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The Structure of Current School Chemistry

A Quest for Conditions for Escape

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The Structure of Current School Chemistry

A Quest for Conditions for Escape

De structuur van het huidige schoolvak scheikunde

Het zoeken naar voorwaarden voor ontsnapping

(met een samenvatting in het Nederlands)

Proefschrift

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To conclude, I think there is only one way to science—or to philosophy for that matter: to meet a problem, to see its beauty and fall in love with it; to get married to it, and to live with it happily, till death do ye part—unless you should meet another and even more fascinating problem, or unless, indeed, you should obtain a solution.

Karl R. Popper (1983, p. 8)

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1 Problems of current school chemistry

In this thesis I will address two main problems of current school chemistry. The first problem I will address is the *problem of the structure*: what is the structure of the chemical concepts and chemical relationships present in school chemistry textbooks? The second problem I will address is *the problem of escape*: why do reforms of the current school chemistry curriculum lead only to marginal changes? This in turn raises the question whether the structure of the current school chemistry curriculum is an asset or an obstacle for reforming school chemistry. Thus the solution of the problem of escape bears on the solution of the problem of structure.

In this Chapter, I will first describe the origin and relevance of these problems (1.1). Second, I will discuss the research design and methods I use to address the problems of structure and escape (1.2). Third, I outline the theoretical curriculum framework used in this thesis – based on the work of Schwab, Goodlad, Kuhn, and Roberts – which I use to analyze and explain the curriculum data I gathered in my research into the structure of current school chemistry (1.3).

Finally, I will give an overview of the contents of my thesis in terms of the general argument which is based on the research I have undertaken to formulate and test a hypothesis on the current structure of school chemistry, and to analyze and evaluate an attempt to escape from the currently dominant school chemistry curriculum by an innovative chemistry course, called Salters' Chemistry (1.4).

1.1 Relevance of problems of structure and escape

The problems of structure and escape arose, initially, in the context of a citizen-oriented reform of school chemistry (1.1.1). Besides this practical root, the problem of structure also had a theoretical root in the fundamental research as performed by the Department of Chemical Education of Utrecht University in the 1980s on the topic of explanation in chemical education (1.1.2). In line with the practical and theoretical relevance of the problem, I will further describe how the structure and escape problems were of personal relevance to my own learning, teaching and researching of school chemistry (1.1.3).

1.1.1 Societal relevance

In a curriculum study on the development and implementation of a new society and citizen oriented chemistry curriculum for lower secondary education, the researchers (Joling et al.,1988) reported a crucial finding relevant for my research on the current structure of school chemistry:

> The transition to “Chemistry for the Citizen” resulted in a *tension between aim and structure* of chemical education (Joling et al., 1988, p. 82; all translations from Dutch original quotes are mine).[1]

The general *aim* of this two-year course, titled “Chemie-mavo”, was interpreted by the developers of the course as providing future citizens with knowledge of relevant chemical aspects in their personal and social lives. The developmental project, of which the “Chemie-mavo” course was to be the outcome, started in 1975 and aimed from the outset to develop a course different from the customary “paper chemistry of just formulas and reaction equations” (ibid., p. 324). Instead, as the developers put it:

> We wanted to show the role of substances and reactions in processes of daily life in society and in other natural sciences (p. 325).[2]

Accordingly, the developers felt that the teaching materials had to be context-oriented, developed on the basis of practical experiments, and related to daily life experiences of pupils. In this way pupils who did not choose chemistry as an exam subject were provided, at least in the first year, with a self-contained course (Joling et al.,1988, p. 2).

By choosing a research design which consisted of document analysis of the teaching materials, of interviews with developers, and of extensive classroom based research of the teaching-learning process, the researchers wanted to ascertain the extent to which the general aim of the “Chemie-mavo” course had been realized, both in the textbook produced by the developers and in the teaching-learning process as enacted by teachers and students.

The chemical content selected by the developers to realize the newly set societal aim of the course was, according to the researchers, *structured* in the first year of the course around a “backbone” of the three related chemical concepts: pure substance, chemical reaction, and chemical element. The second and last year of the course dealt with the corpuscular view of matter, that is, with concepts such as atom, molecule, and ion (ibid., pp. 82, 87). This structure, they noted, was largely similar to the conceptual structure of upper secondary chemical courses, albeit in a diluted form.[3] It is a conceptual structure which has a strong scientific orientation and is, therefore, traditionally used to teach future chemists. Two conclusions of the curriculum study of “Chemie-mavo” are relevant here. First, contrary to the intentions of the developers:

> Chemical education emerges for many pupils as a closed system, both with regard to space, the classroom, and time (a couple of hours per week) with no visible relationships with the rest of the observable world.[4]

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[1] Dutch original: Bij de overstap naar “Chemistry for the Citizen” ontstond een spanning tussen doel en structuur van het scheikunde-onderwijs” (ibid., p. 82).

