, took on an hypothetical attitude and open-mindedly suggested some kind of systematic investigation. In yet another class some pupils' proposals already were attempts at a systematic investigation. Furthermore, the final results of the above activity also differed in the different classes. In one class it ended with the formulation of the general problem. Another class already arrived at substantial contributions to its solution. In yet another class, possible contributions to its solution were not yet recognized as such.

It did not matter, however, that the process proceeded differently for different (groups of) pupils in the indicated ways. One reason is that the activity itself, which is basically of the 'devise - carry out - conclude' type, is not very sensitive to these differences as long as it is appropriately managed by the teacher (see section 9.4.1 for the importance of this proper management). It is not very sensitive, for instance, to the intentions with which the various experiments are proposed and carried out, as long as a rich enough variety of experiments is proposed and carried out. Both for the pupils who had not (yet) taken on an hypothetical attitude and for those who had, it was worthwhile to carry out more proposals to make the apple radioactive: for the former to show that the new experiments will lead to the desired result; for the latter to open-mindedly and somewhat systematically find answers to the general problem. The activity is also not very sensitive to when (groups of) pupils come to draw which conclusions or ask which questions. Another reason why it did not matter that the process proceeded differently for different (groups of) pupils, is that the activity was followed by activities that are not very sensitive to its outcomes. The task in which it was asked how fishes in the Irish Sea could have become radioactive, for instance, simply was relatively easy for the pupils who had already arrived at substantial contributions to the solution of the problem, while it was very useful for those who had not yet recognized possible contributions as such or had only arrived at the problem itself.

So a general, and perhaps obvious, suggestion is the following. If there are good reasons to expect that the process will proceed somewhat differently for different (groups of) pupils, one will have to take that into account in the construction of a didactical structure by choosing an appropriate activity (or a sequence of activities) that is not very sensitive to the expected differences. A more concrete suggestion is that suitable such activities may be ones of the type 'devise - carry out - conclude.'

My final conclusion is that the didactical structure that has been evaluated and presented in this chapter and the preceding one, with the suggested adjustments and improvements incorporated in it, is a worthwhile piece of empirically based science educational theory.

10 The teacher's role

10.1 Introduction

In the preceding I have repeatedly pointed at (the importance of) the role of the teacher. In chapter 8 I have noted that the teacher's role in working with a didactical structure as the one outlined there is different from the teacher's role in more traditional approaches. For example, giving pupils more control over, and thus more responsibility for, their progress with respect to content implies a shift in the teacher's control and responsibility: a shift towards procedural control and responsibility for managing the process. In section 7.4.3 I have noted that it also involves a shift from wanting to make pupils say and do particular things (with the associated danger of 'hearing and seeing much more' in what the pupils say and do), towards the teacher's being more prepared to find out what the pupils actually do say, believe, want, etc and to (re)determine his or her goals on the basis of what they actually say, believe, want, etc. In section 7.3 I have noted that even if a didactical structure as such can be judged as 'good enough,' which is the maximum attainable, it still needs the creativity of a good teacher for it to lead to successful education.

In section 7.3 I have also noted that at least the evaluation of a didactical structure should take place in cooperation with the teacher that has worked with it. In section 9.2.1 I have mentioned that I cooperated quite closely and intensively with one teacher. He not only worked with the second version of the didactical structure outlined in chapter 8, but had also worked with the first version, and was involved in the construction and evaluation of both versions. By this cooperation it was tried to secure as well as possible that the teacher had made himself so familiar with the essence of the didactical structure and his role in it that he would not deviate essentially from it.

In this chapter I somewhat elaborate the above themes. But I now first briefly report on some experiences during the first year of my research, which have made me realize that a cooperation with a teacher should be very carefully set up and that it should be set up with a teacher that has good managing qualities.

In the first year of my research I observed two series of lessons in middle ability classes that used the unit *Radiation, you cannot evade it...* (Knoester & Lancel, 1988; cf section 3.3 for some findings of the observations). One of these series was taught by a teacher that possibly was to further participate in my research, and the main aim of my observation of the series of lessons taught by her was to find out whether there was a basis for further cooperation. Before the series of lessons I told her my at that time still very vague ideas about the aim and nature of my research: I wanted the pupils to meaningfully learn about the topic of radioactivity, and for that purpose one should somehow start from pupils' existing knowledge; I later was going to write a series of lessons on the topic myself, and to get some ideas for that I would like her to try out some additional activities while teaching the unit *Radiation, you cannot evade it*.... The teacher then indicated that she was somewhat sceptical about my aim. Her scepticism did not so much consist in a denial that pupils have ideas of their own, but rather in her experience that the gap between their own ideas and those of physics was rather large and hard to bridge. In fact, she indicated that in her worst moments she sometimes sighed that all that can be achieved is that pupils learn to solve standard exercises for examinations. Nevertheless, she said that she herself constantly tried to bridge the gap and so she was quite prepared to participate and to try my proposals. In fact, she already saw the unit *Radiation, you cannot evade it*..., of which she was one of the authors, as making a serious attempt to bridge the gap.[1)]

During the series of lessons her scepticism was not noticeable at all (at least not by me). She was enthusiastic, put quite a lot of time in it, tried to carry out my proposals for additional activities as well as possible, and regularly indicated to enjoy it all. I too was satisfied about the series of lessons in the sense that I was confirmed in my suspicion that the structure of the unit I was going to write myself had to be quite different from the structure of the unit *Radiation, you cannot evade it*.... Moreover, from how the tried out additional activities worked out I got some ideas about activities that might be useful for the unit I myself was going to write.[2)] There was also a source of trouble, however, relating to the teacher's order-keeping abilities. The situation in her classroom could most of the time best be described as a 'non-aggressive disorder' (cf Créton & Wubbels, 1984). She did not show much leadership, and quite often the lessons were poorly structured. She generally tolerated quite some disorder, and the pupils very often were not task-oriented. Although she was quite concerned about the class and willing to explain things over and over to pupils who had not been listening, the whole situation was usually so unstructured that only the pupils in her direct neighbourhood were attentive, while the others would do other things such as talk with each other or make some homework. They were not provocative, however, i.e., their other activities were not directed against her, and she usually ignored them while talking loudly to the pupils near her. Her few efforts to also involve the other pupils were usually delivered without emphasis and mostly had little or just a short-term effect. Though most of the pupils seemed to like her and she certainly liked most of the pupils and took a great deal of interest in them, the interaction between her and the pupils very often resulted in a non-productive equilibrium in which all of them sort of seemed to go their own way. The teacher's limitations especially came forward during the additional activities, most of which were of the 'class discussion'-type. For even though the teacher really attempted to involve all pupils, she mostly did not succeed. The result was that the discussion was also hard to follow for the few pupils that were attentive, because of the many times that it was interrupted by the teacher's (vain) attempts to call the other pupils to order. The teacher was well aware of all

1. Because the unit is based on micro-level explanations (cf section 3.2), I myself could not see it that way.
2. Some of the tried out additional activities are indeed precursors of activities that figure in the first and/or second version of the didactical structure.

this, and although she herself also did not find her teaching style particularly good, she also maintained that, at least for the time being, it reflected her best way of surviving in the classroom. So if there was to be a further cooperation with this teacher, it would have to be accompanied by an in-service training in managing order problems.

However, and at the time quite unexpectedly for me, the teacher herself decided that there was not going to be a further cooperation. The results of the test that followed the series of lessons had reawoken her old scepticism. The test consisted for about two-third of rather standard tasks (about half-life, the different penetrating power of the different kinds of radiation, the number of protons neutrons and electrons that a given isotope consists of, etc, i.e., exercises of the type that could come up in the examination), and for about one-third of tasks that demanded some insight (in e.g. the point of distinguishing between contamination and irradiation). It turned out that generally the pupils answered the standard tasks sufficiently well, though not overwhelmingly so, but the insight-tasks rather poorly. I did not make much of those test results, or at any rate I found them quite understandable. For, as I have already noted, the additional activities, which explicitly aimed at insight, went past most pupils. Furthermore, the additional activities were not backed up by worksheets and also did not fit nicely into the unit *Radiation, you cannot evade it*.... For me, all this meant that adding just a few activities was not sufficient. Although some of them might be useful, they had to integrated in a structure that was quite different from the structure of the unit *Radiation, you cannot evade it*..., and had to backed up by written material that would serve as a hold for pupils. In short, I would have to write my own series of lessens and that was precisely what I was going to do. For the teacher, however, the results of the tests confirmed her earlier scepticism. Below I give some fragments of her verbal explanation of her decision to quit.

> If I look at the enormous amount of time I have spent on it and that the part that does later come up for examination, that already that part is not really right, and that this [the part relating to insight, KK] apparently also has not got across, then I say... well, this is wrong, this is a waste of my time, period.
>
> These pupils [middle ability pupils, KK] have been taught tricks and memory aids from primary school on, otherwise they do not make it through that school. And then you cannot in six weeks all at once aim at insight... and forget that there is something like an examination waiting for them that they will have to do. So I think that in this context it is indeed unfeasible [to aim at insight, KK].
>
> I have followed your road all along, and if I now look at what it has yielded then I think... well, if I had done it my way it would have taken me, a, less time and the test would have been made better. [...] Not the second part [the insight-tasks, KK], the multiple choice [the standard tasks, KK]. Then I would have shifted the emphasis. And then I think, simply from the point of view of my pupils, that is what they have to know. And then I will do my best to also bring in those other things, but already beforehand I accept that that will largely be a wasted effort. I told you so at the beginning: you can try it, but I don't think that it will work. And then I am working on it and then I am really enthusiastic and then... and I did terribly enjoy doing it, I would like to always work like this, but... well, I just notice that it has had little or no effect up to now.
>
> I think we have done all that we could have done in this context [she later specifies this to: with these pupils, in these times, with this previous education; KK]. I would not know what else you should have done.

Whereas for me the whole thing still had to begin, for the teacher it was all over; whereas I thought the time was ripe to lay my own road, she thought she had already followed my road all along, and with little or no effect.

In order to find a new teacher some heads of physics were approached with the question whether they knew a good and experienced teacher that might be willing to participate in an educational experiment. In this process the teacher that I worked with for the rest of my research came forward. In section 10.2, this teacher is characterized. In order to carefully prepare a productive working relation, the teacher and I took quite some time to get acquainted. In section 10.3, I report on this preparatory period. In section 10.4, I go into some aspects of our cooperation during the (re)construction of the didactical structure. In section 10.5, finally, I try to go beyond this one teacher and more generally address the question what it means for a teacher to work with a didactical structure that is 'good enough.'

10.2 Characterization of the teacher

The teacher I worked with was born in 1945. He graduated from a college of education in 1967, but only taught for about two months at a primary school. By means of some refresher courses he in 1969 acquired a qualification to teach physics and chemistry at the LBO and MAVO types of education and at the first three years of the HAVO and VWO types of education (cf section 9.2.1). From 1969 to 1984 he taught physics and chemistry at a school which consisted only of a MAVO-stream. In 1984 this school merged with another school to form a school for MAVO, HAVO and VWO. It is at this school that up to this day he has taught physics and chemistry at the levels he is qualified for. It is thus also the school at which he has worked with the various versions of the didactical structure. The above may suffice to illustrate that he is a very experienced teacher.

The head of physics that recommended him also assured us that he is a good teacher, i.e., a teacher of whom pupils say that he is a good teacher. I also got this impression by observing some of his lessons in the preparatory period (cf section 10.3). There was a pleasant and productive working atmosphere in his lessons, there were hardly any order problems and if some cropped up the teacher usually managed to immediately and effectively deal with them. I would have characterized him as 'strict, but nice' or 'nice, but strict.' In order to somewhat further substantiate these claims, the so called Questionnaire on Teacher Interaction (QTI) was administered to the teacher and several of his classes. The QTI, which was developed in the early eighties by Créton & Wubbels (1984), is an instrument to characterize the affective climate of the learning environment, as perceived by the participants (pupils and teacher). If we roughly discern two aspects of teacher behaviour, a methodological one that relates to content presentation and instructional methods and an interpersonal one that has to do with the teacher's interpersonal actions that create and maintain a positive classroom atmosphere, the QTI can be said to capture the latter aspect of teacher behaviour. By discerning these two aspects I do not mean to deny, of course, that they are interconnected. Wubbels & Levy (1993b) note in this respect that "[i]f the quality of the classroom environment does not meet certain basic conditions the methodological aspect loses its significance." In fact, concerning the teacher whose lessons I observed during the first year of my research I have made a similar remark (cf section 10.1).

The QTI leads to a characterization of interpersonal teacher behaviour in terms of eight different types of interpersonal behaviour, which can be represented in a two-dimensional plane (cf figure 10.1).

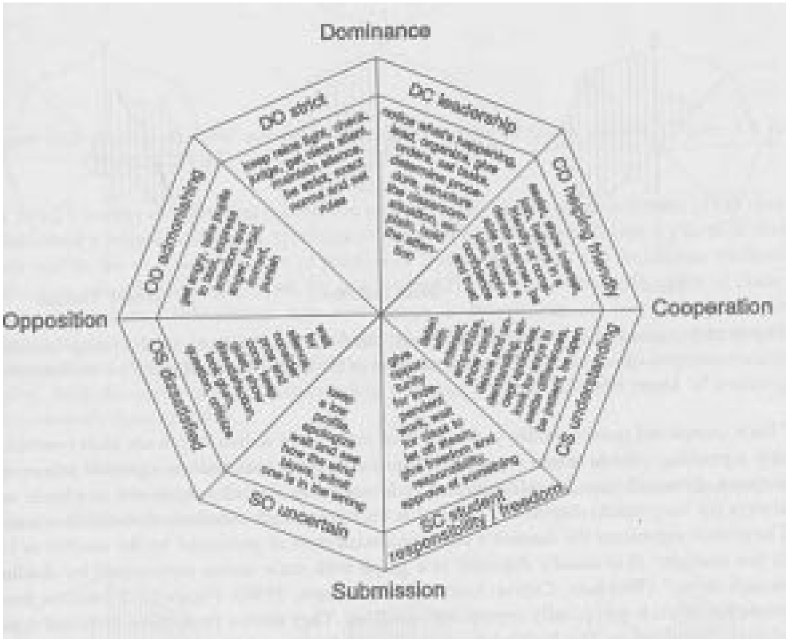

Figure 10.1 The model for interpersonal teacher behaviour. (Figure 2.2 in Wubbels & Levy, 1993a.)

The two dimensions of the plane have been labelled 'proximity' and 'influence.' The 'proximity-dimension' indicates the teacher's degree of cooperation with or closeness to pupils, on a scale between Opposition (O) and Cooperation (C). The 'influence-dimension' indicates the extent to which the teacher directs or controls the interaction with pupils, on a scale between Submission (S) and Dominance (D). In figure 10.1 the eight different types of behaviour are represented by the eight sectors DC, CD, etc, "according to their position in the coordinate system (much like the directions on a compass). For example, the two sectors DC and CD are both characterized by Dominance and Cooperation. In the DC sector, however, the Dominance aspect prevails over the Cooperation aspect" (Wubbels, Créton, Levy & Hooymayers, 1993). In figure 10.1, each of the eight sectors is also characterized in words, both briefly (DC by 'leadership,' CD by 'helping friendly,' etc) and somewhat more elaborately in terms of characteristic teacher behaviour.

The questionnaire itself, the QTI, of which there is a Dutch and an American version, "is divided into eight scales which conform to the eight sectors of the model. In the Dutch version each sector scale consists of about ten items (seventy-seven in total) which are answered on a five-point Likert scale. The American version has sixty-four items and a similar response scale" (*ibid*). For a discussion of the reliability and validity of the QTI, I refer to Brekelmans *et al* (1990).

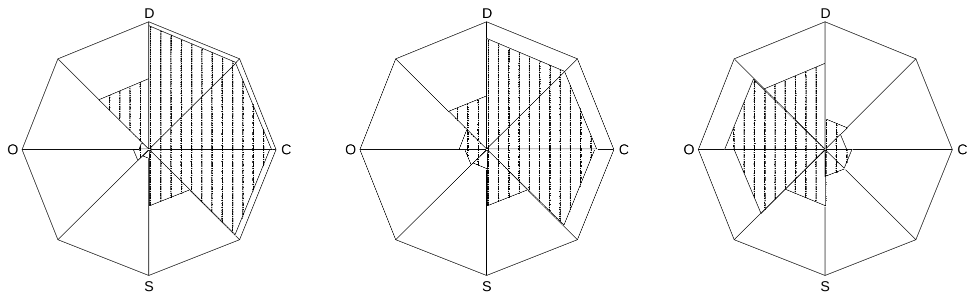

Figure 10.2 Average teachers' perceptions of ideal teacher behaviour and average students' perceptions of best and worst teachers in the United States. (Figure 3.7 in Wubbels & Levy, 1993a.)

"Each completed questionnaire yields a set of eight scale scores which are then combined into a profile ... Scale scores equal the sum of all item scores and are reported in a range between zero and one. A scale score of 'one' indicates that all behaviours in a scale are always (or very much) displayed. A 'zero' is the opposite: the absence of scale behaviours. The profile represents the teacher's communication style as perceived by the teacher or his or her students. It is usually depicted in a graph with scale scores represented by shading in each sector" (Wubbels, Créton, Levy & Hooymayers, 1993). Figure 10.2 contains three examples of such graphically represented profiles. They derive from three different types of data. "Students in The Netherlands, the United States and Australia were asked to rate their best teachers on the QTI. Also, teachers in the three countries provided self-perceptions about their ideal behaviour. Finally, a smaller group of Dutch students completed the QTI for a teacher they thought of as their worst. Figure [10.2] shows the average scores for these three groups in the United States. The results are similar for the other countries" (Levy *et al*, 1993). Figure 10.3 may be another profile of interest. It "shows the average of 463 students' perceptions for a random sample of 118 Dutch teachers." (*ibid*). So in a sense it represents the communication style of the mean Dutch teacher, as perceived by students.

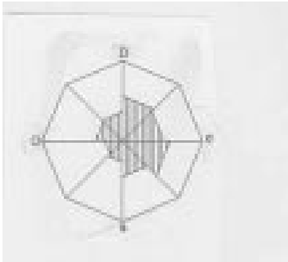

Figure 10.3 Average students' perceptions of random sample of Dutch teachers. (Figure 3.2 in Wubbels & Levy, 1993a.)

By using a variety of clustering procedures and similarity measures, Brekelmans (1989) has established a reliable and stable typology of eight types of communication style, such that each profile out of a large number of profiles of Dutch, American and Australian teachers belongs to one of these eight types. By combining QTI data with descriptive data of classroom atmosphere, Brekelmans has also given a description of each of the eight communication styles in terms of teacher/student behaviours and learning environment characteristics. Brekelmans *et al* (1993) contains, for each of the eight communication styles, both the mean profile corresponding to it and its description in terms of learning environment characteristics.

I hope the above gives sufficient information on the QTI. As I have already noted, the QTI has also been administered to the teacher and to several of his classes that worked with a version of the didactical structure.

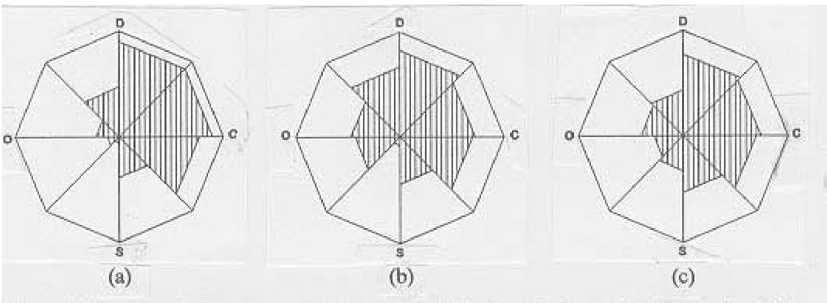

Figure 10.4 The teacher's perception of ideal teacher behaviour (a); the teacher's perception of his interpersonal behaviour in one of his classes (b); that class' perception of the teacher's interpersonal behaviour (c).

The profile in figure 10.4a is the result of the teacher's completion of the QTI in terms of his ideal behaviour; figure 10.4b is the resulting profile of the teacher's completion of the QTI for his behaviour in one particular class (in fact, one of the classes in which the first version of the didactical structure was tried); figure 10.4c represents the teacher's communication style as perceived by the pupils in that particular class (it corresponds to the class means of their completion of the QTI). The profiles corresponding to the teacher's perception and the pupils' perception of the teacher's communication style in other classes are similar to figures 10.4b and 10.4c respectively. In fact, in terms of Brekelmans' typology all those profiles are of the type that she has labelled 'Authoritative.' In Brekelmans *et al* (1993) it is characterized as follows.

> The Authoritative atmosphere is well-structured, pleasant and task-oriented. Rules and procedures are clear and students don't need reminders. They are attentive, and generally produce better work than their peers in the Directive [another category in the typology, KK] teacher's classes. The Authoritative teacher is enthusiastic and open to students' needs. He or she takes a personal interest in them, and this comes through in the lessons. While his or her favourite method is the lecture, the Authoritative teacher frequently uses other techniques. The lessons are well planned and logically structured. He or she is considered to be a good teacher by students.

The teacher's ideal communication style (i.e. the one that corresponds to the profile of figure 10.4a) is of the type that Brekelmans has labelled 'Tolerant and Authoritative.'[3] In Brekelmans *et al* (1993) it is characterized as follows.

> Tolerant/Authoritative teachers maintain a structure which supports student responsibility and freedom. They use a variety of methods, to which students respond well. They frequently organize their lessons around small group work. While the class environment resembles Type 2 [the above 'Authoritative' type, KK], the Tolerant/Authoritative teacher develops closer relationships with students. They enjoy the class and are highly involved in most lessons. Both students and teacher can occasionally be seen laughing, and there is very little need to enforce the rules. The teacher ignores minor disruptions, choosing instead to concentrate on the lesson. Students work to reach their own and the teacher's instructional goals with little or no complaints.

Hereby I hope to have sufficiently characterized the interpersonal aspect of the teacher's classroom behaviour. Let me close this section by noting that the quality of the classroom environment that he manages to create is such that the methodological aspect, on which my research mainly focuses, could indeed be given full consideration. In devising the didactical structure we have been in the luxurious position that whatever technique or instructional method we proposed (be it group work, class discussion, experimental work, or complex combinations of these), we could always count on the teacher's ability to satisfactorily handle them.

10.3 A preparatory period

3. I want to thank Rob Houwen for the analyses of the QTI data: for producing the profiles like those in figure 10.4, and for determining the type of communication style to which each of them belongs.