[2] Dutch original: We wilden laten zien dat stoffen en reacties een rol spelen bij processen in het dagelijks leven, in de samenleving en in de andere natuurwetenschappen (p. 325).

[3] Developers had to work under the external constraint, set by the overseeing committee, that most of the traditional chemical concepts had to be addressed in the course.

[4] Dutch original: Scheikunde-onderwijs ontwikkelt zich voor veel leerlingen tot een in ruimte (het leslokaal) en in tijd (enkele uren per week) gesloten systeem zonder zichtbare relaties met de rest van de waarneembare wereld (p. 313).

The second conclusion of the researchers is that:

> The research shows that is not easy for pupils to make a context switch [between a daily-life context and a chemical context], and that teachers are often not able to provide a solution which is consistent with the intentions of the authors of the course (ibid., p. 312, 313).[5]

In brief, the overall aim of the “Chemistry for the Citizen” course as embodied in “Chemie-mavo” was not met by either teachers or the developers, and consequently was not realized with the pupils. Despite the context-and-experiment led approach to the chemical content selected, developed, and taught in the course, the outcome seemed to be that many pupils still learned a kind of “paper chemistry”, or chemistry in a “closed system”. Thus, contrary to the intentions of the developers, the reform resulted in only marginal changes.

This led the researchers to ask the penetrating question: “Why was this aim not met more successfully in the development and teaching of the new course?” The answer, they thought, had to do with the crucial finding mentioned at the start of this subsection, namely, that there is a serious *tension* between the newly set aim of the “Chemistry for the Citizen” course and the traditional conceptual structure of school chemistry used in chemistry courses for both lower secondary and upper secondary education. I will come back to this crucial finding in Chapters 4 and 5 of this thesis, where I report on my curriculum research on the society-oriented Salters’ Chemistry course as executed in the 1980s in England.

This example of an unsuccessful attempt to reform school chemistry in the Netherlands, to change the quality of chemical education especially for those pupils who most likely would *not* go on to study chemistry, raised a vexing question. Was this finding to be seen as a curriculum phenomenon of a merely local nature, or did it perhaps have a global character as suggested by one of the researchers, Wobbe de Vos? Were there not similar curriculum experiences and findings in other countries? If so, what was the general *mechanism* preventing these society- and citizen-oriented school chemistry reforms from becoming successful?

First, however, an important preliminary question had to be answered, namely, what was exactly the structure of the current school chemistry curriculum, that is, the structure of the chemical concepts and chemical relationships present in school chemistry textbooks? What was needed, was a valid description of the content and structure of chemistry as a school subject in order to analyze, and possibly overcome, via reforms of school chemistry, the *tension between aim and structure* of chemical education.

Recruitment or citizenship

It is not difficult to see that most pupils of lower secondary chemical education, from whatever stream or school type, will not choose to go on with further study in chemistry. More surprisingly, perhaps, is that this is also the case for upper secondary education, as various researchers have argued. Hondebrink & Eykelkamp (1988) concluded for The Netherlands that at most 10% of the pupils of upper secondary education would go on to study chemistry or subjects requiring basic chemical knowledge. Fensham (1984)

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[5] Dutch original: Uit het onderzoek blijkt dat deze wisseling van context [tussen een leefwereld context en een chemische context] niet gemakkelijk door de leerlingen wordt uitgevoerd en dat docenten dikwijls geen oplossing in de geest van de bedoelingen van the auteurs kunnen bieden (p. 312).

in a study surveying the international situation concluded that at most 20% of the pupils in secondary education would choose to continue studies requiring chemistry as taught in secondary schools. Roald Hoffmann, a Nobel laureate with a great interest in chemical education, made the point that:

> Education is a conservative enterprise, and it does not change very quickly. I think the shift in chemistry education has to come from the recognition of the fact that 99.9% of the population are not going to be chemists (Hargittai, 2000, p. 208).

So, the majority of pupils are not provided with an appropriate chemical education in accordance with their needs. Fensham (1984) formulated the accompanying challenge:

> Can chemistry, as a subject field, contribute to the schooling of the 80+% of learners in each age group who are most unlikely to study chemistry again after leaving school?

Since the start of the "Science for All" movement in the early 1980s (Fensham, 2000), there have been several attempts to develop and implement science and/or chemistry curricula "aimed primarily at the non science student, at the informed citizen, not toward the professional" (Hoffmann, 1995, p. 228). Hoffmann gave two arguments for the urgent development of chemistry courses for the general public:

> First, if we do not know the basic workings of the world around us, especially those components that human beings have added to the world, then we become alienated. My second point of concern about chemical illiteracy returns me to democracy. Ignorance of chemistry poses a barrier to the democratic process.