Before the teacher and I decided to cooperate on an educational experiment, we had an exploratory talk in which I told something about my ideas concerning the experiment and the teacher about his attitude towards it. I told him that I wanted pupils to meaningfully learn about the topic of radioactivity, that recent research had shown that this aim was very often not reached (not just for the topic of radioactivity, but for almost any topic), and that part of this failure might be due to the fact that most approaches do not start from where pupils are. It almost seems as though for pupils the scientific knowledge they 'learn' is something alien that only has application in the science classroom. I also told him about the cause of our having this exploratory talk: another teacher's decision to quit, and why that other teacher had decided so (cf section 10.1). Of course, I would like to prevent a repetition of that situation. In order to do so I told him I had first of all planned a quite extensive period to carefully prepare a productive working relation. So taking an active part in this preparatory period would be one thing I expected him to do, if he decided to cooperate. Other things would be that he helped in writing new teaching materials (in the first instance in a commenting role), worked with these new materials (while the relevant lessons were being videotaped), etc. What he would get in return were two non-teaching periods and a piece of in-service training that, hopefully, was going to be useful for him.

Of course I also wanted to know how he felt about the aim of my research, however vague it was. In particular I wanted to know, in the context of preventing a repetition of the situation with the previous teacher, whether or not he shared her sceptical attitude. The teacher said to recognize that knowledge does not always function, in the sense that pupils cannot apply it. He told that he thinks that is a problem: it frustrates. So he suspected that he somehow worked on that problem, although it was not a conscious element of his teaching practice. At any rate, from what I had told him he said to have gathered that participating in my research would give him the opportunity to explicitly think and learn about an attempt to tackle that problem, and he certainly did not already beforehand consider such an attempt to be a lost cause. In fact, he said to see no reason why insight would be impossible for middle ability pupils. Finally, the teacher said to hope that by participating in my research he could learn something that might also be of use for other topics than the topic of radioactivity. From this I gathered that at least he had a non-negative attitude towards (the aim of) my research.

On the basis of this exploratory talk the teacher and I decided to cooperate. In this section I report on the first stage of our cooperation: the preparatory period. In section 10.3.1, I sketch the aims, procedure and outline of this preparatory period; in section 10.3.2, I sketch the way it developed and mention some of its main outcomes.

10.3.1 Aims, procedure and outline

The main aim of the preparatory period was to prepare a productive future working relation with respect to writing, trying, etc new teaching materials. In a process in which he came to familiarize himself with (the aim of) my research and I came to familiarize myself with his way of teaching we would have to develop a common way of talking about teaching and learning in general, and about teaching and learning the topic of radioactivity in particular.

The preparatory period took place during the fall of 1989. In that period I visited about one lesson per week, mostly in one of the classes in which later in the school year the first version of the didactical structure was going to be tried. Furthermore, the teacher and I had eleven meetings of about two hours each. The teacher's preparation of a meeting consisted in his doing some homework (of about two hours per meeting). Mostly the homework tasks were given by me, e.g.: study the similarities and dissimilarities between two units on the topic of radioactivity; study some transcripts of interviews with pupils about molecules or radioactivity and relate these to your own teaching about those topics; study some transcripts of fragments of lessons on the atomic model (what are pupils' difficulties and do you recognize these difficulties from your own experience?); study a description of pupils' existing knowledge about radioactivity (along the lines of section 2.5 of this thesis) and comment on it. Occasionally the teacher also set his own homework task, e.g.: carry out a small scale questionnaire study in one class at his school and analyze the results. My preparation usually took me about one working day. It consisted of things like: selecting useful homework tasks for the teacher; anticipating his reactions to it and thinking of ways to build on that in order to clarify some of my ideas about teaching and learning (the topic of radioactivity); studying the conversation we had during a previous meeting (the meetings were recorded on audiotape), and making a reflective report of it in order to identify themes that deserved a further treatment in later meetings; thinking of ways to integrate what I had noticed during visits of lessons in our meetings.

Some of the themes that came up during the meetings were: the aim of the preparatory period and an outline of it; the tendency to base units on the topic of radioactivity on particle models (cf section 3.2); the way such 'models' are often understood by pupils and its consequences for their learning about radioactivity (cf section 3.3); parallels between the teacher's and my learning process during the meetings on the one hand, and pupils' learning on the other; the teacher's role with respect to content: holding back versus steering; the knowledge that seems to be required for an adequate understanding of (the possible dangers of) daily life situations having to do with radioactivity; the usefulness of the meetings.

The teacher's homework for the final meeting of the preparatory period was to write a review of it: on what he had learned from it, on whether through it he felt prepared for a further cooperation, etc. In the final meeting we discussed his review. The totality of my reflective reports of each meeting can be seen as my review of the preparatory period. Section 10.3.2 is based on it.

10.3.2 Development and outcomes

At the beginning of the preparatory period I had some ideas about themes that I wanted to bring up for discussion (cf the previous section), but I did not really have much ideas about how to structure each of the meetings, about a suitable order in the themes I wanted to bring up for discussion, about useful homework tasks for the teacher, etc. In fact, the latter ideas gradually developed during the meetings and also as a result of my making reflective reports of each of the meetings. Below I sketch and exemplify these developments, the use of my regular visits to lessons given by the teacher, and some of the main things the teacher and I have learned from the meetings.

The structure that the meetings gradually assumed

After a while the structure of the meetings between the teacher and me was based on our awareness that we approached educational matters differently and with different experiences, and took the form of trying to make explicit each other's approach and experiences while discussing concrete material (transcripts of lessons and interviews with pupils, results of questionnaires, textbooks, things that happened in a lesson I visited, etc). Below I exemplify how an analysis of the earlier meetings gave rise to this structure and how this structure was made explicit.

The first meeting was a brief one and concerned the procedural aspects of future meetings (how often, how long, how much preparation, etc). The second meeting was the first one in which we discussed issues. The theme I wanted to bring up then was the obviousness of the tendency to base a unit on the topic of radioactivity on particle models. In order to first of all make clear this tendency, I selected two such units (the unit in the textbook the teacher normally used and the unit *Radiation, you cannot evade it*...), which, although they are quite different with respect to e.g. content presentation, essentially have the same structure. So the homework task I gave to the teacher was to study those two units and capture the main lines of the way each of them is build up. I expected that thus he would also find that the two units are essentially the same and, in particular, both begin with the presentation of a nuclear 'model.' (This would then allow me to ask whether it is obvious to begin in that way.) More or less for the sake of completeness I added to the homework assignment the question what the differences between the units are. It turned out that the teacher had indeed noticed the similarity in structure, which he framed as 'what atoms are; what radiation is; how radiation emerges; what the effects of radiation are,' but that he was most struck by the differences between the two units. He found the unit *Radiation, you cannot evade it*... much more pupil-friendly, especially for middle ability pupils: better geared to them and more surveyable for them. For it consists of relatively short and easily readable pieces of information, each of which is followed by some questions that directly refer to it, it contains regular and short summaries, etc. The other unit, in contrast, contains many long stretches of text with too high a level of difficulty, which, as was the teacher's experience, a middle ability pupil simply cannot get through.

Our different approach can in this case be characterized as our laying a different emphasis. Although I noticed the difference in content presentation (and had, in fact, selected the two units because of this difference), I emphasized the similarity with respect to structure. And although the teacher noticed this similarity, he emphasized the difference in content presentation. The teacher's emphasis can be said to reflect his practical and pragmatic approach, with an immediate link to his everyday teaching experience. One of the first things he asked me when discussing the two units was: what do you have in mind, something like this unit or something like that one? My own emphasis can be said to reflect my more theoretical approach, which is also related to existing teaching practice but more in the sense of looking at it from some distance and bringing it up for discussion -in this case, the obviousness of the existing tendency to base a unit on the topic of radioactivity on particle models.

What enabled the teacher to also bring in his points was the part of the homework assignment that asked for dissimilarities between the two units. I have already mentioned that at the time I more or less accidentally included that question in the homework assignment, or had at any rate not included it in order to allow the teacher to bring forward his points. If only for the reason that in a period of getting acquainted the teacher should also be given the opportunity to bring forward his own points, for future meetings I very consciously tried to devise such homework tasks, that the teacher, with his more pragmatic approach, and I, with my more theoretical approach, could each bring forward our own points, thus make explicit each other's approach and experiences, and thus also learn from each other. Indeed, it was not just out of politeness that the teacher was given the opportunity to bring forward his own points, and the fact that in the meetings I naturally had to take the initiative did not imply that only the teacher was supposed to learn something. I also learned from the teacher. The teacher's comparison of the two units, for instance, made me realize that in the later writing of new teaching materials I would have to seriously deviate from my normal writing style. Instead I would have to write relatively short and simply constructed sentences that would have to be organized in a whole that is easily surveyable for middle ability pupils. At least in that respect, so I learned from the teacher, I should take the unit *Radiation, you cannot evade it...* as an example.

In later meetings I also tried to make this structure of our meetings explicit: by illustrating it at examples like the one above; by explicitly telling one another what each learned from the other and how that relates to the other's approach; by drawing parallels between our learning from each other and pupils' learning from their teacher (or teacher's learning from his or her pupils). In the fifth meeting, in which among other things we looked back on the previous meetings, the teacher also recognized the structure that the meetings had assumed:

> I do also sense it like that. That we are feeling out, catching up from each other. I hear new things, you learn new things. Obviously you take the initiative. Well, that's how I see it: you are... I'm here for you. I think you have to take the initiative. I think I get all room. If I dwell on something, then there simply is time for that, then we simply keep on talking about that subject. I... up to now... I actually think it's getting easier and easier for me. The first time I thought: Jesus, it looks like an examination or it looks like... I have the feeling that I'm being interrogated about what I do and do not know. And now I don't have that at all. We're simply feeling out: how do we think about some things?

Later on the teacher told me that his initial feeling also derived from his not feeling very safe at the time. He, the dumb teacher, had to go to a place where he did not really belong: The University.

Of course the teacher and I gradually grew closer to each other. When in later meetings we e.g. discussed some transcripts of lessons, the teacher would bring forward points that I also found relevant, and for very much the same reasons. The main difference between us then was that I usually brought forward more similar such points, which the teacher, after I brought them forward, mostly also recognized as similar. At first this difference in quantity gave the teacher the impression that he had not done his homework well enough and, in fact, made him feel sort of guilty. Of course, I then told him that there was no need for such impressions and feelings. On the contrary, the fact that he focused on very much the same points as I did was evidence for the fact that our approaches converged with respect to some themes. The difference between us then no longer was a matter of different approaches, but rather of different amounts of time spent on homework assignments.

Shifts in theme: from content to didactics

There usually also was a shift in theme in each meeting, which at first again occurred rather accidentally but, after I had noticed it in earlier meetings, was planned more consciously in later meetings. I would characterize the shift as one from content to didactics. Let me again try to illustrate this at the meeting in which the two units were compared. The question concerning the similarity between the two units can be said to deal with content, in the sense that its answer is that with respect to content the two units are essentially the same. On the basis of that answer, which as already noted the teacher had also given, our discussion gradually developed in a didactical direction in the sense that the structure of the content presentation was related to teaching and learning. To my question why the units begin with atomic models, the teacher's initial response was as follows.

> This book simply assumes that... I later have to tell about those isotopes with which something special is up, so I first have to tell what isotopes are. [...] In order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you can't explain it. But you think it can be done differently?

The teacher's argument is of course valid within the existing structure of the units. But it was this structure that I wanted to bring up for discussion. I tried to do so by noting that beginning with atomic models is like beginning on the most advanced level. Is it not possible to already say something about radioactive phenomena without using particles, without immediately going deeply into the theory behind them? This at least made the teacher understand that I wanted something that differed from the existing structure.

> You don't want to begin with... straight to the smallest particle and everything is connected to those smallest particles. You want to begin with... what does happen, how could that be, search... arouse interest... and first spend some time on that before we go more deeply into it, right?

I then tried to link up with his 'to arouse interest' in the sense of 'to induce a need for a deeper explanation,' an explanation at any rate of something they already know at a phenomenological level. The teacher put this in his own words as follows:

> Would they be more inquisitive, that really is... more eager to learn about the particle model if they are going to hear about it later? First, what is it and what do we notice of it and effects, slowly settling in, and only then the explanations.

This 'to make pupils eager to learn about something,' which fitted into my developing ideas about a problem-posing approach, is a didactical theme that often recurred in our subsequent meetings.

Another more didactical theme that the teacher had picked up from this meeting is the following: is one thing really needed as a preparation for something else? This turned out when several meetings later he came back on his earlier statement that "in order to teach the concept 'isotope' they first have to know something about atomic models, otherwise you cannot explain it," and concluded that it is possible to talk about isotopes without first having to talk about atomic models, which was in fact *his* first step in loosening himself from the existing structure. His reasoning was that all that is really needed to understand the concept of isotopes is the idea of slightly different things. He used the example of a bag of a hundred white marbles, of which on closer observation it turns out that one has a little crack and one a little black spot. By calling the three possibilities (perfect white marble, marble with little crack, marble with little black spot) three isotopes of white marbles, pupils could thus get the idea of what an isotope is without having to know anything about atomic models. He went on by noting that also in a subsequent treatment of atomic isotopes, there really would be no need to talk about protons, electrons or differing numbers of neutrons. All that needs to be said is that some atomic isotopes are different in the sense that something special can happen to them. I then elaborated on the theme the teacher brought forward, for I believed that he was very close to noticing that it is possible to talk about 'the something special that can happen to them' in other terms than changes in microscopic structure. I tried to do so by admitting his conclusion that it is possible to talk about isotopes without having to talk about atomic models, and by going one step further: is it also possible to talk about radioactivity without having to talk about isotopes? The teacher thus came to the insight that it is possible by simply calling something radioactive if a Geiger counter starts ticking in its vicinity. I could then also inform the teacher that I had this possibility in mind as a means to start up the series of lessons we were going to devise.

The didactical theme brought up here by the teacher also came back in later meetings. When later on we e.g. discussed the general constraints on the series of lessons we were going to devise, it returned in the following form: an activity should be meaningfully prepared by preceding ones and meaningfully prepare following ones.

When thinking about a suitable order in the themes I wanted to bring up for discussion, I also tried to make use of the idea 'making someone eager to learn about something.' That is, I tried to arouse the teacher's interest in a new theme on the basis of previous themes. In some cases I succeeded in this. The teacher for example understood why on the basis of the meeting in which the two units were discussed, I gave him the homework assignment to study some interviews in which pupils were prompted to give particle explanations.

> You want to get rid of that particle model in your new planning. [...] We teach them that all right, those particles and how all of that... but can they themselves handle that too? For, of course, if you find out, they cannot handle that at all and haven't formed any idea at all of.., then you will be on strong ground in saying we have to try it in a different way.

When shifting to a didactical theme I often used such concrete examples from our own meetings as a means to bring it up for discussion. If possible I would, for the same purpose, also use concrete examples from the lessons I visited.

Apart from shifts from content to didactics within one meeting, in retrospect I notice a similar shift in the course of the meetings as well. In later meetings we more often and more directly discussed didactical themes, e.g.: pupils enter the classroom as empty vessels versus pupils have a background and this background influences their participation; explaining versus challenging pupils to find things out by themselves (as a form of making them eager to learn about something); asking pupils questions versus making pupils ask questions (as a form of making them eager to learn about something).

In discussing such themes, the teacher was of course especially interested in the consequences for his own role in the classroom. In fact, our discussion about his role was one an ongoing one. It continued during the following construction, try-out, reconstruction, etc of the didactical structure (cf section 10.4). In the preparatory period we often talked about the teacher's role in relation to yet another didactical theme: holding back versus steering. We tried to sort of take stock of the various ways in which these terms might be given content, if possible by using concrete examples. Steering or helping pupils, for instance, need not only consist in explaining. Pupils might e.g. also be helped in their learning process by making them arrive at some problem that they themselves come to see as worthwhile to work on. 'Holding back,' on the other hand, is not meant as 'withdrawing' or 'laisser faire.' It might e.g. be given content in the form of 'getting into the skin of the pupils' and 'trying to learn along with the pupils.' Since the preparatory period was also meant as a preparation for the coming construction of a series of lessons, in the later meetings we more and more began to talk about that as well (as part of our shift towards more didactical themes). In that context it was concluded that a substantial steering role should also emanate from the design of the series of lessons. In the construction of the series of lessons, we would have to think out such tasks and such an order in tasks that we have al reason to expect that by working on them pupils are steered in the direction of some goal (e.g.: their recognition of some problem). 'Holding back' might in that context be given content as sort of opposite to 'seeking confirmation of our expectations' or 'pursuing our goals at all cost.' Whereas the latter two attitudes do not prepare the ground for a meaningful evaluation, holding back in the sense of trying to learn along with the pupils may bring to the fore both the need for adjustments concerning (the order in) tasks, expectations and/or goals, and suggestions for plausible such adjustments (cf section 7.4.3).

Use of visits to lessons

One aim of the preparatory period was to familiarize myself with the teacher's classroom behaviour, i.e., in the terminology of section 10.2, both with his methodological and his interpersonal teaching style. In this respect my regular visits to his lessons were of course useful. They were also of use for our meetings, however, as I now try to illustrate. Let me first of all repeat that in our meetings we mainly focused on the methodological aspect. The interpersonal aspect of classroom behaviour, and in particular the teacher's interpersonal teaching style hardly came up in our talks. In the first place I did (and do) not feel competent to discuss the latter aspect. Secondly, it seemed to me that in his case there was hardly any reason to discuss it (cf section 10.2). So concerning this aspect I limited myself to occasional remarks how well I thought he managed to create and maintain a pleasant and productive working atmosphere.

Especially during our first meetings, I tried to bring forward some features of his methodological teaching style that I had picked up from visiting his lessons. He e.g. hardly ever gave a direct answer to pupils' questions, but instead tried to challenge them to themselves find the answer, if necessary by giving some casual clues: 'I don't know, but might it be that...' He would then some time later come back to see how they were doing and, if necessary, help them yet another bit further. Out of examples such as these, and the teacher's comments on them, eventually grew didactical themes such as: explaining versus challenging pupils to find things out by themselves; asking pupils questions versus making pupils ask questions; holding back versus steering.

In the above I have already repeatedly mentioned this aspect of the use of my visits of lessons, i.e., to have available concrete examples that both of us witnessed. Those examples could then e.g. be used to make explicit each other's approach, to start a discussion about further or similar experiences, to bring up or illustrate other didactical themes, etc.

Another aspect of the use of my visits of lessons derives from the different approaches of the teacher and me. One of my aims of our discussion of some interviews in which it was tried to make pupils give particle explanations, for instance, was to explore why pupils failed to do so, and this aim reflects my more theoretical emphasis. The teacher's more practical and pragmatic approach, with an immediate link to his everyday teaching practice, is e.g. reflected by the fact that following our discussion he wanted to find out about *his* pupils' ability to give particle explanations. Moreover, and in this sense my visits, and particularly the ones at the beginning of the preparatory period, provided a stimulus for him to try things out in my presence, so that we could later talk about it. Later on, however, he no longer needed my actual presence in order to try things out. It was then rather his own enthusiasm that made him do it. Of course, he would then still report about his experiences in a subsequent meeting.

Some learning outcomes
In his review of the meetings, the teacher indicated what he had learned from them:

> Well, one of the things that have most struck me is that much more than before I wonder whether my way of teaching, treating the subject matter, observing and evaluating pupils... is done in the right way. Less than before I rely the old routine in which, as I have come to realize, I was somewhat getting stuck. So you could now describe it as greasing the whole thing in order to counter the getting stuck.

Also during the meetings themselves he had already made similar remarks, e.g.:

> ...you are confronted with what you are really doing the whole day, and self-evidently so. So you see, not just here I am wondering... but also during my lessons I am... it already is on my mind. Well, why am I doing this? I do not wonder whether I am doing it right, really, but could I do it differently, does it make sense that I tell it to them, what do they really pick up from it, what will they do with it?

So the teacher has experienced the meetings as useful, as refreshers of his teaching practice in general. This may also be illustrated by the enthusiasm with which he tried things out that were discussed in meetings.

More in particular, the teacher has also experienced the meetings as useful. Concerning the themes relating to content, for instance, he indicated to have become sensitive to the problems that pupils have with particles and to the question whether a treatment of the topic of radioactivity should be based on particle models. He in fact admitted to have been shocked by the poor understanding that pupils have of particle models. And his pupils too, as he found out when in one of his classes he challenged the pupils to explain why a roadway expands on a hot day and they came up with answers such as: the molecules expand, the air between the molecules expands, or the intermolecular spaces between the molecules expand. Here is one more example of the influence that in this respect the meetings have had on his teaching practice:

> Today, for instance. [...] Someone drops the word 'molecule.' Another one immediately says: the smallest particle of a substance with all its properties. Never ever would I have reacted to that. That is correct. Today we have talked about it for a quarter of an hour. Have talked about it for a quarter of an hour! Would it really be like that? [...] I don't know whether those pupils have gained anything from it. But at any rate it is the result of these meetings.

Concerning the didactical themes, the teacher wrote in his review that especially our recurring discussions about 'holding back and steering' had been very instructive. He also indicated to have gathered from the totality of our meetings that I am a proponent of "letting pupils themselves experience, describe and tentatively process, instead of the traditional model of learning, digesting and testing." In this respect too the teacher noted that the meetings have had their influence on his teaching practice, e.g.:

> ...I more often try to get into the skin of the pupils...
> It has already yielded fruit (still to be seen whether it is ripe) in my daily teaching practice. Holding back, listening to pupils, adjusting a little later. A changed attitude with regards to pupils' making notes of observations. Less direct 'explaining.'

The main thing I learned from the meetings was to further specify and illustrate what the consequences for the teacher's role are of my ideas about how pupils could meaningfully learn about the topic of radioactivity. For up to then those ideas mainly concerned pupils' learning process, e.g.: whether *for pupils* one thing (e.g. particle models) really is a meaningful preparation for another thing (radioactive phenomena). Of course I had some ideas about the teacher's role in pupils' learning process, but it was the teacher, with his pragmatic demand for immediate applicability to his practice, who continuously challenged me to do further develop those ideas and also contributed to that further development. For me too, our discussions about 'holding back and steering,' and particularly about how the notions 'holding back' and 'steering' could be given further content in relation to my developing ideas about a problem-posing approach, were most instructive.

Another thing I learned from the way the meetings themselves proceeded, was how useful it is to regularly and explicitly build in reflective activities. For it had been beneficial for our meetings that each of us regularly thought about, and that we then explicitly talked about, questions such as: what have we done, what have we achieved and where does that leave us? So it would also be useful, and moreover in line with a problem-posing approach, to build in such activities in the series of lessons we were going to devise.

Some of the minor, but still important, things I learned also relates to the construction of the series of lessons. The textbook that pupils are to work with should be carefully edited, and easily surveyable and readable. It should be clear to them that quite some time and effort has been put in it, in order to increase their willingness to seriously work with it. The latter point may be compared to a remark that the teacher made in his review, namely that it was also due to my careful preparation of the meetings that he was challenged to invest quite some time in the homework assignments.

I conclude that our preparatory period had met most of its aims. I had come to familiarize myself with his way of teaching. He had become sensitive to the problems with the existing structure to treat the topic of radioactivity, and had gathered some ideas about an alternative structure. We had developed a common way of talking about teaching and learning that promised to be useful for a productive future working relation with respect to writing, trying, etc new teaching materials. Particularly the theme 'holding back versus steering' seemed to be useful for both of us. For the teacher because it directly concerned his role; for me to further think through what, in terms of holding back and steering, the consequences for this role are in a problem-posing approach. I felt prepared for our future cooperation, and so did the teacher: "I'm one hundred per cent behind the experiment. I have confidence in it."

What had not become clear, as the teacher remarked in his review, is "what precisely the lines are along which and why your research takes place." I guess I myself also did not know that at the time.

10.4 Cooperation during the (re)construction and try-out of the didactical structure

Following the preparatory period, the teacher participated in my research for a period of two and a half years. In this period he worked with both versions of the didactical structure and was also involved in the construction and evaluation of them. In this section I describe some aspects of our cooperation in this period, and in particular how in this period our discussion about his own role in the classroom continued, with the eventual aim that he made himself so familiar with the essence of (especially the second version of) the didactical structure and his role in it that he would not deviate essentially from it.

10.4.1 Construction and try-out of the first version

For the construction of the first version of the didactical structure there was about three months available. In these three months I had to put flesh to my still vague ideas about another way to structure the treatment of the topic of radioactivity (e.g.: not begin with particles but rather end with them), by thinking of suitable tasks and a suitable order in the tasks. Choices had to be made (sometimes rather *ad hoc*) in order to meet some constraints: the total series should take about 10 lessons (of 50 minutes), applications of radioactivity should be treated, the examination syllabus had to be covered, etc. Furthermore, a textbook for pupils had to be written, edited and laid out in such a way that for them it would be challenging to work with, and easily readable and surveyable. At the end of the three months there was indeed a pupils' textbook but, as it had been produced under heavy time-pressure, I was not quite satisfied about it. I did have the feeling, however, that it was worth being tried in the sense that from the try-out we could learn a lot about possible improvements.

In those three months the teacher was one of the people who commented on my intermediate products, and what occupied him most was to see how the vague ideas about an alternative structure that we had talked about during the preparatory period gradually assumed a more definite and concrete form. There simply was no time left to discuss his role in relation to the material that was being written any further than whether he thought it feasible to do the activities in the time that was planned for them. Moreover, the teacher guide that was also being written, was more a justification of the new structure of the treatment of the topic of radioactivity than a practical guide. So also concerning the teacher's role I had the idea that a lot could be learned from the try-out. It was in the evaluation of the first version of the didactical structure that the main work had to be done, with respect to both the structure itself and the teacher's role in it.

The first version of the didactical structure was tried in two classes. The procedure of the class observations had been much the same as later in the try-out of the second version (cf section 9.2.1). In one of the classes the lessons were recorded on audiotape, in the other on videotape; on the basis of the experiences in the class in which a particular lesson was given first, some changes were sometimes made concerning the matching lesson in the other class, etc. But whereas the procedure of the observations was similar, the first impressions from the observations differed markedly. For, in line with the above mentioned expectations, the first impressions I gathered during the try-out of the first version the didactical structure were that it certainly was not yet 'good enough.' That is, too often the things the pupils did and said were too far out of line with what they were expected to say and do. Moreover, whereas in some cases rather cosmetic changes might suffice to improve matters (e.g. by avoiding unspecific terms in the formulations of the tasks, cf section 7.4.1), in others more structural improvements seemed necessary. In order that pupils perceive the coherence in successive tasks (cf section 7.4.2) or come to appreciate some problem in the right way (cf section 7.4.3), for instance, it seemed necessary to not just superficially change some tasks but also to change their function and aim, and the way in which they are to be put in a coherent structure.

After the try-out of the first version the teacher was asked to write down his first impressions. The following may give an idea of what they were.

> The last weeks before the start of the series of lessons were marked by a lot of pressure, concerning the normal work at school as well as the preparation of the start. [...] In addition to this the material still had not got its definite form and a remark of [one of the other people who commented on the material] about the amount of subject matter and the in his opinion too optimistic planning had made me doubt about the possibilities of the material. After in the end the material had got its definite and carefully edited form my concerns were somewhat taken away again.
> Once the lessons had begun I was glad to have the opportunity to always teach the lesson once again in the other class in order to then deal with problems that had been found in the first lesson. Because of that it turned out that after four lessons I myself got the feeling that the planning was feasible and my decreasing tension for the lessons of course made that the further lessons proceeded less tensely.

10.4.2 Evaluation of the first version and construction of the second version

The above may already indicate that at the beginning of the evaluation the teacher and I had a different attitude, which may again be characterized as the difference between a theoretical and a pragmatic attitude. For me the real work still had to begin, and I was sure that the evaluation would lead to suggestions for structural changes, for substantial changes in the didactical structure itself. For the teacher, however, things had worked out well, and by this he meant things like: we made it in time, the pupils learned something and they were involved.

In the first stages of the evaluation this difference was not properly taken into account, however. We had weekly sessions, for which we prepared by studying one lesson. The teacher studied the videotape of that lesson, i.e., the lesson in one of the classes. I studied the videotape too (together with Hans Créton and Wout Moerman), and also the audiotape of that lesson (i.e., the lesson in the other class) and pupils' notes. During the session we then exchanged our findings. At least, that was the plan. It turned out, however, that there was hardly any exchange, but rather a one-way transmission from me to the teacher, in which I pointed at numerous cases in which what the pupils did and said was (far) out of line with what we had expected, at cases in which the teacher's role could have been better, at possible suggestions for improvements in the didactical structure itself and the teacher's role in it. I was far from content about this one-way traffic. The teacher, on the other hand, felt sort of guilty for not having enough critical remarks. So the sessions were increasingly dissatisfying for both of us.

In order to escape this situation, we spend a session on the sessions themselves. Below are some fragments of what the teacher then brought forward, which also illustrate our different attitudes.

> I've looked quite differently at [the lessons]. I think: I have my material, I give my lessons, well, I think that my pupils have learned something of it, right. You've looked quite differently at it, because your starting point was: well, we'll see whether the pupils have learned something of it. Well, I don't look that way at lessons, I don't look months back. I think: well, the lessons are over, we have made it in time, so I was satisfied, right. So I thought that the lessons went well. If you're looking at it through such a magnifying-glass, well, then indeed you're going to say, and I really do admit that now too: what we had expected did not quite come out and it might have been done differently.
>
> [During the try-out] I myself didn't have the idea that we were going to discuss it that well, that accurate, that we'd go that deeply into it.
>
> So I really am content about the sessions, about the way we're working on it, but it is different from what I had imagined. Much more about small things, of which you say: here, see that, now? [...] I found it for instance nice... a nice example, that that second lesson I had watched, that I had hardly made any notes really and that I tell you those and that you then come with [..] no less than thirty remarks, well, five pages full. And if I read them over, then I think: and it is like that too. Well, and that you pull them out much more easily than I do. I obviously take notice of quite different things: whether the children are participating, or that they... I don't take notice of whether they... And I do think along with you whether it can be done differently, but I do not pick it out myself.

We concluded that it had been a kind of strange experience for the teacher to look through a magnifying-glass at the small things of something that was well over and that on the whole he was quite satisfied about. On the other hand, now that he got used to the idea he also appreciated that by looking this way it became clear that what we had expected did not always come out and that things might have been done differently. In fact, the teacher also indicated that through the evaluations he had become aware that during the try-out he had not grasped the point of some activities, which accordingly he had not carried out very well, and had also become aware of other cases in which his role had not been adequate. Furthermore, the teacher indicated that the many small things added up to suggestions for quite structural changes, which he appreciated as improvements: "It is a whole different approach, it is quite a different approach. I do think so. The new design appeals to me."

So the main source of the problem seemed to us that, although he did think along with me and appreciated the points I brought forward, the teacher himself did not pick out the things that I did and did not himself come up with suggestions for structural changes. It was not so much problematic that I picked out more things and that I came up with the suggestions for improvements. After all, I had given the didactical structure a lot more thought than the teacher had. Moreover, it was precisely in this period that things began to fall in place for me, that I began to arrive at the global outline for a didactical structure as outlined in chapter 6. So it was quite naturally that I took the lead concerning the structural aspects. What was problematic, however, was that in the sessions up to then this inequality had not been properly taken into account. For the teacher had the same general assignment that I had: study a lesson and comment on it.

As a solution to the problem we suggested that each of us would study the lessons with a special assignment. I would especially focus on the *structural* aspects, e.g.: whether the things pupils do and say is in line with what they were expected to say and do; whether by changes in formulation, aim, function, order, etc pupils might come to perceive the coherence in successive tasks or come to appreciate some problem in the right way, etc. The teacher, on the other hand, would especially focus on, what we called, the *procedural* aspects, e.g.: whether the way in which an activity was carried out has contributed to reaching the aim of the activity; whether by changes in instructional technique or teacher participation (more) pupils might come to (better) appreciate some problem in the right way, etc. Of course the structural and procedural aspects hang closely together. So the teacher had to keep on thinking along with me with respect to the structural aspects, though he was no longer expected to make substantial contributions concerning them. And of course I had to discuss the procedural aspects with him, and in particular their relation to the structural aspects.

It turned out that by the above division of tasks the problem was indeed solved. Firstly, it made more clear that both concerning the structural and the procedural aspects the series of lessons needed to be considerably improved, and also which were the structural and which the procedural improvements. Secondly, the teacher's new task was directly related to what most concerned him: his own role, and he was willing, and able, to work on his new task. Thirdly, the new task was a good preparation for his task during the writing stage of the second version of the didactical structure, namely to write his own guide. His new task, finally, enabled us to continue our discussion about his own role in the classroom, which in the preparatory period we had already begun, and this time more concretely in close relation to the didactical structure.

So the teacher began to study the tapes again, this time especially focusing on the procedural aspects. In the terms of our theme 'holding back versus steering,' he noticed that there were many cases in which his participation had been far too steering. There were cases in which he virtually took over an experiment that pupils were performing, put words in their mouths, heard and saw much more in what pupils said and did than what they actually intended to say and do (cf section 7.4.3), was too focused on pulling out the desired answer (as in: "I've already heard the right answer"), he tended to address himself to especially the 'better' pupils, etc.

Obviously we did not discuss such cases in a blame-context, but acknowledged that a lot of them derived from the fact that the whole thing had been new and stressing for the teacher. He had been nervous, especially during the first lessons (cf his review of the try-out). He had felt the responsibility to make it happen as expected, and therefore was very much focused on the desired answers, apt to hear and see more than there was to see and hear, etc. He also had his initial doubts about the possibilities of the material, whether the pupils are indeed able to find things out for themselves or in the time planned for it, and therefore he had sometimes tried to speed things up by putting the words in pupils' mouths, taking over experiments, addressing himself especially to the better pupils, etc. Furthermore, sometimes our expectations had simply been too high, so that on the spot the teacher had to deal with unexpected situations. I also think that keeping a tight control with respect to content was an ingredient of his way of keeping order.

In our discussions I rather tried to make the teacher take two steps. First, to gain confidence both in the material and in the pupils. That is, the tasks, certainly when the suggestions for structural improvements are taken into account, are such that the pupils are indeed able to take control over their progress with respect to content, that also without a tight control of him in that respect they are willing and able to themselves think of experiments, carry those out, draw conclusions, formulate questions, etc. So with respect to content the steering part of the process should be initiated by the material and further driven by the pupils as they work with the material. The second step relates to the procedural aspects: to find ways to so guide the process that, on the one hand, all pupils are involved, make contributions, listen to each other, etc while, on the other, the process still proceeds orderly and structured.

In the first step we discussed cases in which, as the teacher himself had already noticed, his participation had been far too steering, and compared those to cases in which he had appropriately held back. Sometimes it was even possible to make this comparison with respect to the way that one particular activity was carried out in the two classes. This was the case, for instance, concerning the task whether or not the cleaners of an X-ray department need lead aprons.[4)] In the one class pupils were divided over the matter. The teacher subsequently gave both sides the opportunity to convince each other, an activity that he ingeniously managed by imposing the rules that the two sides have to take turns in bringing forward a point, that someone who wants to bring forward a point for his or her side has to stand up and that only someone who is standing up is allowed to speak, and that pupils are allowed to switch sides each time one side has made a point. Since neither of the sides turned out to be able to make a convincing case, the pupils were then asked to think of an experiment that could be done with the material present in the classroom and that might decide the issue. The pupils proposed to put the X-ray machine on for a while and then measure whether its walls had become radioactive. The final conclusion, on which everybody agreed, was that lead aprons are not necessary. In the other class, however, things went rather differently. There all of the pupils initially agreed that lead aprons are needed. This unexpected result (he had expected that, as in the other class, the pupils would be divided over the matter) so unnerved the teacher, that he completely took over from then. He forgot to let the pupils think of an experiment that would prove them right. Instead he called a pupil forward, told him to put the X-ray machine on for a while, to then measure the walls with a Geiger counter, and concluded that lead aprons are not necessary. This conclusion lead to quite some protests from the pupils, probably because they did not have the faintest idea why the experiment had been carried out. They certainly had not decided for themselves that it is an experiment by means of which it can be decided whether or not lead aprons are needed. Consequently, the experiment played no role in their further reasoning. What had become clear to the pupils, however, is that the teacher had launched an offensive at their communally held opinion that lead aprons are not needed, and they began to passionately defend that opinion, e.g.: dust particles or the air in the X-ray department have been irradiated and therefore are radioactive. The experiment also played no role in the teacher's further reasoning. Instead he tried to explain why e.g. dust particles cannot have become radioactive, pretty soon got stuck in the explanation when he noticed that in it he would have

4. In the second version of the didactical structure this task returned (cf section 8.4.2), but, due to some structural changes, at a different place.

to use the not yet settled concepts of irradiation and contamination, and ultimately saw no other possibility than to force the matter: as you will learn in the next chapter, irradiated dust particles are not radioactive. At that stage it had of course become clear to the pupils that the teacher very much wanted them to say that lead aprons are not necessary. So in the end they decided to meet the teacher, at least part of the way: okay, the cleaners do not need lead aprons, but they do need something else. So here we had a case where the teacher's very steering role had rather been detrimental to pupils' learning process. If the teacher had given the pupils the opportunity to themselves steer their learning process (by letting them, as the pupils in the other class, think of an appropriate experiment), then they would have been confronted with experimental facts that, for good reasons, they themselves had brought forward. The further discussion could then have been based on facts (on what is seen and heard) instead of vague speculations and not yet justified conclusions, and would then not have proceeded in an undesirable attack-and-defence context.

In the second step, the teacher thought of ways to so structure the classroom process that as much pupils as possible are given ample chance to take control over their progress with respect to content: in which cases group work is most appropriate and how it could best be organized; in which cases a class discussion is most appropriate and how it could best be initiated, guided, rounded off, etc. It was of course clear to the teacher that giving the pupils control over their learning process does not imply his withdrawal, especially not if the process is still to proceed orderly and structured. On the contrary, it requires him to draw on a whole repertory of management techniques. So the teacher studied which such techniques he had already spontaneously used (in the above I have given an example), how they had worked out, where else they could be applied, and he explicitly thought of other techniques. As it was part of his way of keeping order, for instance, to be very much present and in particular to be speaking quite a lot, we thought of a way to combine this with not taking over with respect to content, e.g.: when pupils were carrying out an experiment he could physically withdraw, but verbally be very present as a kind of commentator.

As my evaluation of the first version, via ever more concrete suggestions for structural improvements, gradually transformed into the construction of the second version, so the teacher's second step gradually transformed into writing his own guide for the second version, i.e., into a detailed specification of the instructional techniques and his role in the activities that were planned in the second version. This guide was indeed very much geared to the teacher himself, and contained all sorts of reminders that especially concerned him, e.g.: do not yet go into it; aim at mutual agreement; do not take over!; try to involve especially the 'lesser' pupils in the discussion; do not run ahead of things; take stock of all suggestions and solutions. Writing his guide was at the same time the teacher's preparation for the try-out of the second version.

10.4.3 Try-out and evaluation of the second version

At the start of the try-out of the second version of the didactical structure, both the teacher and I had quite some confidence in it, i.e., we both expected that it would come out as 'good enough.' Both of us also expected that the teacher had made himself so familiar with the essence and details of it and had so well prepared his role in it, that he could carry it out as intended. In chapter 9 I have already tried to show that both expectations came true, although some structural as well as procedural modifications were still necessary (see e.g.

section 9.4.1). I also refer to chapter 9 for a description of the cooperation between the teacher and me during the try-out and evaluation of the second version.

After the evaluation, the teacher has written a draft teacher guide that is no longer meant to be especially geared to him. It can be characterized as a shortened and more easily readable merger of (parts of) chapters 8 and 9 of this thesis, i.e., a justification of the main tasks, augmented by pupils' reactions to them and some practical clues for teachers. Out of this draft teacher guide I now quote some fragments of the closing section in which the teacher himself gives a general evaluation of the material.

> Once I described the material as 'the engine,' the 'fuel' for which is represented by pupils' contributions. Now that I've worked for several years with this material, I've discovered that this metaphor is not that badly chosen at all. The pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions. And even to the extent that the engine always got that well run in that almost as a matter of course it made its way through the topic of radioactivity. [...]
>
> Apart from that all, I in fairness have to tell that teaching in this way, with 'holding back' and 'listening,' does require quite an effort. After these lessons I generally was more tired than after lessons taught in my old way. The question then presents itself whether that additional effort balances the achieved result. I do give this question a cautious 'yes,' though. The design of the material (its structure, emphases and basic assumptions) has more appeal to me than the traditional treatment of the topic of radioactivity. Furthermore it is my experience that practically throughout the series of lessons the pupils enthusiastically continue to take part. In evaluations of the unit the pupils themselves too indicate that they have experienced 'learning from each other' and 'having come to solutions oneself' as positive [cf section 9.6, KK]. [...]
>
> I have confidence in the strategy described in this guide. You too will have to get confidence in it. All I can say is that in my series of lessons on the basis of this material [...], the necessary fuel for the engine has always been sufficiently supplied by the pupils. To put it differently: I've never been afraid that we would come to run dry; we've never even driven on the reserve tank.

10.5 Some general remarks on the role of a teacher

In this section I try to go beyond the educational experiment that this thesis reports on, i.e., beyond this particular teacher that has worked with this particular material in this particular research. In doing so I also go beyond a firm ground of experiences to base my opinions on and, to some extent, beyond my competence. So this section is of a speculative nature and should accordingly be read as a representation of some of my personal ideas. Let me begin with going beyond this particular topic. This is what the teacher has to say about it (in his draft teacher guide).

> My most important finding, though, is that you will not be able to work with this material if you haven't at least come to believe in its basic assumptions, e.g., confidence in the importance of 'postponing questions' and 'holding back' of you as teacher. Are these basic assumptions and strategy also applicable to other topics from the physics curriculum? I do think so: postponing questions will be going to function as something normal for the pupils. Especially if more often they notice that the answers are found (and often by themselves) as a matter of course. [...] Thinking of experiments oneself and drawing conclusions from those is, according to me, also of use for more topics. Does all this mean that in your physics

> classes you will tomorrow be able to begin with 'holding back,' postponing questions, letting pupils themselves think of experiments, carry those out and note down conclusions? The answer to this question is a very distinct: no! Material that makes possible such an approach for other topics simply isn't available. But if such material is to come, and it isn't up to me to take care of that, I will surely use it.

Like the teacher, I believe that the basic assumptions and strategy are applicable to other topics as well. In fact, in chapter 6 I have already quite generally presented a global outline of a didactical structure. I also think that the teacher will be able to work with material that, for some other topic, makes possible a similar approach, i.e., with a 'good enough' didactical structure of some other topic. I also think that it would not take him that much preparation time as his learning to work with the didactical structure of the topic of radioactivity has taken him. After all, he does already believe in the basic assumptions and strategy, so his preparation would simply be a matter of finding out how the basic assumptions have been detailed and how the strategy could be detailed for the case at hand. In all this, he would of course draw on his experience with (working with) the didactical structure of the topic of radioactivity. I also think that the teacher himself would not be able to construct, for some other topic, material that makes a similar approach possible. This, of course, is no disgrace. I myself, for instance, think that I am able to construct didactical structures for other topics, and that those (re)constructions will much quicker converge to 'good enough' didactical structures than has been the case for the topic of radioactivity, but I do not think of myself as good enough a teacher to be able to work with such didactical structures without any further training. But, as I have already noted, all this is speculation.

Let me speculate a bit further and ask whether other teachers than the one who participated in my research are able to work with the 'good enough' didactical structure of the topic of radioactivity (or some other 'good enough' didactical structure), and what it takes to make them able to do so. One thing that it takes, as the teacher who participated has repeatedly emphasized, is confidence in its basic assumptions and strategy on the one hand, and in the pupils on the other. In order that other teachers gain such confidence, I do not think it is necessary that they go through the whole process that the teacher who participated has gone through (and that has been the main topic of this chapter). Neither do I think that it will be necessary that they study the theoretical background, i.e., something like chapter 4 of this thesis. What I think might be useful is that they actually *have* lessons that are based on the 'good enough' didactical structure at hand and that they watch videos of (fragments of) lessons in an actual classroom. As a pupil and an observer they will thus, as it were in play, get acquainted with why and how the didactical structure is as it is. What they will have to gain confidence from, I guess, is that they see it working, that they also are impressed by the fact that "[t]he pupils indeed keep the engine going by their contributions, their enthusiasm, their ideas and especially also by their questions." I do not know whether this kind of in-service training will work. We have not (yet) got any experience with it. The teacher and I have run a couple of workshops at a teacher conference, however, in which we, be it in a time span of just one and a half hours, tried to do the sort of things just mentioned. And the fact that most teachers present at our workshops were quite enthusiastic about it, is an argument in favour of attempting an in-service training along the sketched lines.

However, having gained confidence in its basic assumptions and strategy is one thing, being able to work with a 'good enough' didactical structure quite another. It requires, for instance, that one can rather flexibly draw on a quite extensive repertory of management techniques. In the terms of Brekelmans (cf section 10.2), I would without any reservations advise only teachers with an 'authoritative' or 'tolerant and authoritative' communication style to work with a 'good enough' didactical structure. They seem to be the best teachers anyhow, no matter what instructional methods they use. Whether, and how, someone (e.g. a student teacher) can acquire the sort of desired management techniques or communication style is beyond my competence. I do think, however, that such an acquisition will involve the abandonment of some of the common ways in which (student) teachers (learn to) structure lessons, often as a means to keep order. This was once more brought to my attention by Marjolein Vollebregt, a PhD-student who, concerning her first attempts to write a didactical structure (for the introduction of particles, see e.g. 1994), had written in the diary she keeps: "I still don't succeed in writing a scenario that starts from the pupils. Too strongly I hold on to the activities and aims with respect to content in order to maintain with those the *common* control of the teacher."[5] In a verbal explanation she said that as a student teacher she had learned to structure her lessons as follows: set your goals, i.e., what pupils should be able to do at the end of the lesson; think of activities that are needed to achieve that; think of ways to control that the activities are indeed carried out as desired. So she had learned to think about the appropriateness of activities from the point of view of the teacher's aims and not from the point of view of pupils' motives. And she had learned to keep a tight control with respect to content, especially as a means to keep order, i.e., as a means to survive in the classroom. Now, of course, I also want student teachers to survive, but I wonder whether for that purpose it is necessary that they learn to structure their lessons and to keep order as indicated above. Are there no other ways that are still within the reach of student teachers? It seems to me that such questions concerning the interconnection between the methodological and the interpersonal aspects of teacher behaviour deserve a thorough investigation.

5. Quoted with approval.

11 Looking forward

11.1 Introduction

As mentioned in section 5.4.3, I take it to be an important task of science educational research to devise, empirically test, improve, etc, concrete didactical structures, with as eventual aim an empirically based didactical structure of science. I think I have taken a few steps in this direction. I have devised, empirically tested, improved, etc, a concrete didactical structure: of the topic of radioactivity (cf chapters 7 to 9). In chapter 6, furthermore, I have presented some ideas for outlining a didactical structure at a global level, of which I have suggested that they are also of use in thinking about concrete didactical structures of other scientific topics, and about the general outlines of a didactical structure that covers the whole of science education. In sections 11.2. and 11.3 I somewhat further elaborate these suggestions. They may also be read as some first thoughts about future steps that I intend to take.

11.2 Sketch of a didactical structure of the topic of heat and temperature

In this section I try to illustrate how the ideas for outlining a didactical structure at a global level that are presented in section 6.3 give a purpose and direction to one's construction of concrete didactical structures. In particular, I present an attempt to give content to these ideas in the form of a didactical structure of a topic that may provisionally be called 'heat and temperature' (what I have in mind is such subject matter as heat flow, combustion and heating processes, calorimetry, specific heat, calorific value of food, melting heat, etc).[1]

In section 11.2.1 I begin with a rough indication of what the first coherent and worthwhile endpoint in a didactical structure (a descriptive level) might look like for the case of the topic of heat and temperature. Section 11.2.2 concerns the first part of a didactical structure (the emergence of a ground level for a descriptive level), in which

1. In giving concrete form to the general ideas presented in section 6.3, one will of course have to call forth all that might be of use: one's knowledge about the topic at hand, the way the topic is treated in various curricula, the historical development of the topic, etc. In the case at hand, I have been inspired by a series of lessons on the topic of heat and temperature that has been developed and taught by Rupert Genseberger.

the foundation is laid of a descriptive level of the sort indicated in section 11.2.1. Section 11.2.3 is about the transition from ground level to descriptive level, and in section 11.2.4 I explore the possibilities for a transition from descriptive level to theoretical level.

11.2.1 First thoughts about a suitable descriptive level

Let me begin with what, from the curriculum deviser's point of view, a suitable descriptive level might be, i.e., specific ways of describing and a set of generalizations involving these ways of describing, by means of which it is possible to explain and predict a range of events that are of practical interest to an extent that is quite sufficient for practical purposes.

Concerning the specific ways of describing, I think that the following two are basic for the topic of heat and temperature: a specific use of the expression 'the temperature of *O*' and a specific use of the expression '*E* is a heat flow from O_1 to O_2,' where $O_{(i)}$ is an object (taken in a broad sense, such that, e.g., also the air in this room is an object), and *E* is an event. The specific use of the first expression involves a specific way of characterizing objects, and is straightforward: the temperature of an object is the number a thermometer displays when held against that object. The specific use of the second expression involves a specific way of relating an event and a pair of objects: it applies to an event *E* and a pair of objects O_1 and O_2 just in case the two objects are in contact and the event *E* is a simultaneous fall of the temperature of O_1 and rise of the temperature of O_2.[2)] A sentence of the form 'Heat flows from O_1 to O_2' is, accordingly, to be understood as: 'O_1 and O_2 are in contact, and an event occurs that is a simultaneous fall of the temperature of O_1 and rise of the temperature of O_2.' Henceforth I will refer to these specific ways of using the two terms as their 'scientific use,' and speak of the terms thus used as 'the two basic scientific notions.'

The two scientific notions are basic in the sense that they have simple criteria of application. They are also basic in the sense that further notions can be based on them. The qualitative notion '… is a heat flow from … to …' can e.g. be turned into a quantitative one: 'the amount of heat that has flown from … to …,' by reference to the change in temperature of some conventionally chosen 'standard' (one litre of water). This quantitative notion in turn allows the introduction of further quantitative notions such as those of specific heat, calorific value or rate of heat flow.

Concerning the generalizations involving the basic scientific notions, one can for

2. Note that concerning the words 'temperature' and 'heat' similar comments can be made as in section 2.2.3 concerning the word 'force:' they too do not refer to any entity whatsoever; they too do not have a meaning in isolation, but only as they are part of larger expressions; and also to understand those expressions no other ontology is required than the familiar one of objects and events (no abstract entities -one might try temperatures or portions of heat, whatever those might be- need to be added to this familiar ontology). The smallest meaningful expressions in which the words 'temperature' and 'heat' occur are 'the temperature of …' and '… is a heat flow from … to …' respectively. Of course, when it is clear what is meant shorter expressions may be used, e.g.: 'The temperature is 13°C' as shorthand for 'The temperature of the surrounding air is 13°C.'

instance think of the following one: if two objects of different temperature are brought into contact, then there will be a heat flow from the object with the initial higher temperature to the other until, in the end, the temperature of both objects is equal. Or of a quantitative form of that generalization, which involves specific heats. Or of a generalization that involves rates of heat flow between the two objects.

A descriptive level of the sort outlined above, moreover, offers the perspective of an improved understanding of real life situations or situations that are of practical interest, to an extent that is quite sufficient for practical purposes. Together with the numerical values of the specific heats of some materials, it can, e.g., be used to (at least partly) understand why seas react rather slowly to changes in temperature, or to choose appropriate lagging materials. And if one chooses to also indicate how the calorific value of food is determined (roughly: burn a piece of food and measure the resulting change in temperature of a surrounding bath of water), the descriptive level can be used to (at least partly) understand how we keep our body temperature.

11.2.2 The emergence of a ground level

This section concerns the emergence of a ground level, i.e., an intermediate stage that, from the pupils' point of view, provides their further process with a purpose and direction and, from the curriculum deviser's point of view, contains enough germs for that further process to develop into a descriptive level of the sort outlined above. Pupils' arrival at a ground level involves the inducement of a global motivation and practical problems, and the creation of appropriate places in pupils' existing conceptual apparatus for the two basic scientific notions to occupy. Below I devote quite some space to the emergence of a ground level, because in a sense it is the most important part of a didactical structure. It is the part in which the whole process has to be set on the right track.

Inducing a global motivation

In thinking about a way to induce a global motivation for the topic of heat and temperature, one will have to think of a way of introducing the topic that makes a further study of the topic relevant to pupils, at least to some extent. One may, e.g., try to introduce the topic in the context of some questions concerning real life situations that, from the pupils' point of view, are interesting enough and clearly have got something to do with 'heat and temperature,' and that, from the curriculum deviser's point of view, are such that in the further course they can (at least partly) be answered. E.g.: why it is that seas react so slowly to changes in temperature (summer and winter), and how this influences the weather; how houses can best be insulated in order to save money and resources; how it is that we ourselves stay warm. I think it would be good to think of some more questions of this kind in order to induce a global motivation that is strong enough to make pupils stand ready to learn more about the topic of heat and temperature.

A suitable practical problem

It will be clear from section 11.2.1 that, whatever the details of the descriptive level turn out to be, pupils' reaching it will for an important part consist in an empirical study of what happens to the respective temperatures of two objects that are brought into contact. Pupils' arrival at a ground level for the descriptive level will therefore have to consist in making them see the point of such a study. Accordingly, a suitable practical problem to be induced in the case at hand will be something like: to systematically find out what happens to the temperatures of two objects that are brought into contact.

Analysis of the relation between the basic scientific notions and pupils' existing conceptual apparatus

As I try to demonstrate below, the above practical problem is more or less naturally induced in the process of creating appropriate places for the two basic scientific notions in pupils' conceptual apparatus. Or, put differently, their seeing the point of a systematic study of what happens to the respective temperatures of two objects that are brought into contact emerges more or less simultaneously with their seeing the point of having available the two basic scientific notions. As a preparation to this demonstration it will be good to first analyze how those notions relate to pupils' existing conceptual apparatus.

Let me begin with the scientific notion 'the temperature of ....' It may at first be argued that this notion is already part of pupils' existing conceptual apparatus. And in a sense this is true, of course: pupils are familiar with thermometers and know that they are used to measure, e.g., the temperature of the surrounding air, or one's body temperature.

I also think, however, that there is a sense in which the scientific notion 'the temperature of ...' is not part of pupils' existing conceptual apparatus, namely in the sense that it is not an independent notion in their existing conceptual apparatus. To be more specific, in everyday life a thermometer functions as a sort of extension of our senses, which is used to obtain a more precise indication than our senses allow (taking someone's temperature) or to communicate to others how warm it will feel (weather forecast), and which can also be used when we ourselves would not want to feel how warm something is (very hot or cold objects). What makes a thermometer a trustworthy instrument for these purposes, is that it displays a higher number when it, or something, feels warmer. For daily life purposes, therefore, the relation 'O_1 has a higher temperature than O_2' (i.e., 'the temperature of O_1 is higher than the temperature of O_2') serves as a kind of objective form of the more basic relation 'O_1 feels warmer than O_2,' in the sense that statements of the kind 'This has a higher temperature than that' serve to indicate that this will feel warmer than that.

So although the everyday relational expressions 'O_1 has a higher temperature than O_2' and 'O_1 feels warmer than O_2' do have a different meaning, in the sense that to establish whether the former relation holds one has to use a thermometer and to establish whether the latter holds one's own senses, for daily life purposes they are (and can be) used as having the same extensions, i.e., as either both holding or both not holding.

Let me now turn to the second scientific notion, '*E* is a heat flow from O_1 to O_2,' and see how it relates to pupils' existing conceptual apparatus. Recall from section 11.2.1 that this notion applies to an event *E* and a pair of objects O_1 and O_2 just in case the two objects are in contact and the event *E* is a simultaneous fall of the temperature of O_1 and rise of the temperature of O_2. Now surely this notion is not part of pupils' existing conceptual apparatus.

There is, however, an existing everyday use of the expressions 'heat/cold flow from/to' that is very basic in the sense that it relates to one's own heat sensation. The everyday use I have in mind here is that someone, when touching a cold object, says: "I feel the cold flow into my hand" or "I feel the heat flow out of my hand." The relation between this everyday use and the scientific notion is as follows. If, according to scientific usage, there is a heat flow from one object to another and one of the objects is (a part of) our body, we experience what, according to everyday usage, is called 'a heat/cold flow from/to (that part of) our body.'

So there are clear differences between the scientific use of the expression '… is a heat flow from … to …' and the everyday use: the scientific use involves thermometers and the everyday use one's own heat sensations; the scientific use is broader in the sense that it allows one to establish whether the expression has application in cases where the everyday use has no direct application, i.e., where neither of the two objects that are brought into contact is (a part of) one's body. But in those cases in which the expression has application according to everyday usage, i.e., in which we have a bodily experience of a heat/cold flow, it also has application according to scientific usage.

The creation of appropriate places for the basic scientific notions in pupils' conceptual apparatus more or less naturally induces the practical problem

Let me now address the creation of appropriate places in pupils' existing conceptual apparatus for the two basic scientific notions to occupy. Concerning the notion 'the temperature of …,' the above analysis suggests that what has to be created in pupils' conceptual apparatus, is a place for the relation '… has a higher temperature than …' *as distinct from* the relation '… feels warmer than ….' In a while I will come back on how this creation can appropriately be given concrete form. Let me here just note that, obviously, part of this creation will consist in pupils' observation, in a few clear cases, that the latter two relations do not have the same extensions, e.g., the observation that the temperature of this wooden bar equals the temperature of that iron bar, while the wooden bar feels warmer than the iron bar. What I want to illustrate first, is that such observations more or less naturally trigger further observations which, in turn, *both* create a place in pupils' conceptual apparatus for the scientific notion '… is a heat flow from … to …' eventually to occupy *and* give a point to a further study of what happens to the respective temperatures of two objects that are brought into contact. The basic idea is as follows.

The above analysis suggests that a place for the scientific notion '… is a heat flow from … to …' eventually to occupy can be created by pupils' observation, in a few clear cases, that a bodily experience of what, according to everyday usage, is called a 'heat/cold flow from an object to (a part of) our body,' or *vice versa*, is accompanied by a rise or fall in the temperature of that object. Or, to put it somewhat differently, the reason why the scientific notion is not part of pupils' existing conceptual apparatus, is not that its application is particularly difficult or something. In fact, its application involves not much more than the ability to read a thermometer. The reason that there is no such existing everyday use is rather that in daily life simply no occasions arise in which it is worthwhile to measure with thermometers what happens to the respective temperatures of two objects that are brought into contact.

Once a place for the relation '… has a higher temperature than …' as distinct from the relation '… feels warmer than …' has been created, however, I think that such an occasion quite naturally arises. For I think that, once it has e.g. been established that the temperatures of the wooden bar and the iron bar are equal while the wooden bar feels warmer than the iron bar, it is at least not strange to raise the question what happens to the temperatures of the wooden bar and the iron bar when they are held in one's hands.[3)]

It will then be noticed that while both temperatures rise, and in the end to approximately the same temperature, the temperature of the iron bar rises faster than that of the wooden bar. Moreover, while noticing the rise in temperature of e.g. the iron bar, one experiences what, according to the everyday usage, is called 'a heat flow out of one's hand' (or, alternatively, 'a cold flow into one's hands'). In the end, furthermore, the wooden bar and the iron bar feel equally warm.

I think that such observations play an important role, on the one hand, in making pupils see the point of having available an expression that applies to an event and a pair of objects in case the two objects are in contact and the event is a simultaneous fall of the temperature of one and rise of the temperature of the other object, and on the other hand in making pupils see the point of agreeing to use the expression '… is a heat flow from … to …' for this purpose.

Firstly, the observations give a point to a further study: at first, perhaps, of what happens to the temperature of one's hand when, e.g., one holds the iron bar; later, more generally, of what happens to the respective temperatures of two arbitrary objects that are brought into contact. In this further study the point will come forward of having available an expression that applies to what then invariably seems to happen: a simultaneous fall of the temperature of the object with the initial higher temperature and rise of the temperature of the other object.

Secondly, an agreement to use the expression '… is a heat flow from … to …' for this purpose, can be made plausible for pupils by their observations that, when one of the objects involved is a part of their body, the rise or fall of the temperature of the other object (and simultaneous fall or rise of the temperature of that part of their body) is accompanied by a bodily experience of a heat/cold flow from/to (that part of) our body.[4)] By this agreement, then, the scientific notion '… is a heat flow from … to …'

3. The experimental setting here can be rather straightforward. Genseberger uses wooden and iron bars in which a hole has been drilled to accommodate a thermometer. The thermometers that he uses, furthermore, are quickly responding liquid-in-glass thermometers.
4. Note that it is part of making this agreement that, instead of calling an event that is a simultaneous fall of the

functions as a sort of extension of our senses: it has application in those cases in which one has a bodily experience of a heat/cold flow; its criteria of application are such, moreover, that it can also be established whether it has application in other cases.

In the above I have already noted that some of the observations give at least some point to a further study of what happens to the respective temperatures of two objects that are brought into contact, i.e., to pupils' appreciation of the practical problem. Let me here add that pupils' intention to tackle a problem like this one will of course be further strengthened if the problem can be given a further point, e.g. by relating it to some of the questions that have been raised in the global motivation. I think this is indeed possible. Take, for instance, their observation that, when holding the wooden bar and the iron bar in one's hands, the temperature of the iron bar rises faster than that of the wooden bar. I think it will be intuitively clear to pupils that this finding is somehow of relevance to understand why seas react so slowly to changes in temperature and why one material has better insulating quality than another, and that the findings which will come forward in a further study can be expected to throw further light on such matters.

Some concrete activities to set the creation of appropriate places in motion

Let me now come back on what I have left open in the above: to give concrete form to the creation in pupils' conceptual apparatus of a place for the relation '… has a higher temperature than …' as distinct from the relation '… feels warmer than …' in an appropriate way, i.e., by productively making use of their existing knowledge and uses of language. I have already noted that part of this creation consists in pupils' observation, in a few clear cases, that the two relations do not have the same extensions. I think it would not be appropriate, however, if the creation started with this part, i.e., if in one of the first activities pupils were asked to measure the temperatures of, e.g., a wooden bar and an iron bar (or to first predict and then measure). For although they will then find, probably to their surprise, that the temperatures are equal, may come to realize that their surprise (and/or previous prediction) has to do with the fact that the wooden bar feels warmer than the iron bar, or perhaps even come to realize that in their expectation that the temperature of the wooden bar would be higher than that of the iron bar they implicitly made use of a generalization that was based on situations they had come across[5)] (e.g., whenever an object feels warmer than another its temperature is higher than that of the other), I think some further preparation is needed in order to secure that pupils will be able to give this finding (with accompanying realizations) its proper place amidst their existing knowledge. In particular, this finding should not lead them to call in question that, for daily life purposes, a thermometer *is* a trustworthy instrument. On the contrary, the proper place of the finding ought to be that, although a thermometer is and remains a trustworthy instrument for everyday purposes, there are also situations (such as that of the wooden and iron bar) which show that the above

temperature of one and rise of the temperature of the other of two objects that are in contact 'a heat flow from the one to the other object,' one could also have agreed to call such an event 'a cold flow from the other to the one object.'

5. See section 2.2.3 for a similar remark.

mentioned generalization does not hold good, and that these situations deserve a further investigation.

The above objection to letting pupils (predict and) measure the temperatures of a wooden and iron bar too soon, can also be put as follows: pupils will then become aware of the generalization (as part of their realization that their expectation was implicitly guided by it) in a *negative* context, namely as part of their finding that it does not hold good; and this may prevent that their finding finds the above mentioned proper place in their existing knowledge. Putting the objection this way, readily suggests an activity that has to precede one in which they (predict and) measure the temperatures of, e.g., a wooden and iron bar, in order that their finding then does find its proper place (e.g. in the form that the generalization does *not always* hold good), namely an activity in which they first become aware of the generalization in a *positive* context, i.e., in a context in which its holding good is explicitly reinforced. The following task may initiate this.

> Describe some situations in which you want to know how warm (or cold) something is, or whether something is warm (or cold) enough.
> Why do you want to know this in these situations?
> How do you find this out in these situations?

Note that this task links up with everyday language in the sense that the everyday expression 'how warm … is' is used. Furthermore, the task links up with pupils' existing knowledge in the sense that they are asked to draw upon their own experience. It can be expected that they will bring forward all sorts of situations (the weather, food, drink, shower, flame, body, freezer, etc); several different purposes, depending on the situation (not want to be surprised by a throw of cold water, find out whether someone has fever, etc); and all sorts of ways of finding out, depending on the situation (just feel it, feel with hands, lips, elbows, measure with thermometer, trust the measurements of others, hear a whistling kettle, see a misted window, etc). In order to find out how warm something is, the use of a thermometer is thus expected to naturally come forward as one of the means, alongside in particular the more basic use of one's own heat sensation. As an introduction to the following task, the teacher may explicitly bring this to pupils' attention, e.g.: in some situations we feel for ourselves how warm something is, in others we (also) use a thermometer; why is that, or, why do we use thermometers anyhow for something we ourselves are also able to feel? The following task, accordingly, is:

> What is the point of using thermometers?

I expect that, on the one hand, this task will challenge pupils because they have never actually thought about the point of using thermometers while, on the other, they will be able to answer the question by reflecting on and productively using what they have brought forward in the previous task. In particular I expect that in thinking about the question the above generalization's holding good is explicitly reinforced: although we could in principle feel for ourselves instead of using a thermometer, in some situations there nevertheless is a point in using a thermometer (to obtain a more precise indication than our senses allow, to communicate to others how warm it is, to find out how warm something is when we ourselves would not want to feel it, etc).

The generalization's holding good can be further reinforced as part of an activity that the above quite naturally gives rise to. An activity, namely, in which some measurements with thermometers are actually done in order to substantiate some of the points of using thermometers that pupils have brought forward, e.g.: that there are indeed thermometers by means of which it can be established how warm or cold, e.g., a flame or solid carbonic acid is; that a clinical thermometer allows a more precise indication than our senses, etc. Some experiments can then also be done in which it is found that, indeed, a thermometer displays a higher number when something feels warmer. Furthermore, when thermometers with different scales are used (e.g., Fahrenheit and Celsius) it may come forward that the fact that they display different numbers does not really matter. All that matters is that both do what they are supposed to do: display a higher number when something feels warmer.[6)] Towards the end of an activity like this one, finally, some experiments can be done in which it is not the case that a thermometer displays a higher number when something feels warmer, e.g. by measuring the temperature of a table's wooden top and one of its iron legs.

In the above I have in some detail indicated how pupils can come to see the point of extending their conceptual apparatus with the two basic scientific notions. Since part of this extension consists in agreements to use some expressions in a specific way, they will then also see the point of using those expressions in accordance with the agreements. Let me add here that in general it will take some time before they will be able to do so routinely, and so they must be given that time. They can, of course, be challenged to appropriately use the appropriate expressions, e.g.: if they use the everyday expression '… is warmer than …,' they can be reminded that in some situations it is necessary to be more precise and to specify both which of two objects feels warmer and which of those has a higher temperature.

11.2.3 From ground level to descriptive level

I think that in a process of the sort outlined in the previous section a proper ground level emerges for a descriptive level of the sort outlined in section 11.2.1. Pupils have come to see the point of a further study of heat flows between objects that are brought into

6. An activity in which some measurements with thermometers are done can also be made useful in other ways. For one thing, it offers opportunities to bring forward points that later on can be referred back to. More or less in play, for instance, the pupils will get familiar with some thermometers (with their range, precision, mode of handling, etc) such that later on they can choose the appropriate ones for a given situation. Moreover, the fact that there are thermometers with different scales, each of which does what it is supposed to do, pro-vides a relatively simple case for realizing that some arbitrary choices have to be made if one wants to turn some qualitative notion (in this case '… is warmer than …') into a quantitative one (in this case 'how warm … is'). This can be referred back to later on, in the more difficult case of turning the qualitative notion '… is a heat flow from … to …' into a quantitative notion 'the amount of heat that has flown from … to ….'

contact, and expect that this further study will also lead to an improved understanding of real life situations or situations of practical interest. From the curriculum deviser's point of view, moreover, it is reasonable to expect that in the course of a further study pupils will arrive at, and come to value, a descriptive level of the sort outlined in section 11.2.1. Since the two basic scientific notions have simple conditions of application, for instance, their further study naturally consists in an empirical investigation. Thus, pupils can play an active part in the establishment of appropriate generalizations involving the basic notions, e.g.: if two objects of different temperature are brought into contact, then there will be a heat flow from the object with the initial higher temperature to the other until, in the end, the temperatures of the two objects are equal. In order to throw further light on real life situations or situations of practical interest, a need to make this finding more precise is expected to arise, e.g.: what the final temperature, the rates of temperature change, etc, depend on, and how. In this process, the point of introducing further notions such as those of amount of heat flow and specific heat is expected to come forward. And as already noted in section 11.2.1, such further notions can be based on the two basic scientific notions that pupils already command. Appropriate generalizations involving the further notions, finally, are indeed relevant to matters of practical interest (as also noted in section 11.2.1).

I now leave unspecified any further details of a transition from ground level to descriptive level. Let me just make two general remarks that ought to be borne in mind in giving concrete form to this transition. The first is to pay special attention to the 'specific way of describing' part that plays an unavoidable role in applying generalizations to specific cases. In particular I think that pupils need to be given the opportunity to become skilled in analyzing ever more complex situations in terms of pairs of objects that are in contact and between which heat flows occur. The second general remark relates to the fact that, in principle, the descriptive level could be extended almost without end: in the direction of heaters, combustion processes, melting and boiling processes, the calorific value of food, physiological processes that are involved in heat sensation, and so on. The remark is an obvious one: in choosing between possible further extensions, a guiding principle is to ask oneself (as curriculum deviser) which further extensions are most relevant to matters of practical interest.

11.2.4 From descriptive level to theoretical level

Let me finally briefly discuss the possibilities of a transition to a theoretical level. I think that an attempt at such a transition can be made if (1) the descriptive level is extended far enough, in particular in the direction of melting and boiling processes, and if independent of the topic of heat and temperature (2) pupils have already got somewhat at home in scientific particle models in the course of arriving at one specific such model, namely (a simplified version of) the kinetic theory of gases.[7] In section 5.3.2 I have already noted that to achieve the latter poses a non-trivial educational task. I will not address this task now (see Vollebregt, 1995, for some suggestions), but rather

7. Perhaps it is also good to add that the pupils I have in mind here are higher ability pupils in the top classes of secondary school.

assume that it has been met, i.e., that condition (2) above is satisfied. If then also condition (1) is satisfied, I think that in the course of arriving at the descriptive level some theoretical problems are likely to come forward (or rather easily to induce) that at least offer the perspective of a transition towards a theoretical level, namely in the form of an extension of the kinetic theory of gases towards a (simple) scientific particle model that also applies to liquids and solids. Let me give an example.

One of the generalizations that pupils have established quite early in the transition from ground level to descriptive level is that if two objects of different temperature are brought into contact, then there will be a heat flow from the object with the initial higher temperature to the other until, in the end, the temperatures of the objects are equal. In studying melting and boiling processes, pupils will have found, probably to their surprise, that for such processes this generalization does not hold. Where they had expected, e.g., a heat flow from an object with an initially higher temperature to an object undergoing a change of phase, in the sense that if the latter object were replaced by an object not undergoing a change of phase its temperature would rise, this turns out not to be the case for the object undergoing the change of phase. In fact, it will be found that its temperature remains constant during the phase transition.

Although in the further process pupils may have modified the agreement concerning the expression '… is a heat flow from … to …' in order to also speak of heat flows in the case of melting and boiling processes, and may have established and come to value some further regularities governing such processes (including, e.g., the definition and measurement of melting and boiling heats of some substances), I think that the above finding itself is also likely to raise a theoretical question. The question, namely, why it is that in some cases there is a rise in the temperature of some target object and in other cases not, and that asks for an answer that goes beyond the true, but nevertheless somehow unsatisfactory statement that in the former cases the target object does not and in the latter cases does undergo a phase transition. This demand for deeper understanding may also be called a demand for a unification of 'ordinary' heat flow processes and melting and/or boiling processes.

In order to meet this demand, pupils' already being somewhat at home in scientific particle models can be brought into play. That is, a switch to a vocabulary similar to the one they have made in arriving at (a simplified version of) the kinetic theory of gases may be suggested: to also characterize liquids and solids as a collection of particles, and to try to reach the required deeper understanding in terms of changes of position and velocity of these particles (as the kinetic theory of gases has enabled them to reach a deeper understanding of the behaviour of gases). It may further be suggested to take over one of the hypotheses of the kinetic theory of gases, and to generally equate the temperature of an object with the mean speed (or something like that) of the particles.

I think it is then not beyond higher ability pupils in the top classes of secondary school to at least try to answer the theoretical question, guided by the sorts of explanation they have already given in terms of the kinetic theory. Perhaps they can also arrive at (or at least come to appreciate) an answer somewhat as follows. When two collections of particles, of which the mean speed (or something like that) in the one collection is initially higher than that in the other, are brought into contact, such that collisions can occur between particles of both collections, one thing that can happen as a result of the collisions is that the mean speed of the particles in the former collection gradually decreases while at the same time the mean speed of the particles in the other gradually increases until, in the end, the mean speed of the particles in both collections is equal (ordinary heat flow between two objects); another thing that can happen is that the collisions not so much lead to an increase in the mean speed of the particles in the latter collection, but to structural changes in the pattern of motions of the particles in that collection (change of phase). Further assumptions can be made about the sorts of pattern of motions that distinguish solids, liquids and gases. The relative stability of these sorts of pattern, as well as the transitions between them (the changes of phase), can eventually be further accounted for by means of appropriate (qualitative) hypotheses concerning the forces that the particles mutually exert on each other. And so on.

11.3 Toward a didactical structure of science

In the above I have pointed at what I think is an important task of research in science education: the development, evaluation, improvement, etc of didactical structures of a variety of science topics. As an equally important task I consider the construction of, what may be called, a didactical structure that covers the whole of science education, from kindergarten to the end of secondary school (or even further). What I have in mind is a map of science, for a science education fit for all the people (cf Ogborn, 1994a): a global outline of science education, with a segregation into its various subdisciplines at a time that this makes sense to pupils, "with staging posts along the way which also provide coherent and worthwhile endpoints," e.g., for the various ability levels or for pupils who at some stage drop a particular subject (Millar *et al*, 1990); by means of which pupils get a fair idea of what science is about, of its (various) modes of explanation, of how it is made, of its value, of its relation to society, technology, mathematics, the humanities, etc; which contributes, moreover, to their development towards grown-ups with a charitable and critical attitude who are willing and able to take their responsibility;[8)] all this, finally, as a part of providing pupils with an orientation on possibilities to fill their future lives.

I do not think that the two above mentioned tasks are separate ones, nor that the one can

8. I think that science education provides plenty of opportunities to contribute to this, if it is cast in a problem-posing form. For then pupils will have to reason both deductively and inductively, follow the reasoning of others, weigh their hypotheses and those of others in the light of available evidence, collect new evidence in order to decide between various hypotheses, weigh the value of scientific knowledge also in the light of e.g. the ethical issues raised by its possible applications, and, more generally, take some control over and responsibility for what they are doing -in particular, concerning the progress they make with respect to content. The way the scientific content itself is expressed, moreover, which e.g. involves the use of expressions in a way that is different from everyday use, provides an excellent playground for practising careful interpretation.

only be dealt with after the other has been completed. Rather, work on one task may benefit from work on the other. Let me just give a few examples, without in any way pretending to be exhaustive. Having available some examples of how, for a specific topic, pupils' learning may be cast in a problem-posing form, for instance, may serve as a source of inspiration to also try to do so on a more global level, i.e., to so arrange science education that not only topic by topic pupils themselves will experience their learning process as an internally coherent one with a certain direction that in important respects is being driven by their own questions and interests and over which they have some control, but also across various topics or even subjects. When thinking about a didactical structure of science, one will thus, among other things, have to think both of topic- or subject-transcending themes (e.g., modelling) and of topic- or subject-immanent themes (e.g., particular modes of explanation), because it is by means of themes of both kinds that pupils may, e.g., become explicitly aware of how the whole of science hangs together, or come to see the point of a segregation of science into its various subdisciplines. Having available some such themes, will in turn influence one's construction of a didactical structure of some specific topic, because one must then also think of whether and how such themes can for the topic at hand be brought forward in a way that makes sense to pupils and in relation to how it has come forward in other topics.

Another aspect of devising a didactical structure that covers the whole of science education is, as already noted, to specify staging posts along the way that may also serve as coherent and worthwhile endpoints. Since a didactical structure of some specific topic has a hierarchical structure, with as natural intermediate level a descriptive level, such a (more or less extended) descriptive level may very well serve as a staging post,[9] at which some pupils get off the bus and others (perhaps later) continue their trip. On the other hand, and perhaps inspired by the sort of hierarchical structure within a didactical structure, one may also look for some kind of hierarchical structure within e.g. a subject-transcending theme from which one may derive intermediate staging posts concerning that particular theme (as Ogborn, 1994b, has done concerning the theme 'modelling'). As above, having available some such intermediate staging points will in turn influence one's construction of didactical structures of specific topics.

9. A ground level does not provide a coherent and worthwhile staging post, because it only functions as a foundation for a following descriptive level. It is no endpoint in itself.

Appendix 1: Toward a theory of interpretation

1 Introduction

This appendix concerns Davidson's theory of interpretation,[1)] which aims to make explicit what it is that makes one rational agent intelligible, more or less, to another. Davidson's inspiration concerning the form that an interpretative theory should take comes from theories of fundamental measurement. In section 2 I point at some main aspects of theories of measurement, in order to indicate how an interpretative theory could be modelled upon them. In section 3 I sketch an interpretative theory that is so modelled: Bayesian theory of preference, which concerns the interpretation of choice behaviour as intentional action. In section 3 I also discuss its essential differences with theories of measurement. In section 4 I point at a deficiency of the theory of preference, and mention the possibility of mending this deficiency. If this possibility is realized, the result will be an interpretative theory that incorporates a structure with the following very interesting property: the observable behaviour of an agent whose behaviour exhibits that structure fixes what that agent believes, wants, and means by his or her words. This theory, in turn, may serve as the bedrock of an even more comprehensive interpretative theory, a further development of which in my opinion deserves a lot of effort because it promises to be of important methodological relevance to the social sciences.

2 The structure of a theory of measurement as a source of inspiration

2.1 An axiomatically specified structure with intuitively desired properties

Measurement, roughly, is the assignment of numbers to objects or events to represent their qualitative properties and relations. Theories of fundamental measurement contain two (interrelated) parts: a formal component and an empirical component. The formal component axiomatically specifies a structure, which contains some basic or primitive (in the sense of undefined) terms on the basis of which the axiomatization is made. For example, the formal component of a theory that is intended as a measurement theory of length contains as primitive terms the following three: a non-empty set A, a binary relation $\supseteq$ on A, and a closed binary operation that maps $A \times A$ into A; a structure specified by, amongst others (see, e.g., Krantz *et al*, 1971, for more details), the following axioms:

(*Transitivity*) $\supseteq$ is transitive on A: if $a \supseteq b$ and $b \supseteq c$ then $a \supseteq c$,

1. The reader who is familiar with the work of Davidson will in what follows recognize fragments or paraphrases of fragments from several of his articles. In order to increase readability I have, in what follows, chosen to not explicitly refer to any of these articles. The interested reader will find enough references in chapter 4 of the main text.

(*Connexity*) $\supseteq$ is connected on A: $a \supseteq b$ or $b \supseteq a$ (or both),

(*Positivity*) $a \quad b \supseteq a$;

with the set A read as 'the set of straight, rigid rods,' the relation $\supseteq$ as 'is at least as long as,' and the operation as 'joining rods end-to-end along a straight line.'

As with any system of axioms, one will first of all have to make some comments concerning the formal adequacy of the structure thus axiomatically specified. That is, one will have to make plausible that the structure has intuitively desired properties that make it adequate to its designed purpose. One thing one will have to ask oneself is whether what the axioms formally specify is indeed what one intuitively requires of the primitive terms under the intended reading. What the axiom of transitivity specifies, for instance, is indeed at least one thing intuition demands of the relation 'is at least as long as.' That is, it is (at least partly) *constitutive* of the relation 'is at least as long as' that it should be transitive. Another aspect concerning the formal adequacy consists in the discovery and proof of a so-called *representation theorem*. That is, a theorem that asserts the existence of a relation-preserving function from any structure that satisfies the axioms to a numerical structure of a specified kind, and thus in effect asserts that the axiomatically specified structure is adequate to its intended application as a theory of measurement. For structures specified by the above (and some other) axioms, for example, which are known as positive extensive structures, one can prove the following representation theorem: there exists a positive real-valued function $\Phi: A \rightarrow \mathrm{R}^{+}$, such that, for all $a, b \in A$

(i) $a \supseteq b$ if and only if $\Phi(a) \geq \Phi(b)$;

(ii) $\Phi(a \quad b) = \Phi(a) + \Phi(b)$.

2.2 Empirical content

The formal structure in itself clearly cannot yet serve as some particular empirical theory of measurement. Indeed, we require the axioms of connexity and transitivity to hold in any particular measurement theory, whether of length (in which case we read the relation $\supseteq$ as 'is at least as long as'), weight ('is at least as heavy as'), temperature ('is at least as warm as'), or whatever. For unless these two axioms hold in full generality on some specified set A, there is no consistent (relation-preserving) assignment of a number to any entity in the set. Nor does the formal axiom system as a whole exhaust the import of any particularly intended reading of the relation $\supseteq$. The formal axiom system of a measurement theory of length, for example, is the same as that of a measurement theory of weight, and so that axiom system itself does not distinguish between the relations 'is at least as long as' and 'is at least as heavy as.' What has to be added to the formal structure is an empirical component: an indication of how the formal structure is to be applied to appropriate objects or events; a way of giving empirical content to the undefined relations and operations in terms of empirically realizable relations and operations, which e.g. distinguishes 'is at least as long as' from 'is at least as heavy as.'

We cannot beforehand demand a precise indication of how to do this, though our attempts to relate e.g. the notions of being at least as long as or at least as heavy as to empirically realizable tests will of course be guided by our intuitions as to what is the content of the idea of one thing being at least as long, or heavy, as another. Finding a useful method for applying the theory thus is an enterprise of fitting and fudging: of trying out various ways of giving empirical content to the undefined terms in the formal structure, and eventually choosing one that satisfies pre-existing intuitions fairly well and at the same time verifies the axioms fairly well. Two outcomes of such fitting and fudging are of course familiar:

- *A* is the set of rigid rods; when rods *a* and *b* are placed side by side with one pair of endpoints coinciding and the opposite endpoint of *b* does not extend beyond that of *a*, then a $\supseteq$ b;   is the operation of joining rods end-to-end along a straight line;
- *A* is the set of material objects; when objects *a* and *b* are placed on the two pans of an equal-arm pan balance and the pan on which *b* is placed does not drop, then $a \supseteq b$; is the operation of placing objects in the same pan.

The combination of each of these two outcomes with the axiomatically specified structure yields an empirical measurement theory (of length and weight respectively). These theories should, of course, not be considered in isolation. In fact, both of them are, in turn, partly constitutive of the idea of a system of macroscopic objects.

2.3 Indeterminacy

A representation theorem asserts the existence of an assignment of numbers to objects or events that maps their relations. In general there exist many different such assignments, which are all acceptable in the sense that they map the same relations. And for many types of non-numerical relational structure one can prove a so-called *uniqueness theorem*, which precisely characterizes in what the different acceptable assignments differ. For the case of positive extensive structures, for instance, the corresponding uniqueness theorem is as follows: if both Φ and Φ' satisfy (i) and (ii) above, then there is a positive constant α such that $\Phi' = \alpha\Phi$. Or alternatively, an acceptable assignment is unique up to multiplication of all the numbers by some positive constant. For other structures the acceptable assignments may be unique up to some other class of transformations. For example, in the case of structures that are intended as a measurement theory of time (which contains, amongst others, primitive terms that are intended as 'the set of all events' and the relation 'does not begin later than') or as a measurement theory of ordinary temperature, any acceptable assignment of numbers can be converted to another by a positive linear transformation ($\Phi' = \alpha\Phi + \beta$, with $\alpha > 0$).

One might express the establishment that in each case there are many different but equally acceptable assignments of numbers by saying that the measurement of weight, temperature or time is indeterminate, or that there is no fact of the matter as to what an object weighs or how warm it is, or as to when an event begins, but these would be unhappy ways of stating what has been established. For what has been established is not that something is there which it is impossible to determine, but rather that there is nothing there to determine. The question whether the relations between rigid rods are better represented by an inch scale or a centimetre scale, for instance, has no answer, not because we cannot find the answer but because the question is meaningless. A better way of putting the value of a uniqueness theorem is that it clearly separates matters of fact from conventional matters. Matters of fact alone do not single out one of the many possible assignments of numbers, and precisely for that reason some things still have to be (arbitrarily) settled by agreement if we decide to assign numbers: a unit in the case of length or weight; a unit and a zero point in the case of temperature or time.

2.4 Testing a measurement theory versus applying a tested measurement theory

From the above it is clear that we cannot intelligibly assign, e.g., a length to any object unless a comprehensive measurement theory holds for objects of that sort. A comprehensive measurement theory is specified, as suggested above, by some formal axioms that are (at least partly) constitutive of the primitive terms under the intended reading, and some postulates that give (at least partly) the empirical content of the primitive terms under the intended reading. For the relation $\supseteq$, under the intended reading 'is at least as long as,' such a postulate may be given by:

(*Postulate for* $\supseteq$) If, when rods *a* and *b* are placed side by side with one pair of endpoints coinciding, the opposite endpoint of *b* does not extend beyond that of *a*, then a $\supseteq$ b.

The axioms and postulates together yield an empirical theory of great strength. For example, the axioms of transitivity and connexity tog ther with the above postulate for $\supseteq$ entail the following empirically testable statement or theorem within the measurement theory of length:

(*Theorem*) There do not exist three rods *a*, *b* and *c* such that:

(1) when rods *a* and *b* are placed side by side with one pair of endpoints coinciding, the opposite endpoint of *a* extends beyond that of *b*, and
(2) when rods *b* and *c* are placed side by side with one pair of endpoints coinciding, the opposite endpoint of *b* extends beyond that of *c*, and
(3) when rods *a* and *c* are placed side by side with one pair of endpoints coinciding, the opposite endpoint of *c* extends beyond that of *a*.

The measurement theory does not, however, entail quantitative statements like, e.g., 'The length of this object is 1.92 metre,' and consequently quantitative statements do not play any role in testing whether or not the theory holds. It are only qualitative statements like the above theorem that are directly involved in testing the measurement theory of length. If the theory ustains such tests, this is evidence for the existence of a certain structure in empirically realizable operations and relations, a structure we can find in nature.

The existence of this structure, then, is the fact of the matter, to which a representation or uniqueness theorem does not add anything substantial. They are not theorems *within* a measurement theory but theorems *about* it. A representation theorem only makes a comment, so to say, on the structure found in nature, namely that it is of a kind that allows it to be represented in numbers. And a uniqueness theorem makes the further comment that, if we decide to use numbers, we have some (specified) freedom as to how to do this. Numbers, and quantitative statements, thus come in only as a convenient way of keeping track of the relations among the entities under consideration.

The above postulate has been said to give (at least partly) the empirical content of the primitive term ⊇ under the intended reading 'is at least as long as.' It does so by stating a condition in the form of an empirically realizable test such that, if the condition was satisfied (if two objects passed the test), it would be in accordance with the common-sense use of the term 'is at least as long as' to call the one object at least as long as the other. Once the measurement theory of length, which contains this postulate, has been well established, however, we can, conversely, agree to use the expression 'is at least as long as,' within physical theory, in accordance with the condition -i.e., use the antecedent of the postulate as *the* criterion or (operational) definition of the expression. And we can then go on to precisely indicate a procedure, which involves (among other things) the use of appropriately calibrated measuring rods, to measure the length of an object. The definition and measurement procedure make sense, precisely because they can be backed by an empirical measurement theory of length. Physical science, moreover, not only comprises theories like that of the measurement of length but also draws the concepts in terms of which its laws are formulated from such theories. Since its concepts thus have precise criteria of application, physical science provides clear empirical tests of whether or not the conditions of application of its laws are satisfied. It also offers the hope of empirical laws that are indefinitely correctible within its own conceptual domain (cf section 4.4.2 of the main text).

2.5 Interpretation as a process of connecting an axiomatically specified rational structure with observable behaviour

Let me now indicate the way in which an interpretative theory can be modelled upon fundamental theories of measurement. Interpretation, roughly, is the attribution of beliefs, desires, intentions, decisions, preferences, hopes, fears, expectations, and the rest, to someone else. It may be compared to the assignment of, e.g., lengths. We have seen that a measurement theory of length pretty clearly indicates what it is that makes the assignment of lengths possible: the existence of an empirical structure of relations and operations, the formal properties of which allow them to be represented by numerical ones. These formal properties, moreover, are not arbitrarily chosen, but are constitutive of the relations and operations involved. It is constitutive of the relation 'is at least as long as' that it is transitive; intuition demands at least that much.

In the same way intuition recognizes some constitutive elements concerning the concepts that are employed in interpretation, concepts such as those of belief, desire, intention and action (cf sections 4.2 and 4.3 of the main text). It is e.g. constitutive of the concept of belief that beliefs entail, and are entailed by, other beliefs. It is part of what makes a belief a belief that Caesar was killed that it entails that Caesar died and is entailed by the belief that Brutus killed Caesar. It is also constitutive of the concept of belief that beliefs are, directly or indirectly, related to objects or events in the world. It is part of what makes a belief a belief that a cat is before me that it is the presence and absence of cats that causes the belief to wax and wane. It is constitutive of the concept of desire that desires, in conjunction with beliefs, tend to cause and so explain intentions and intentional actions of certain sorts. It is part of what makes a desire a desire to stay dry that, in conjunction with the belief that it is about to rain and the belief that something that gets into contact with rain will get wet, it entails that there is something intention-worthy about staying indoors or, else, about taking appropriate action such as searching a raincoat or carrying an umbrella.

Such (and other) relations amongst beliefs, desires and intentions, between beliefs, desires, intentions and objects and events in the world, being constitutive of the concepts of belief, desire and intention, are also constitutive of the application of such concepts to others. Thus, if I attribute to you the belief that Brutus killed Caesar, it must also be the case that you believe that Caesar was killed. This 'must' does not put any burden on you, but rather constrains me in my interpretation of you. In attributing beliefs to you I am constrained to do this in such a way that you also believe what those beliefs entail (their logical consequences), i.e., in such a way that your beliefs are consistent with one another. This is not an arbitrary constraint; it is a constraint that cannot be separated from what it is to have beliefs. No one who has beliefs can ever make sense of someone's having a certain belief and at the same time not believing what it entails. The constraint can also be said to express a fundamental aspect of what it is to be rational, a fundamental norm of rationality -fundamental in the sense that it is a condition of having beliefs at all that this fundamental norm has application. What this fundamental norm does, by demanding that beliefs are logically consistent with each other, is impose a rational pattern, a pattern that must be there, or at least nearly enough so, if someone is to have beliefs.

It is perhaps worthwhile to contrast this fundamental norm of rationality with rules of conduct or legal rules such as 'keep your appointments' or 'drive on the right side of the road.' Although it may (at least in some societies) constitute good social practice or even be of vital importance to abide by such rules, and although such rules may help us to understand why people act as they do, may provide a basis on which to criticize them, and so on, such rules are not fundamental norms of rationality as the term is used above. For even though I normally keep my appointments, I may on occasion have very good reasons not to keep one; and even though I normally drive on the right side of the road, such things as crossings of the Channel make me change sides. But we cannot ever rationalize a deviation from the above fundamental norm of rationality, nor is its range of application limited by any borders. No one who has beliefs, whatever his or her ethnic or cultural background may be, can believe a proposition of the form (*p* and not-*p*) while appreciating that the proposition is of this form. We do not, at least in any ordinary sense, choose this fundamental norm of rationality. It rather is an ineluctable element of what directs and explains our choices.

In the same way, the other constitutive elements of the concepts of belief, desire and intention necessarily enter into the process of determining what someone believes, wants or intends. They too express fundamental norms of rationality. They too impose rational patterns, patterns that must be there if the concepts of belief, desire and intention are to have application, and thus constrain the attribution of beliefs, desires and intentions. Indeed, the best sort of evidence on the basis of which we will (however tentatively pending other related results) enter as a hypothesis that someone intends some sentence of hers to be interpreted as meaning that a cat is present, is that the presence of cats causes her to hold true the sentence while the absence of cats causes her to hold it false, where we may have inferred this evidence, in turn, from such behaviour as her uttering the sentence in the clear proximity of a cat, with fingers pointing at the cat, and her vigorous nodding when we utter the sentence in the apparent absence of cats. In general, of course, the evidence (plausibly inferred from observable behaviour) will be much more complex. We may have evidence, for example, that some particular sentence of hers apparently stands in certain logical relations to other sentences; that she would prefer it true rather than some other sentences; that her faith in its truth is modified to various degrees by observed changes in the world and by changes in her faith in the truth of other sentences; and so on. The idea now is that the various constitutive elements together impose a rich enough rational structure, a structure that, on the one hand, must be there at least if someone has to have beliefs, desires and intentions at all and, on the other, so constrains the attribution of beliefs, desires and intentions that, on the basis of the sort of evidence just mentioned, it permits the identification of what it is that someone believes, wants and intends.

Enough building blocks are now in place to point out, if not yet the actual assembling of those into the interpretative theory Davidson envisages, at least the architecture of his theory. As in measurement theory, the foundation of the theory is an axiomatically specified structure, in this case a rational structure. Of this structure one will have to show, on the one hand, that it is formally adequate and, on the other, that it can indeed serve as the foundation of an interpretative theory for understanding some agent in that it can be given empirical content on the basis of that agent's observable behaviour.

As the above examples suggest, the axiomatization will have to be made on the basis of such primitive terms as the following (under the intended reading): a set of entities such as propositions or sentences; attitudes directed towards such entities such as 'holding true,' 'wanting to be true' or 'intending to make true.' One aspect that concerns the formal adequacy thus becomes whether what the axioms formally specify is indeed what intuition requires of such attitudes, whether the axioms specify constitutive elements of such attitudes and thus express fundamental norms of rationality. Another aspect, comparable to proving a representation theorem about a measurement theory, consists in giving some sort of a proof that the specified rational structure is adequate to its designed purpose, that it suffices to yield an agent's beliefs, desires, intentions, etc.

The second task is to give an indication of how this structure can be given empirical content, of how to connect its primitive terms with observable human behaviour. As in measurement theory, but now as a matter of principle, we cannot demand a precise indication of how to do this. What matters is that one rational creature (he) can find, in the plainly observable behaviour of another rational creature (she), a structure that satisfies the axioms fairly well, in a process of fitting and fudging that involves his inferring, on the basis of her behaviour, to the relevant attitudes she has towards propositions or sentences. To the extent that he can, he will understand the behaviour that exhibits this structure as intentional action and meaningful speech. It is in fitting and fudging that he uncovers a (near enough) realization of this structure, and thus gives it empirical content.

3 The interpretation of choice behaviour as intentional action

In this section I want to discuss an instructive example of a rational structure: a version of Bayesian theory of preference (decision theory). Its designed purpose is to attribute subjective probabilities that propositions are true and subjective desirabilities that propositions be true to someone. In section 4 I will indicate that, although the theory of preference is deficient, it can be extended to a more adequate rational structure.

3.1 A rational structure with intuitively desired properties that is adequate to its designed purpose

Axiomatic specification of a rational structure with intuitively desired properties

Let me begin with a preliminary remark. What is taken for granted in the theory of preference is a rich enough set of propositions. A proposition is taken here as being associated with certain truth conditions, such that the proposition would be true in case those conditions obtained and false otherwise. The set must be rich enough in the sense that it is closed under the operations of negation, conjunction and disjunction, where those operations are taken here as the familiar truth-functional modes of compounding propositions into longer ones. That is, the negation of proposition *a* (briefly, not-*a*) is true just in case *a* is false; the conjunction of two propositions *a*, *b* (*a* and *b*) is true just in case *a* and *b* are both true; the disjunction of two propositions *a*, *b* (*a* or *b*) is false just in case *a* and *b* are both false. The truth conditions associated with a compound proposition thus only depend on the truth conditions associated with the component propositions and on the compound's truth-functional structure, on how it is made up out of its component propositions by repeated application of negation, conjunction and disjunction.

The theory of preference takes a rich enough set of propositions for granted in two senses. First, it implicitly invests the agent to which it is to be applied with a rich enough set of propositions and with some elementary logic.[2)] Secondly, in applying it to the agent we are simply assumed to be able to tell what the propositions are among

2. It is perhaps worth to note that this does not imply that the agent is required to use the words 'or,' 'not' or 'and' in their truth-functional sense; in fact, the agent need not even have words that correspond to 'or,' 'not' or 'and' in their truth-functional sense. What is required of the agent is that if she, for instance, considers the proposition that there is a book among her birthday presents (briefly, *b*) and the proposition that there is a compact disc among her birthday presents (*c*), it is obvious to her that one, and only one, of the following four conditions will occur, come what may: (1) there is a book and a compact disc among her birthday presents (under which conditions both *b* and *c* are true); (2) there is a book but not a compact disc among her birthday presents (*b* is true and *c* is false); (3) there is a compact disc bot not a book among her birthday presents (*b* is false and *c* is true); (4) there is neither a book nor a compact disc among her birthday presents (both *b* and *c* are false). It is also required that she is able to distinguish, and to give an exhaustive list of, all subsets of the set consisting of conditions (1) to (4) above, and accordingly to associate with each different subset a different proposition, namely one that would be true just in case either one of the conditions in the subset obtained. It is also required, finally, that she recognizes all sorts of relationships between these propositions, such as that the truth conditions of the proposition associated with the subset {(1), (2)} are precisely those of *b*, that the proposition associated with the subset {(2), (4)} would be true just in case *c* would be false, and so on.

which the agent's preferences fall. As will become clear in section 4, it is in this assumption that the major deficiency of the theory of preference lies.

Let me now turn to the theory of preference itself, i.e., present some of its axioms, and discuss those under the intended reading (see e.g. Jeffrey, 1983, for more details and further references). The basic primitive term on the basis of which the axiomatization is made is a binary relation $\supseteq$, which is intended to be read as 'weak preference,' i.e., as the particular attitude an agent has towards two propositions *a* and *b* when she prefers the truth of *a* to the truth of *b* or is indifferent between the truth of *a* and the truth of *b* (in which case '$a \supseteq b$' is said to hold). In the below axioms, furthermore, *P* denotes the (rich enough) set of propositions the agent considers, and $\{f\}$ the logically false ones among them.

(*Transitivity*) $\supseteq$ is transitive on $P - \{f\}$: if $a \supseteq b$ and $b \supseteq c$, then $a \supseteq c$;

(*Connexity*) $\supseteq$ is connected on $P - \{f\}$: $a \supseteq b$ or $b \supseteq a$ (or both);

(*Averaging*) disjunction is an averaging operation with respect to $\supseteq$ on $P - \{f\}$: if (*a* and *b*) is logically false and $a \supseteq b$, then $a \supseteq$ (*a* or *b*) and (*a* or *b*) $\supseteq b$.

It clearly is constitutive of the relation of weak preference that it should be transitive. We cannot ever make sense of someone's preferring the truth of *a* to the truth of *b*, the truth of *b* to the truth of *c*, and (at the same time) the truth of *c* to the truth of *a*, while appreciating that her preferences are so arranged. A more pictorial way of putting the axiom of transitivity is that the propositions the agent considers can unambiguously be put into a preference ranking, in which a proposition is ranked higher than another one if the agent prefers its truth to the truth of the other one and ranked at the same level as the other one if she is indifferent between its truth and the truth of the other. Logically false propositions do not enter the preference ranking, simply because it makes no sense to ask whether the agent would rather have it that this proposition or that proposition came true if one of those propositions is such that it cannot come true, come what may.

The axiom of connexity requires, for instance, that if the agent considers the proposition that there is a book among her birthday presents and the proposition that there is a compact disc among her birthday presents, both of which might come true, that her preference ranking then includes each of the propositions that would be true, or false, just in case one of the following conditions obtained: there is a book among her birthday presents; there is a compact disc among her birthday presents; both of those are among her birthday presents; there is just one of those among her birthday presents; neither of those is among her birthday presents; there is a book but not a compact disc among her birthday presents; there is a compact disc bot not a book among her birthday presents. Because of its holistic scope, this requirement clearly demands a preference ranking to be fuller than any agent's preference ranking in practice will be. Nevertheless it only is an idealization in that it is constitutive of considering propositions at all that, if some propositions are considered and included in the preference ranking, all their truth-functional compounds (except the logically false ones) could in principle be considered and included in the preference ranking as well.

The averaging axiom too is intuitively clear under the intended reading. For, on the one hand, if the truth of one proposition is weakly preferred to the truth of another, it clearly is also weakly preferred to the truth of either one of them, while the truth of either one of them is weakly preferred to the truth of the other. And on the other hand, if the two propositions are logically incompatible (if their respective truth conditions cannot simultaneously obtain), either one of them is true just in case their disjunction is true.[3)]

The adequateness of the rational structure to its designed purpose (representation theorem)

I now turn to the second aspect concerning the formal adequacy of the above specified structure, namely that it is adequate to what (under the intended reading) it is designed for: the construction of scales that measure the agent's degrees of belief that propositions are true (subjective probabilities) and strengths of desire that propositions be true (subjective desirabilities). Such scales cannot, of course, be arbitrarily constructed. It must be done in such a way that intuitions concerning the notions of degree of belief and strength of desire are satisfied or, put differently, the construction must embody the appropriate constitutive elements of what it is to have beliefs (in various degrees) and desires (in various strengths) at all. It clearly is constitutive of the concept of desirability, for instance, that the agent prefers the truth of one proposition rather than the truth of another just in case the truth of the one proposition for her has a higher desirability than the truth of the other. So if we represent the agent's strength of desire that proposition *a* be true by the number *des*(*a*), the following must hold.

(A) $des(a) \geq des(b)$ just in case $a \supseteq b$.

Of the concept of degree of belief it is constitutive that it may vary from total disbelief to total conviction. In particular, degree of belief that a proposition comes true will be at its minimum if the proposition is logically false (cannot come true, come what may), and at its maximum if it is logically true (guaranteed to come true, come what may). Moreover, since the disjunction of two logically incompatible propositions *a* and *b* can come true in just one of two ways -(1) *a* comes true or (2) *b* comes true- intuitions concerning the notion of degree of belief tell that the degree of belief in the truth of (*a* or *b*) must be the degree of belief in the truth of *a* increased by the degree of belief in the truth of *b*. So if we represent the agent's degree of belief that proposition *a* is true by the number *prob*(*a*), and (conventionally) set total disbelief equal to zero and total conviction equal to one, we demand the following.

3. Note that the two propositions in the averaging axiom need to be logically incompatible. In particular, if *b* and *c* are not logically incompatible and $b \supseteq c$, it is not generally the case that (b or c) $\supseteq c$. The agent might, for instance, value the presence of both a book and a compact disc among her birthday presents so much more than the occurrence of the other conditions that she would welcome the news that there will be a compact disc among her birthday presents more than the news that there will be a book or a compact disc among her presents, simply because in the former case the chances are better that there will be both a book and a compact disc among her birthday presents. In relation to the above remarks it may be instructive to compare the cases (i) and (ii) of the following theorem within the theory of preference, which holds for propositions *b* and *c* such that *b* is not logically false and *c* is neither logically false nor logically true (and which is easily derived from the above axioms).
(i) If (b and not-c) $\supseteq c$, then (b and not-c) $\supseteq$ (b or c) $\supseteq c$.
(ii) If $b \supset c$ ($b \supseteq c$, but not $c \supseteq b$) and $c \supseteq$ (b and not-c), then (b and c) $\supseteq b \supset c \supseteq$ (b or c) $\supseteq$ (b and not-c).

(B) $prob(a) \geq 0$.
(C) $prob(a \text{ or not-}a) = 1$.
(D) if (a and b) is logically false, then $prob(a \text{ or } b) = prob(a) + prob(b)$.[4]

The most important constitutive element of the concepts of degree of belief and strength of desire, however, is that subjective probabilities and desirabilities together explain intentional choices of one course of action over another and preferences that one state of affairs obtain rather than another. Suppose, for example, that part of the agent's preference ranking is as follows: $b \approx c \supset \text{not-}c \supset \text{not-}b$; that is, though the presence of a book and the presence of a compact disc among her birthday presents would equally please her, she would be more displeased in case there was no book than in case there was no compact disc among her presents. We can explain (understand) this, if we assume that she expects to get a book more than she expects to get a compact disc. Her higher degree of belief in not getting a compact disc explains why she evaluates the prospect of the absence of a compact disc among her birthday presents as not so bad.[5]

In order to more precisely formulate the constitutive element in question, it is perhaps best to turn to the case in which attributions of probabilities and desirabilities are best understood, namely to their role in explaining intentional actions. The idea is simple. Suppose the agent wants to achieve a certain result and that in order to achieve it she contemplates two actions, both of which she feels able to perform, though one of them (action 1) will, as she sees it, require more effort than the other (action 2). Suppose, furthermore, that part of her preference ranking is as follows (where r is the proposition that the result is achieved, and a_i the proposition that she performs action i, i = 1, 2): $(a_2 \text{ and } r) \supset (a_1 \text{ and } r) \supset a_1 \supset a_2 \supset (a_2 \text{ and not-}r) \supset (a_1 \text{ and not-}r)$; that is, as far as the possible outcomes are concerned she would be more pleased to achieve the result with less effort and more displeased to not achieve the result after a lot of effort, and as far as the contemplated actions are concerned she prefers to perform action 1 instead of action 2. We can explain (understand) this if we assume that she thinks action 1 is more likely to lead to the result than action 2. Her higher degree of belief that she achieves the result if she performs action 1 compensates, so to say, for her having to take more trouble to perform action 1. In order to make the explanation in terms of probabilities and desirabilities more explicit, we can also put it as follows. The value the agent puts on a_1 lies somewhere between the value she puts on (a_1 and r) and the value she puts on (a_1 and not-r): if her degree of belief that she achieves the result given that she performs action 1 is near one, the desirability of a_1 is near that of (a_1 and r); if it is near zero, the desirability of a_1 is close to that of (a_1 and not-r); if it is near one half, the desirability of a_1 is somewhere halfway those of (a_1 and r) and (a_1 and not-r). The value she puts on a_1 is thus some kind of weighted sum of the values she puts on (a_1 and r) and (a_1 and not-r), where the weight is a conditional probability: her degree of belief that she achieves

4. Note that (B) to (D) are precisely the Kolmogorov axioms of probability theory.
5. This example also indicates a first step of how it is possible to arrive, merely on the basis of the agent's preference ranking, at measures of degrees of belief and strengths of desire, by requiring that they explain the preference ranking. Of course it only indicates just a small step, in that it yields no more than a comparison of the agent's degrees of belief in the truth of propositions b and c. Further steps depend on taking the agent's preference ranking more fully into consideration.

the result given that she performs action 1. The same goes, *mutatis mutandis*, for the value she puts on a_2. Now, if the weighted sum corresponding to action 1 comes out higher than the weighted sum corresponding to action 2, that explains (makes it understandable) why, all things considered, she performs action 1 instead of action 2. For she is then simply doing the best she can by her own lights, i.e., in the light of all her relevant subjective probabilities and desirabilities (her degrees of belief to achieve the result, given the contemplated actions, and the values she puts on the various possible outcomes). The constitutive element can now be formulated as follows.

(E) $des(a) = prob(b \mid a) \cdot des(a \text{ and } b) + \{1 - prob(b \mid a)\} \cdot des(a \text{ and not-}b)$.

As indicated above, (A) and (E) together explain why the agent chooses one course of action rather than another (or why she prefers that one state of affairs obtain rather than another).

(A) to (E) together, moreover, embody, be it in somewhat idealized form, ineluctable constitutive elements of the notions of degree of belief and strength of desire. Intuition demands at least that much of any construction of scales *prob* and *des* to measure the agent's probabilities and desirabilities (and I do not see anything else it demands).

An important theorem that can be proved *about* the theory of preference, about the structure that has (at least partly) been specified above by the transitivity axiom, connexity axiom and averaging axiom, is the following (comparable to a representation theorem about a measurement theory): any structure that satisfies the axioms of the theory of preference allows the construction of scales *prob* and *des* that satisfy (A) to (E) above. That is, if the agent's weak preferences form a rational structure, a structure that must be there at least if the agent is to have preferences at all, then it is possible to explain the agent's preferences, in an intuitively desired way, in terms of subjective probabilities and desirabilities. The theorem thus effects a reduction of the quantitative concepts of degree of belief and strength of desire to the more basic, and qualitative notion of preference. It shows that our ability to understand the agent's actions as done for a reason ultimately rests on the existence of a rational structure in her preferences and on our ability to uncover such a structure.

Indeterminacy (uniqueness theorem)

The idea that the concepts of degree of belief and strength of desire are derivative, and both depend on the concept of weak preference, may be further illustrated by the uniqueness theorem that can be proved *about* the theory of preference. A preference ranking that satisfies the axioms of the theory of preference allows the construction of not just one pair of scales (*prob*, *des*), but of a whole class of such pairs.[6] Though two different pairs (*prob*, *des*) and (*PROB*, *DES*) in this class assign different subjective probabilities and desirabilities to the agent, both pairs explain the same preferences and both do so in an intuitively desired way, in that both pairs satisfy conditions (A) to (E) above. There is thus no further fact of the matter to decide which of these pairs is the

6. The uniqueness theorem precisely states in what two pairs (*prob*, *des*) and (*PROB*, *DES*) in this class differ: $DES(a) = \{\alpha des(a) + \beta\} / \{\gamma des(a) + \delta\}$; $PROB(a) = prob(a) \cdot \{\gamma des(a) + \delta\}$, for some numbers α, β, γ and δ such that $\alpha\delta - \beta\gamma > 0$ and, for every proposition a, $\gamma des(a) + \delta > 0$ and $\gamma des(a \text{ or not-}a) + \delta = 1$.

right one; in fact, the question which is the right one is as meaningless as the question whether an inch scale or a centimetre scale is the right one. The fact of the matter, on which all different assignments of probabilities and desirabilities depend, is the existence of a rational structure in the agent's weak preferences among propositions. All different assignments are equally acceptable, in that they are all convenient and appropriate ways of summarizing the same basic properties of this structure.

3.2 An indication of how to connect the rational structure with observable human behaviour

Yet another way to point out that the concept of preference is more basic than those of degree of belief and strength of desire, is that preferences are more open to both introspection and observation than subjective probabilities and desirabilities. It normally is much clearer to us that one course of action or state of affairs is preferable to another than that either is desirable. It is immediately clear to me, for instance, that I very much prefer the truth of the proposition that I am not struck by lightning before I finish this paragraph to the truth of its negation, but I would have to sit back and think about my own subjective desirabilities: is it that I highly value the truth of the proposition, greatly disvalue the truth of its negation, or both? In the same vein we normally are not very good at judging our own subjective probabilities in terms of numbers. The reason for this is, of course, that our mundane concerns hardly ever give occasion to take isolated propositions into consideration. Our deliberations are always relative (be it implicitly) to a background of assumptions as to what things would be like if one or another option were rejected. Preferences, therefore, enter our deliberations directly, whereas probabilities and desirabilities are more intricately embedded in them.

The sturdy connection between preferences and mundane concerns also makes the preferences of others more open to observation than their subjective probabilities and desirabilities. There is no plain behaviour in which degrees of belief or strengths of desire directly manifest themselves, though there are many ways in which preferences rather directly do: most plainly, of course, in choice behaviour, but to some extent also in other behaviour that can be understood as intentional (for if an action is intentional, performing an action of that kind is at least preferred to not performing one.) Probabilities and desirabilities are more like theoretical constructs; they are part of an explanatory mechanism. The (basically common-sense) idea is this. To explain a particular choice or preference, we observe other choices or preferences; to the extent that we can see them as falling into a rational pattern of the kind specified by the theory of preference, that theory allows the construction of a system of probabilities and desirabilities in terms of which the original choice or preference (along with the others) can be explained. There is no way, however, to test for probabilities and desirabilities independently.

The above mentioned connection between preferences and behaviour should not be interpreted as a nomological or definitional reduction of preferences to behaviour. This point can perhaps best be made clear in the form of an essential difference between measurement theory and theory of preference. The primitive terms of a measurement theory are given empirical content in terms of empirically realizable relations and operations that are as precisely as possible circumscribed. Recall, for instance, the postulate for the relation 'is at least as long as' in the measurement theory of length: *a* is at least as long as *b* if, when rods *a* and *b* are placed side by side with one pair of endpoints coinciding, the opposite endpoint of *b* does not extend beyond that of *a*. The concepts of the theory of preference, on the other hand, cannot be given such precise criteria of application. There is no analogous postulate for the relation of weak preference, something like: the agent prefers the truth of *a* to the truth of *b* if …, and here follows some characterization in purely behavioural terms. For suppose we try to thus characterize what it is for the agent to prefer to have an apple rather than a pear. One line we could take is this: when both an apple and a pear are brought within her field of vision, she points at the apple. But of course this shows she prefers to have an apple rather than a pear only if her pointing at the apple was intentional, was a response to an offer to choose one of the two objects presented to her, was towards the one she preferred, and so on. We could try to improve the behavioural criterion, but no matter how we patched and fitted it we would always find the need for additional clauses that are mental in character: provided she notices, understands, etc.[7)]

Lacking a precise behavioural criterion for applying the concept of weak preference, the theory of preference cannot be given empirical content by assigning preferences to the agent one by one on the basis of her behaviour, no matter how plain and evident the local signs may be. On the other hand, her observable behaviour is all we have to go on in giving empirical content to the theory of preference. What this amounts to, is that our process of assigning preferences to the agent is an ever evolving one, not just in the trivial sense that we are never in the position that we know all the agent's preferences, but more significantly in the sense that every step in the process is holistically constrained by the constitutive ideal of rationality, by the ineluctable requirement that the totality of the agent's preferences (nearly enough) forms a rational structure (cf section 4.4.2 of the main text).

So when, as first entrances into the agent's system of preferences, we naturally assume that her basic preferences are very much like our own and plausibly infer to further preferences on the basis of what we take to be plain and evident cases of choice behaviour, we must always do so tentatively, pending other related results, and always stand prepared, as more and more structure becomes apparent, to revise those assumings

7. There is also a second essential difference between the two theories: whereas both the theory of preference and measurement theory of length allow the construction of scales (to measure probabilities and desirabilities in the former and lengths in the latter), assignments of probabilities and desirabilities have a property that assignments of lengths lack, namely that they explain the structure from which they are extracted. If the weighted sum of the desirabilities of the various possible outcomes of one course of action is greater than the weighted sum of the desirabilities of the various possible outcomes of another action, that explains why the agent prefers to perform the one rather than the other action. But if the length of one rod is greater than the length of another, that does not explain why the one rod is longer than the other. The two differences are related and, moreover, do not just concern the theory of preference and measurement theory of length, but are rather paradigmatic of the difference between the social and the physical sciences, with respect to both the concepts and the modes of explanation that are employed in each domain (cf section 4.4.2 of the main text).

and inferences in the light of considerations of overall rational coherence. When we already have attributed quite a lot of preferences to the agent, for example, constitutive elements such as the axiom of transitivity or the averaging axiom allow us to predict still further preferences, and in effect thus also to test for these further preferences, e.g. by facing the agent with choices in which they might plausibly manifest themselves. The outcomes of such tests then also bear on the justification of our original attributions.

Our process of assigning preferences to the agent thus involves a multitude of considerations, in the light of which we ourselves too will have to make choices. This also shows that the process necessarily involves at least two rational creatures, both of which have (and thus share) the fundamental norms of rationality that are constitutive of the concept of preference. In other words, for the process to work there must be minds at both ends (cf section 4.2 of the main text).

4 Toward a comprehensive interpretative theory

4.1 Deficiency of the theory of preference

The theory of preference that is outlined in the previous section cannot yet serve as a fundamental interpretative theory. For what it tries to connect with observable behaviour, the agent's preferences between the truth of propositions, is in fact still too far removed from what can plausibly be inferred on the basis of her behaviour. The problem is not that preferences do not manifest themselves in behaviour, they do, but rather that this does not tell us what the contents of the preferences are. Consider once more the example that the agent points at the apple when both an apple and a pear are brought within her field of vision. Even when we have good reasons to assume that her pointing was intentional, was a response to an offer to choose one of the two objects presented to her, and was towards the one she preferred, this still does not settle the question of what she has chosen. We may take it as expressing a preference to have an apple rather than a pear, what is on her right rather than her left, what is red rather than yellow, what is seen first, what is judged more expensive, and so on. So what the theory of preference assumes to be already settled is in fact an essential ingredient of interpretation, the question namely what the propositions are among which the agent's preferences fall.

It seems obvious, moreover, that this question can only be satisfactorily settled if there is the possibility of linguistic communication. That is, unless there is behaviour that can be interpreted as linguistic utterances, the behavioural basis would be much too slender to infer to, and to justify, the fine distinctions that the theory of preference requires us to detect. For just imagine what it would be like, short of being able to linguistically communicate with her, to find out whether or not the agent prefers the truth of the proposition that there is a book among her birthday presents to the truth of the proposition that there is a compact disc among her birthday presents; or to face her with choices in which her preferences among the truth-functional compounds of those two propositions might plausibly manifest themselves.

4.2 Mending the deficiency of the theory of preference

The above suggests that what must be added to the theory of preference, or incorporated in it, is a theory that yields an interpretation of linguistic utterances. This suggestion may be further strengthened by the following consideration. The basic problem with the theory of preference is that the gap between the evidence it assumes to be available, preferences among propositions, and observable behaviour is too large, simply because it cannot be observed which propositions the agent is choosing between. Now, if we think of propositions as sentences with content, a plausible candidate for an evidential base that is more closely related to observable behaviour offers itself: preferences among sentences. For although sentences themselves are also not observable, their utterances, inscriptions, gesticulations, etc, are. The idea is that it is possible for us, as interpreters, to detect how the agent's preferences fall among her own utterances and from this to infer preferences among sentences. Or, put differently, that it is possible for us to use the agent's own sentences to keep track of her preferences before we are in a position to assign propositional contents to her sentences (and thus also to her preferences). The sentences do of course have contents for the agent, but *we* are no longer supposed to know in advance what they are. So the prize we have to pay for bringing the evidential base closer to observable behaviour is that we are farther away from where we intend to end up, namely at what the agent prefers (and believes, wants, etc). For we now also have to make the step from the non-propositional to the propositional. The further idea is that this can be realized by imposing adequate constraints on the evidence assumed available, i.e., by specifying a rational structure that must be there (nearly enough) in the agent's preferences among sentences.

I will not here attempt to specify this rational structure. Let me just sketch, in very brief outline, some sort of representation theorem about it. Like the theory of preference, the more general rational structure will allow the construction of appropriate scales *prob* and *des*. In the general case, however, these scales do not concern propositions, but as yet uninterpreted sentences: they measure the agent's subjective probabilities that her sentences are true and subjective desirabilities that her sentences be true. The subjective probabilities can then be used, by methods outlined in section 4.2 of the main text, to interpret the contents of the agent's sentences. If it is found, for instance, that the agent is caused to award a high subjective probability to one of her sentences when and only when it is raining in her vicinity, the interpreter will enter as a hypothesis (tentatively, of course, pending other related results) that it is a sentence that means that it is raining. This interpretation is further supported when rain perceived under poor conditions for observation causes a lower degree of belief, and a down-pour experienced in the open a degree of belief of about 1 in the truth of the sentence. More evidence still accumulates as further sentences are given tentative interpretations. Thus a sentence interpreted as meaning that there is a patter on the roof, if given a high subjective probability, ought to increase the agent's degree of belief in the truth of the sentence interpreted as meaning that it is raining. In this way, by marking what the agent takes as evidence for the truth of a sentence, it is possible to interpret sentences of an increasingly abstract and theoretical nature. That is, conditional probabilities provide the interpreter with what is needed to determine the contents of the agent's more theoretical sentences.

4.3 Further developments

The upshot of the above is that, if the observed pattern of the agent's preferences among sentences fits an appropriate rational structure, it will be possible to infer the degrees of belief she accords her sentences, how much she would like those sentences to be true, and what the contents (truth conditions, meanings) of those sentences are. In other words, the rational structure, if true of an agent, would serve to interpret the beliefs, values and words of that agent. Although this in itself is, in my opinion, already a major accomplishment, there is still much more to be done. Let me close with mentioning just a few directions for further developments.

First of all it is perhaps good to note that, as far as I know, the required rational structure and the representation theorem about it have not yet been given in any detail. So there is still a lot of, predominantly technical, work to be done in this direction. Secondly, one will have to inquire whether what the required rational structure promises to yield (beliefs, values and meanings), is enough for the attribution of a whole array of further attitudes to someone else: intentions, hopes, fears, perceptions, expectations, regrets, emotions, obligations, unconscious beliefs and desires, memories, and so on. Perhaps it will turn out that to support such broad-based interpretation one will have to add to the primitive terms of the rational structure. A final direction of development I want to mention is to somehow make the interpretative theory dynamic, by adding to it appropriate norms of rationality that deal with the incorporation of new information into a going system of thought.

Appendix 2: Pupils' textbook

To get an idea of what the textbook looks like, this appendix contains copies of three pages of the textbook. Recall that in the textbook itself, the pages are of A4-size.

2-2 Bouwen van een "kerncentrale"

1 Veilig in de buurt van een kerncentrale wonen
Kerncentrales staan soms in de buurt van een stad. Maar de inwoners van zo'n stad mogen daar geen straling van ontvangen.
Hoe zorgt men daarvoor?

2 Een "kerncentrale" in het klein
In de klas ligt wat radioactief materiaal. Stel nu eens dat dat het radioactief materiaal in een kerncentrale is. De radioactieve spullen liggen dus al klaar. Er is alleen één probleem: de kerncentrale zelf is er nog niet.
Jullie mogen die "kerncentrale" straks zelf gaan bouwen. Of beter gezegd: een opslagruimte in die "kerncentrale". Een ruimte dus om die radioactieve spullen veilig in te bewaren.
De opslagruimte moet aan één belangrijke eis voldoen. Dichtbij jullie "kerncentrale" mag je er geen straling van ontvangen.

Bedenk een bouwplan voor de opslagruimte in jullie "kerncentrale". Zorg er wel voor dat jullie dat plan straks echt uit kunnen voeren.
Schrijf hieronder jullie plan op.

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A Problem-Posing Approach

3 Wat we bij het uitvoeren van de bouwplannen hebben geleerd
Jullie bouwplannen zijn nu uitgevoerd. Schrijf hieronder op wat jullie daarbij geleerd hebben.

2-3 Ongelukken met kerncentrales

Jammer genoeg gebeuren er af en toe ongelukken met kerncentrales. Zoals in 1986 met een Russische kerncentrale in Tsjernobyl. Door een explosie werd een deel van die kerncentrale vernield. Misschien kunnen jullie je dat nog herinneren. In kranten en op het nieuws werd daar toen veel aandacht aan besteed.

4 Informatie over het ongeluk in Tsjernobyl
Hieronder staan enkele stukjes uit kranten van die tijd.
Bekijk die stukjes eens om je geheugen wat op te frissen.

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Appendix 2: Pupils' textbook

2-5 Samenvatting

Belangrijk om te onthouden:

Vragen waar we nog een antwoord op moeten vinden:

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Samenvatting

In hoofdstuk 1 beschrijf ik de aanleiding tot het onderzoek waarover dit proefschrift rapporteert, alsmede de opdracht waarmee ik dit onderzoek begonnen ben: het ontwikkelen van een constructivistische didactiek voor praktijkgericht natuurkunde-onderwijs over radioactiviteit en atoombouw op het MAVO en LBO. Ik meen aan deze opdracht tegemoet te zijn gekomen middels de ontwikkeling en evaluatie van een didactische structuur van het onderwerp radioactiviteit.

Gaandeweg mijn onderzoek heb ik mijn blikveld ook verruimd. Zo hebben methodologische vragen betreffende de interpretatie van wat leerlingen zeggen en doen geleid tot een meer algemeen methodologische oriëntatie op het begrijpelijk maken van elkaars doen en laten. Verder zijn mijn gedachten over onderwijs in radioactiviteit hand in hand gegaan met gedachten over onderwijs in de natuurwetenschappen in het algemeen. In mindere mate heb ik mij ook beziggehouden met de rol van de docent.

Hieronder geef ik een samenvatting van wat er dit proefschrift is terug te vinden over interpretatie in het algemeen, over onderwijs in de natuurwetenschappen in het algemeen, en over de rol van de docent. Mijn concrete werk betreffende een didactiek voor onderwijs in radioactiviteit kan worden gezien als een specifieke en gedetailleerde uitwerking van wat ik hieronder schrijf over didactiek van de natuurwetenschappen. Voor die specifieke details zelf verwijs ik naar de paragrafen 2.3 t/m 2.5, en de hoofdstukken 3, 8 en 9.

Interpretatie

Wat ik in dit proefschrift schrijf over interpretatie in het algemeen is gebaseerd op het werk van de filosoof Davidson, en terug te vinden in hoofdstuk 4 en appendix 1. Het hoofdthema daarin betreft de vraag wat het mogelijk maakt dat we van elkaar kunnen achterhalen wat de ander gelooft, wil, van plan is, bedoelt met zijn of haar woorden, wat zijn of haar redenen zijn om te doen wat hij of zij doet, etc. Davidsons antwoord is dat we dit van elkaar kunnen achterhalen doordat ons doen en laten geleid wordt door fundamentele rationaliteitsnormen die we met elkaar gemeen hebben, en doordat we van elkaar weten dat we in een gemeenschappelijke wereld leven. De rationaliteitsnormen zijn onlosmakelijk verbonden met de begrippen in termen waarvan we elkaar begrijpelijk maken. Een essentieel onderdeel van wat het is om een bepaalde bewering voor waar te houden, bijvoorbeeld, is dat je ook de logische gevolgen van die bewering voor waar houdt, m.a.w., dat wat je gelooft logisch consistent met elkaar is, dat je geen tegenspraken accepteert. Een essentieel onderdeel van wat het is om een bepaald verlangen te hebben, is dat een handeling waarvan je gelooft dat die aan dat verlangen tegemoet komt een zekere wenselijkheid heeft, m.a.w., dat je verlangens en wat je gelooft tezamen handelingen begrijpelijk maken. Een essentieel onderdeel van wat het is om voorkeuren te hebben, is dat als je *a* verkiest boven *b* en *b* boven *c* dat je dan *a* verkiest boven *c*, m.a.w., dat je voorkeuren transitief zijn. Een essentieel onderdeel van basale gedachten zoals 'Dat is een hond' en 'Het regent', is dat ze veroorzaakt worden door voorwerpen of gebeurtenissen van een bepaalde soort in de wereld om je heen.

Zulke, en andere, rationaliteitsnormen spelen ook een essentiële rol in het begrijpelijk maken van de gedachten en handelingen van anderen, in die zin dat ze restricties opleggen aan de relaties van gedachten en handelingen met andere gedachten en handelingen en met de wereld. Wanneer we inhoud geven aan de gedachten en handelingen van anderen moeten we dat zo doen dat wat ze geloven logisch consistent is, dat wat ze doen het meest wenselijk is in het licht van wat ze geloven en verlangen, dat hun voorkeuren transitief zijn, dat hun gedachten die selectief veroorzaakt worden door bepaalde voorwerpen of gebeurtenissen in hun omgeving gaan over die voorwerpen of gebeurtenissen, etc.

Deze restricties zorgen ervoor dat de gedachten die we aan anderen toekennen in *hun* totale gedachtensysteem een vergelijkbare rol spelen als in *ons* gedachtensysteem, d.w.z. op een vergelijkbare manier gerelateerd zijn aan andere gedachten en aan de wereld. Interpretatie is dus het kalibreren van elkaars gedachten en handelingen aan (gedeelde) rationaliteitsnormen, het in elkaar schuiven en aan elkaar haken van twee gedachtensystemen, het vinden van overeenstemming middels intersubjectieve interactie met de wereld (i.h.b. verbale communicatie over de wereld).

In hoofdstuk 4 worden bovenstaande ideeën verder toegelicht, en de consequenties daarvan voor de relaties tussen subjectiviteit, intersubjectiviteit en objectiviteit, alsmede voor de relatie tussen sociale wetenschappen en natuurwetenschappen, verder uitgewerkt. In appendix 1 wordt aangegeven dat bovenstaande ideeën perspectief bieden op een serieuze interpretatietheorie die, mits verder uitgewerkt, naar mijn indruk van methodologisch belang zal zijn voor de sociale wetenschappen. Bovenstaande ideeën hebben ook gefungeerd als een algemene achtergrond en inspiratiebron voor mijn ideeën over (onderzoek aan) onderwijs in de natuurwetenschappen.

Didactiek van de natuurwetenschappen

Paragraaf 2.2 en de hoofdstukken 5, 6, 7 en 11 gaan in op onderwijs in de natuurwetenschappen in het algemeen.

Interpretatie van leerlinguitspraken

Paragraaf 2.2 is van methodologische aard en bekritiseert de manier waarop in de literatuur leerlinguitspraken vaak geïnterpreteerd worden. Neem b.v. de volgende uitspraken die, zoals gerapporteerd in de literatuur, veel leerlingen voorafgaand aan mechanica-onderwijs waar vinden, en die daarom ook wel onderdelen van hun 'intutieve bewegingsleer' genoemd worden: 'Om iets in beweging te houden moet daarop een constante kracht worden uitgeoefend'; 'Een voorwerp dat in beweging is heeft een kracht' 'Krachten kunnen van het ene voorwerp op het andere worden overgedragen'. Naar mijn indruk blijkt uit zulke uitspraken duidelijk dat leerlingen aan uitdrukkingen waarin het woord 'kracht' voorkomt een andere betekenis toekennen dan in de natuurkunde gebeurt, of zelfs uitdrukkingen gebruiken die in de natuurkunde niet gebezigd worden -en ik verwacht dat collega-onderzoekers het met deze constatering eens zullen zijn. De volgende opmerking, echter, die naar mijn indruk uit deze constatering volgt, zie ik weinig collega-onderzoekers maken. Namelijk, dat zolang we niet weten welke betekenis leerlingen toekennen aan uitdrukkingen waarin het woord 'kracht' voorkomt, we ook niet weten wat ze geloven wanneer ze uitspraken als bovenstaande waar vinden, en dat we dan dus in feite ook niet weten wat de inhoud van hun intuïtieve bewegingsleer is. Veeleer zie ik veel collega-onderzoekers opmerkingen maken als 'Leerlingen geloven dat bewegende voorwerpen een kracht hebben', en concluderen dat uit bovenstaande uitspraken volgt dat de intuïtieve bewegingsleer van leerlingen in strijd is met de mechanica en dus bij het leren van mechanica overwonnen (afgeleerd) moet worden. Wat deze onderzoekers naar mijn indruk aldus doen, is registreren welke uitspraken leerlingen waar vinden; en wat ze naar mijn indruk alleen maar mogen concluderen, is dat als leerlingen hun woorden gebruikten zoals in de natuurkunde gebeurt dat dan wat ze geloven in strijd zou zijn met de mechanica. Wat deze onderzoekers aldus in feite achterwege laten is een interpretatie van wat leerlingen geloven, van wat de inhoud van hun intuïtieve bewegingsleer is. In paragraaf 2.2 probeer ik, bij wijze van voorbeeld, zo'n interpretatie wel te geven, geïnspireerd door de algemeen methodologische inzichten over interpretatie. D.w.z., ik probeer de uitspraken die ze waar vinden in te passen in een gedachtenpatroon dat ik, in de situaties waarin zij hun uitspraken waar vinden, ook waar vind.[1)] Aldus geef ik inhoud aan hun intuïtieve bewegingsleer (dat gedachtenpatroon dat ze met mij delen), en tegelijkertijd betekenissen aan hun uitdrukkingen waarin het woord 'kracht' voorkomt (waarmee de uitspraken die ze voor waar houden vertalen in dat gedachtenpatroon). Ik deel dus hun intuïtieve bewegingsleer, zie niet in dat die in tegenspraak is met de mechanica, en concludeer dientengevolge niet dat leerlingen die bij het leren van de mechanica moeten afleren. Ze moeten natuurlijk wel een hoop bijleren om tot een begrip van de mechanica te komen.

Introductie van specifieke beschrijvingswijzen
In hoofdstuk 5 borduur ik op dit thema voort, in het kader van een inventarisatie van mogelijkheden om onderwijs in de natuurwetenschappen op een inhoudspecifiek niveau te verbeteren. Wat betreft mechanica-onderwijs, bijvoorbeeld, volgt uit bovenstaande dat leerlingen daarin zullen moeten leren dat '… oefent een kracht uit op …' de basale uitdrukking is die in de mechanica gebruikt wordt, en dat andere uitdrukkingen die het woord 'kracht' bevatten (zoals '… heeft een kracht' en '… heeft zijn kracht overdragen aan …') in de mechanica niet gebruikt worden. In gangbaar onderwijs gebeurt dit niet of nauwelijks. Daarom is het niet verbazingwekkend dat, zoals uit natuurkunde-didactisch onderzoek blijkt, veel leerlingen niet tot een inzichtelijk gebruik van de mechanicawetten komen. Immers, een correcte toepassing van de mechanicawetten op een gegeven situatie kan niet los gezien worden van een specifieke manier van beschrijven van die situatie, namelijk zodanig dat die wetten erop van toepassing zijn. (Deze opmerking heeft niet alleen betrekking op het gebruik van de mechanicawetten, maar meer in het algemeen op het gebruik van generalisaties bij het verklaren en voorspellen van gebeurtenissen.) Om de mechanicawetten inzichtelijk te kunnen gebruiken moeten leerlingen in het bijzonder weten hoe de basisuitdrukking '… oefent een kracht uit op …' gebruikt wordt. Wanneer aan dit laatste niet expliciet aandacht wordt geschonken,

1. In de paragrafen 2.3 t/m 2.5 probeer ik, zo goed en zo kwaad als het gaat, hetzelfde te doen met uitspraken die leerlingen gedaan hebben in interviews over situaties die met radioactiviteit te maken hebben.

wordt het min of meer aan de leerlingen zelf overgelaten om, op basis van de manier waarop de mechanicawetten in het leerboek en door de leraar worden toegepast in verschillende situaties, *zowel* te achterhalen hoe situaties in termen van die basisuitdrukking beschreven moeten worden *als* ook te achterhalen hoe, gegeven zo'n beschrijving van een situatie, die wetten daar vervolgens op toegepast moeten worden. Het lijkt me aannemelijk dat dit voor veel leerlingen teveel gevraagd is. Wanneer hen andere dan standaard-situaties voorgelegd worden, blijkt ook dat veel leerlingen niet veel meer gebruiken dan hun intuïtieve bewegingsleer, d.w.z., blijkt dat ze weinig hebben bijgeleerd.

Wat betreft mogelijkheden om onderwijs in de natuurwetenschappen op een inhoudspecifiek niveau te verbeteren, is de boodschap die ik in hoofdstuk 5 aan bovenstaande verbind dat expliciet aandacht besteed moet worden aan de introductie van de specifieke beschrijvingswijzen die in de natuurwetenschappen gebruikt worden en in termen waarvan generalisaties en wetten geformuleerd zijn. Daarbij moet naar voren komen *hoe* een bepaalde natuurwetenschappelijke uitdrukking gebruikt wordt ter beschrijving van situaties en, als die uitdrukking ook op andere manieren gebruikt wordt, *dat* het een specifieke manier is om die uitdrukking te gebruiken. Bovenal echter moet dat op zo'n manier gebeuren dat het op dat moment voor leerlingen duidelijk is *waarom* het nuttig is situaties op die bepaalde manier te beschrijven, wat voor zin dat heeft, wat de noodzaak of reden daarvoor is, zonder dat ze nog weten dat die beschrijvingswijzen nuttig zijn voor het verdere vervolg (b.v. voor het formuleren van generalisaties). Bovendien zal er in het algemeen enig voorwerk gedaan moeten worden om leerlingen de zin, noodzaak of reden voor een bepaalde beschrijvingswijze in te laten zien. Want als ze de reden daarvoor al inzagen, dan maakten ze hoogstwaarschijnlijk ook al gebruik van die beschrijvingswijze en hoeft die dus ook niet meer geïntroduceerd te worden.

Een probleemstellende aanpak van onderwijs in de natuurwetenschappen

De verdere mogelijkheden die ik zie voor op inhoud gerichte verbeteringen van onderwijs in de natuurwetenschappen sluiten in zekere zin aan op wat ik zojuist over de invoering van specifieke beschrijvingswijzen heb gezegd. Het zou goed zijn dat leerlingen bij *elke* activiteit op inhoudelijke gronden weten waarom ze daarmee bezig zijn, en in het algemeen zullen die inhoudelijke gronden opgeroepen moeten worden in voorgaande activiteiten. Op die manier immers zijn de leerlingen lokaal betrokken bij hun inhoudelijke voortgang. Het zou ook goed zijn dat leerlingen op zijn minst een globaal inhoudelijk doel voor ogen hebben, een globaal beeld van waar wat ze aan het doen zijn toe leidt en goed voor is. Het zou goed zijn, kortom, dat leerlingen zelf hun leerproces ervaren als een intern coherent proces met een zekere richting en doel, aan de inhoudelijke voortgang waarvan ze zelf actief bijdragen.

In hoofdstuk 5 geef ik aan dat veel gangbaar onderwijs hier niet toe bijdraagt. De leerstof is daarin immers vaak van bovenaf gestructureerd, d.w.z. op een zodanige manier dat er voor iemand die het allemaal al begrepen heeft een logische opbouw in zit, en wordt ook als zodanig uitgelegd. Leerlingen worden aldus min of meer gedwongen tot stap voor stap volgen, wat hen op zich vaak al moeite genoeg kost, zonder bovendien zicht te hebben op waar het toe leidt en goed voor is.[2] Verder zijn de experimenten die leerlingen uit moeten voeren vaak illustratief van aard en hebben ze bovendien vaak een kookboek-karakter, waardoor ze in feite geen functie hebben binnen de inhoudelijke voortgang (en dus ook niet tot inzicht leiden in de rol van experimenten binnen de natuurwetenschappen). Vaak zijn leerlingen alleen maar actief betrokken bij het maken van opgaven, maar dan zelden op inhoudelijke gronden en veeleer omdat het maken van die opgaven voorbereid op proefwerken (de zogenaamde sommetjes-cultuur). In het slechtste geval reduceert het leerproces voor leerlingen tot een jacht op het goede antwoord, tot uit het hoofd leren van trucjes om standaardopgaven op te lossen, verbalisme, enz.

In de laatste jaren is er betrekkelijk veel onderwijs gemaakt, veelal onder de noemer 'constructivisme', dat een verbetering op gangbaar onderwijs beoogt te zijn. In hoofdstuk 5 bespreek ik een typisch voorbeeld van constructivistisch onderwijs, namelijk de lessenserie over corpusculaire modellen die ontwikkeld is binnen het Britse CLIS-project. Ik doe dat om aan te geven dat het er mij niet alleen om gaat leerlingen een meer actieve rol te laten spelen dan in veel gangbaar onderwijs, zoals inderdaad het geval is in constructivistisch onderwijs, maar dat hun leerproces zich ook dient te ontwikkelen in de richting van natuurwetenschappelijke kennis. Ik probeer te laten zien dat de CLIS-lessenserie er niet toe bijdraagt dat leerlingen zicht krijgen op het hoe en waarom van deeltjesmodellen, en beargumenteer dat dat komt door de nadruk daarin op de zogenaamde alternatieve ideeën over deeltjes die leerlingen zouden hebben en zouden moeten vervangen. Ik probeer ook aan te geven wat er zou moeten gebeuren opdat leerlingen wèl zicht krijgen op de aard en het doel van deeltjesmodellen.

Een aanpak van natuurwetenschappelijk onderwijs die er expliciet op gericht is leerlingen zoveel mogelijk in een zodanige positie te brengen dat ze zelf op inhoudelijke gronden hun bestaande kennis, begrippenstelsel en ervaringsbereik in een bepaalde richting *willen* uitbreiden, en waarbij een verdere ontwikkeling in die richting uiteindelijk leidt tot inzichtelijke natuurwetenschappelijke kennis, noem ik een *probleemstellende* aanpak. Een concrete vormgeving van die aanpak bestaat in het ontwerpen, uittesten, verbeteren, etc, van didactische structuren. Onder een *didactische structuur* versta ik een gedetailleerd uitgelijnde planning van een onderwijsleerproces waarvan verwacht wordt dat het zich als bovengenoemd zal ontwikkelen. Bij het ontwerpen van een didactische structuur zal men dus niet alleen moeten denken aan de inhoudelijke *doelen* die men als ontwikkelaar wil bereiken, en over manieren om die te bereiken, maar zeer nadrukkelijk ook aan de inhoudelijke *motieven* van leerlingen om hun kennis, begrippenstelsel en ervaringsbereik in een bepaalde richting te willen uitbreiden, en over manieren om die motieven op te roepen. Idealiter zou iedere activiteit in het

2. In hoofdstuk 3 wijs ik in dit verband op de welhaast vanzelfsprekende neiging om een lessenserie over radioactiviteit te baseren op deeltjesmodellen, en aldus van bovenaf te structureren. Uit observaties van lessenseries die aldus gestructureerd zijn blijkt dat leerlingen de uitgebreide behandeling van deeltjesmodellen met enige weerzin ondergaan en als een hinderlijke onderbreking zien van waar het eigenlijk om zou moeten gaan: radioactiviteit. Verder laat ik in hoofdstuk 3 aan de hand van enkele voorbeelden zien dat leerlingen die modellen letterlijk opvatten, als plaatjes van hoe de dingen er 'in het klein' uitzien, en dat die modellen hen ook niet echt helpen om tot een begrip van radioactieve verschijnselen te komen.

onderwijsleerproces ingeklemd moeten zitten tussen door voorgaande activiteiten opgeroepen inhoudelijke motieven van leerlingen enerzijds en inhoudelijke doelen van de ontwerper anderzijds, zodanig dat die motieven voor leerlingen zin geven aan die activiteit, en de in die activiteit te bereiken doelen voor hen zin geven aan (een inhoudelijk motief vormen voor) volgende activiteiten.

Evaluatie van een didactische structuur
Een natuurlijke manier om een didactische structuur te ontwerpen en te presenteren is in de vorm van een *scenario* van het onderwijsleerproces dat, naar verwachting, zal optreden aan de hand van een bepaalde opdrachtenreeks en een bepaald didactisch handelen van de docent. Een fragment van zo'n scenario zou iets als het volgende kunnen zijn: wat het in voorgaande taken opgeroepen motief voor leerlingen is om te gaan werken aan die bepaalde taak waarin hen gevraagd wordt experimenten te bedenken; welke experimenten ze zullen bedenken in het licht van dat motief en gegeven wat ze eerder geleerd hebben of anderszins weten; hoe de docent het uitvoeren van die experimenten structureert; welke conclusies en vragen de leerlingen zullen stellen na het uitvoeren van die experimenten; op welke manier de docent op die conclusies en vragen in kan haken om de volgende taak voor leerlingen zin te geven, etc.[3] Bij het ontwerpen van een scenario zal men onvermijdelijk een (impliciet) beroep doen op rationaliteitsnormen die men met leerlingen deelt: dat ze experimenten bedenken waarvan, gegeven wat ze geloven, redelijkerwijs verwacht kan worden dat die zullen leiden tot wat ze willen bereiken; dat ze hun conclusies op een adequate manier baseren op de relevante experimentele gegevens; dat ze geen tegenspraken in hun gedachtensysteem accepteren, etc. Als een soort voorspelling van het onderwijsleerproces dat zal optreden aan de hand van een bepaalde opdrachtenreeks en een bepaald didactisch handelen van de docent, kan een scenario ook vergeleken worden met het daadwerkelijk optredende onderwijsleerproces. Zoals ik in hoofdstuk 7 aangeef, gaat het er bij zo'n vergelijking niet om dat getest wordt of leerlingen rationeel zijn. Immers, voordat zo'n vergelijking gemaakt kan worden moet het daadwerkelijke gedrag van leerlingen eerst geï nterpreteerd worden, en zo'n interpretatie kan alleen maar gegeven worden voorzover dat gedrag (impliciet) herkend wordt als in belangrijke mate geleid door gedeelde rationaliteitsnormen. In deze context is het misschien goed op te merken dat een verder uitgewerkte versie van Davidsons interpretatietheorie volgens mij een meer expliciete constructie van een didactische structuur mogelijk zal maken, alsmede een meer expliciete interpretatie van (voldoend rijke) onderwijsleerprocessen die zich daadwerkelijk hebben voorgedaan.

Waar het bij een vergelijking tussen scenario en daadwerkelijk optredend onderwijsleerproces om gaat is dat de didactische structuur op die punten waar de twee te zeer uit elkaar lopen verbeterd wordt. In de hoofdstukken 7 en 9 bespreek ik daar enkele voorbeelden van[4]: leerlingen die een taak anders dan bedoeld opvatten door een

3. In hoofdstuk 8 wordt een didactische structuur van het onderwerp radioactiviteit gepresenteerd in de vorm van een scenario.
4. In hoofdstuk 7 betreft het verbeteringen aan de eerste versie van de didactische structuur van radioactiviteit

te vage formulering van de taak; leerlingen die de beoogde samenhang tussen verschillende taken niet zien, doordat de respectieve situaties waarover die taken gaan voor hen niet relevant hetzelfde zijn; leerlingen die een bepaalde taak niet als beoogd kunnen uitvoeren omdat die taak onvoldoende is voorbereid; leerlingen die een beoogde conclusie niet trekken, omdat de docent er voornamelijk op gericht was die conclusie uit hen te trekken en daardoor veel meer hoorde in wat de leerlingen zeiden dan ze feitelijk bedoelden; leerlingen die een bepaalde natuurwetenschappelijke term niet als bedoeld hanteren doordat die prematuur is geï ntroduceerd. In zulke gevallen zijn meer of minder ingrijpende verbeteringen nodig, variërend van herformuleringen van taken, verwijderingen van oude en toevoegingen van nieuwe taken, tot structurele veranderingen in de volgorde van taken, en van duidelijker aanwijzingen voor het didactisch handelen tot ingrijpende aanpassingen in werkvormen. Zulke verbeteringen leiden tot een herziening van de didactische structuur, en tot de verwachting dat een daadwerkelijk optredend onderwijsleerproces aan de hand van de herziene opdrachtenreeks en het herziene didactische handelen van de docent minder zal afwijken van het herziene scenario.

Zoals ik in hoofdstuk 7 aangeef, zullen zulke verbeteringen nooit tot een didactische structuur kunnen leiden die exact voorspelt wat er in de klas zal gebeuren. Dat is echter ook niet nodig. Het is voldoende dat middels de verbeteringen een didactische structuur ontstaat die 'goed genoeg' is, die voldoende houvast biedt om het proces dat zich in de klas voltrekt te begrijpen en begeleiden. In iedere klas echter zal dat proces op een wat andere manier om het door de didactische structuur voorspelde pad kronkelen. Een middels ontwikkelingsonderzoek empirisch ondersteunde didactische structuur die 'goed genoeg' is, zou ik een stukje ß-didactische theorie willen noemen.[5)] Als uiteindelijk doel van ß-didactisch onderzoek zie ik een samenhangende didactische structuur van de natuurwetenschappen, die het gehele natuurwetenschappelijke onderwijs van begin basisschool tot (in ieder geval) eind middelbare school overdekt.

Globale uitlijning van een didactische structuur

Hierboven heb ik aangegeven dat het goed zou zijn dat leerlingen in hun leerproces een globaal inhoudelijk doel voor ogen hebben, een globaal beeld van waar wat ze aan het doen zijn toe leidt en goed voor is. In hoofdstuk 6 bespreek ik, geï nspireerd door het werk van van Hiele en ten Voorde, een min of meer natuurlijke volgorde in drie soorten van zulke globale inhoudelijke doelen, die naar mijn indruk bruikbaar is om een didactische structuur van een natuurwetenschappelijk onderwerp op een globale manier uit te lijnen. De eerste soort bestaat in een globale motivering en betreft het allereerste begin van een didactische structuur; de tweede soort bestaat in praktische problemen die leerlingen zichzelf stellen; de derde in theoretische problemen.

Een *globale motivering* voor een onderwerp maakt het voor leerlingen zinvol

die ik ontworpen heb; in hoofdstuk 9 aan de tweede (en laatste) versie, de versie die in detail beschreven is in hoofdstuk 8.

5. In hoofdstuk 9 concludeer ik, naar aanleiding van een evaluatie van de in hoofdstuk 8 gepresenteerde didactische structuur van het onderwerp radioactiviteit, dat die didactische structuur een stukje natuurkunde-didactische theorie vormt, mits daarin nog enkele aangegeven verbeteringen worden doorgevoerd.

tenminste met een nadere bestudering van dat onderwerp te beginnen, en verschaft hen tevens een voorlopig zicht op wat er ongeveer komen gaat. Een globale motivering zou b.v. opgeroepen kunnen worden door het onderhavige onderwerp te relateren aan bestaande interesses van leerlingen, te introduceren in de context van vragen die van persoonlijk of maatschappelijk belang zijn, of door hen zelf de relevantie van het onderwerp te laten formuleren. De *praktische problemen* maken leerlingen bewust dat er voor hen iets te leren valt in een bepaalde richting, en betreffen b.v. een verrassend element in een alledaagse situatie of onduidelijkheden in situaties die van praktisch belang zijn. Het oproepen van praktische problemen zal vaak gepaard gaan aan, of zelfs in gang gezet worden door, de introductie van specifieke beschrijvingswijzen. De praktische problemen moeten zodanig opgeroepen worden dat het voor leerlingen duidelijke problemen zijn, waaraan ze willen gaan werken in de verwachting dat ze aldus tot b.v. een beter begrip van alledaagse situaties zullen komen, of tot antwoorden op de maatschappelijk relevante vragen in de context waarvan het onderwerp geïntroduceerd is. Vanuit het perspectief van de curriculumontwerper moet de periode waarin de praktische problemen opgeroepen worden zodanig zijn dat daarin voldoende kiemen besloten liggen waarvan redelijkerwijs verwacht mag worden dat die zullen uitgroeien tot functionele praktische kennis: specifieke beschrijvingswijzen en generalisaties die in termen daarvan geformuleerd zijn, waarmee een veelheid aan gebeurtenissen die van praktisch belang zijn verklaard en voorspeld kunnen worden met een precisie die voor praktische doeleinden volstaat. Net als de praktische problemen, maken ook de *theoretische problemen* leerlingen bewust dat er voor hen iets te leren valt in een bepaalde richting, maar verschillen ze van praktische problemen wat betreft de richting waarin ze wijzen. Ze zijn niet zozeer gericht op een beter begrip van praktische situaties, maar op een beter begrip van de praktische kennis waarmee die praktische situaties begrepen zijn. Ze kunnen b.v. opgeroepen worden door geconstateerde gebreken in de beschrijvingswijzen die horen bij de praktische kennis. Wanneer de theoretische problemen en de praktische kennis waaruit ze zijn ontstaan daartoe voldoende kiemen bevatten, kunnen die theoretische problemen een globaal inhoudelijk doel geven aan een proces dat leidt tot theoretische kennis: nieuwe beschrijvingswijzen en generalisaties waarmee, uiteindelijk, meer gebeurtenissen met grotere precisie verklaard en voorspeld kunnen worden.

In hoofdstuk 6 wordt deze volgorde in drie soorten globale inhoudelijke doelen geïllustreerd aan de hand van het onderwerp 'radioactiviteit'. In hoofdstuk 11 wordt de bruikbaarheid daarvan verder geïllustreerd in het kader van een globale uitlijning van een didactische structuur van het onderwerp 'warmte en temperatuur', en van een didactische structuur die het gehele natuurwetenschappelijke onderwijs overdekt.

De rol van de docent

In hoofdstuk 10 ga ik nader in op de rol van de docent in een probleemstellende aanpak. Het zal duidelijk zijn dat die rol anders is dan in veel gangbaar onderwijs. Doordat leerlingen meer controle over en verantwoordelijkheid voor de inhoudelijke voortgang van hun leerproces gegeven wordt, hoeft de docent de inhoudelijke voortgang b.v. niet zo nadrukkelijk meer te trekken. Het is veeleer aan de docent die voortgang zo goed mogelijk te volgen en daar adequaat feedback op te geven. Verder verschuiven de controle en verantwoordelijkheid van de docent in een meer op procedure dan op inhoud gerichte richting. De docent zal erop toe moeten zien dat het proces gestructureerd verloopt, en b.v. klassegesprekken in ordelijke banen moeten leiden. Dit moge genoegzaam illustreren dat ook in een probleemstellende aanpak de docent een essentile rol speelt[6)]: een didactische structuur die 'goed genoeg' is kan niet zonder een docent die bereid en in staat is daarmee te werken.

Met betrekking tot de vraag wat ervoor nodig is opdat docenten daartoe bereid en in staat zijn, kan ik alleen maar enkele suggesties doen. Wat betreft de bereidheid zal het nodig zijn dat de didactische structuur in kwestie docenten op een pragmatisch intuï tief niveau aanspreekt. Een presentatie van de didactische structuur in de vorm van een scenario zou daartoe kunnen bijdragen, zeker wanneer die gelardeerd is met enkele praktijkervaringen.[7)] Wat uiteindelijk de doorslag zal moeten geven, zoals het geval was voor de docent waarmee ik in mijn onderzoek nauw heb samengewerkt, is dat docenten vertrouwen krijgen in de aanpak doordat ze het in de praktijk zien werken: dat leerlingen, mits geholpen door lesmateriaal en docent natuurlijk, inderdaad zelf hun leerproces voortstuwen met hun inbreng, enthousiasme, ideeën en vragen, in een richting die leidt tot inzichtelijke kennis. Echter, bereid zijn op een probleemstellende manier te werken is één ding, daartoe in staat zijn een tweede. Wat dat tweede punt betreft zal het nodig zijn dat docenten, net als de docent waarmee ik heb samengewerkt, flexibel gebruik kunnen maken van een veelheid aan werkvormen. Wat daartoe zou kunnen bijdragen weet ik niet, maar lijkt me zeer de moeite van nader onderzoek waard: onderzoek waarin het 'wat' en het 'hoe' van lesgeven geï ntegreerd bestudeerd wordt.

6. De didactische structuur van het onderwerp radioactiviteit die in hoofdstuk 8 gepresenteerd is laat dit ook concreet zien.
7. Men kan hierbij b.v. denken aan een verkorte combinatie van de hoofdstukken 8 en 9 uit dit proefschrift.

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Curriculum vitae

Kees Klaassen werd geboren op 22 juni 1960 te Bergen op Zoom. Het diploma gymnasium-ß behaalde hij in 1978 aan het R.K. Gymnasium Juvenaat H.Hart aldaar. In augustus 1986 slaagde hij voor het doctoraal examen theoretische natuurkunde aan de Universiteit Utrecht.

Van december 1986 tot juni 1988 was hij als gewetensbezwaarde tewerkgesteld bij de vakgroep Natuurkunde-Didactiek van de Universiteit Utrecht. In die hoedanigheid was hij medewerker aan een SVO-project waarin de voorwaarden werden onderzocht waaraan onderwijs in de bovenbouw van HAVO en VWO zou moeten voldoen om bij te dragen aan het leren afwegen van risico's van ioniserende straling.

Daarna is hij bij dezelfde vakgroep in dienst getreden. Eerst als assistent in opleiding, in welke functie hij het onderzoek heeft verricht waarover dit proefschrift rapporteert. Vervolgens heeft hij zich als toegevoegd onderzoeker en, vanaf juli 1994, als universitair docent beziggehouden met het uitvoeren en begeleiden van didactisch onderzoek in het kader van het VF-programma 'Curriculumonderzoek en Begripsontwikkeling in de Natuurwetenschappen'.