Hoffmann in (Hargittai 2000, p. 208) then concluded that "[t]here is a role for experts, but the public has to decide by themselves. For this, they need to know a little chemistry."

In Chapters 4 and 5, I will report in detail on my research of a society-oriented curriculum for school chemistry, called Salters' Chemistry, which is part of the Salters' Science Project based at York University, England. Fensham (2000, p. 52) said of this 'first generation' of "Science for All" curricula:

> However, their acceptance has been difficult for many science teachers who have been strongly socialized into believing the content of the sciences consists of definitional abstract concepts, with the use of associated algorithms for application to standard, closed problems.

On the other hand, Fensham (1984) and Hoffmann (1995) argued – after analyzing the rich content of chemistry in relation to science, society, technology, culture, and history – that chemistry taken in this broad sense has to offer the general student and the general public much more than the customary one-dimensional concept-based problem solving. Both authors have themselves developed or contributed to rich 'chemistry for all' courses, Hoffmann for college students and Fensham and co-workers (1988) for students of secondary education. Fensham (2000) gave a review of some recent attempts to develop and implement "Science for All" courses, which attempted to overcome some of the problems of the first generation courses as well as to address the necessary curriculum reform on a greater, sometimes even on a national scale. An example of such a large scale attempt is the Dutch project, "New School Chemistry", the preparations of which started in 1999, and whose aim is to reform upper secondary chemical education (Bulte et al. 1999; Westbroek et al. 2000; Westbroek et al. 2001; Van Koten 2002).

Several practitioners in chemical education – researchers, developers, teachers – have been working hard to show that chemistry can contribute, and to some extent is already contributing, to these new chemistry courses, that is, to the schooling in relevant and meaningful chemistry of the general student or the general public. However, most of the work still remains to be done.

1.1.2 Scientific relevance

The problem of the structure of current school chemistry arose initially, together with the problem of escape, from a social root, that is, an unsuccessful attempt at reform of school chemistry. The problem of structure also had two important scientific roots.

Tradition of research in chemical education

Most of the studies performed, from 1985 onwards by members of the Department of Chemical Education / Center for Science and Mathematics Education, Utrecht University, concerned *parts* of the current school chemistry curriculum in The Netherlands. These studies addressed topics such as chemical reactions (De Vos and Verdonk, 1985/86/87), chemical equilibrium (Van Driel, 1990), chemical bonding (Van Hoeve-Brouwer, 1996) and electrochemistry (Acampo, 1997).

After a conceptual analysis of these topics in representative Dutch textbooks, an educational structure of activities was designed which described how and why a particular topic of school chemistry must be taught, and learned, and was trialled in the classroom. The audio-taped data of the teaching and learning process from teachers and students was used to redesign each teaching unit in order to match its structure to the new aims set by the respective researchers.[6]

The completion of a number of these small-scale, in-depth research projects led to the concept of the *hidden structure* of school chemistry, as it was initially called by De Vos (1992). He began to wonder what the current school chemistry curriculum *as a whole* looks like, why school chemistry textbooks from different periods as well as from different countries look so remarkably similar? How can we arrive at a valid description of this structure of school chemistry? Further, why is school chemistry so *resistant* to reforms? Is the structure of the current school chemistry curriculum a support or a hindrance to the quality of chemical education? The problem of structure seemed to be of international scientific relevance.

Conference on explanation

In 1986, the Department of Chemical Education organized a one-day Conference on the subject of "Explaining in Chemical Education" ("Verklaren in chemie-onderwijs") for teachers, developers, and researchers in secondary education. As a result of the activities and discussions of that "Explanation Day", two of the organizers, De Vos and Verdonk, tentatively formulated a set of three important structural relationships that exist between concepts of school chemistry. As we shall describe in more detail below (section 1.2.2), this concerns the three conditions a chemical reaction must obey in order for the reaction to occur: (i) conservation of chemical elements; (ii) decrease of chemical (Gibbs) energy;

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[6] For a detailed description of this research methodology, called "Developmental research", developed, used, and refined by researchers at the Centre for Science and Mathematics Education, see Lijnse (1995).

(iii) kinetic instability. Only these three conditions *together* explain the occurrence of a chemical reaction. In line with this finding, they formulated as the general aim of school chemistry: the explanation and prediction of chemical phenomena in terms of the chemical-reaction conditions (stated above).

Hidden structure

The need to arrive at a valid description of the structure of chemistry as a school subject was felt all the more, because De Vos and Verdonk could not find a "generally accepted description of a conceptual structure underlying school chemistry" in official documents (De Vos et al., 1991), although various authors did mention or seem to refer to such a structure in papers and documents. For example, the exam program for the vocational-oriented stream in secondary education in The Netherlands (HAVO) stated:

> Although it is true that a syllabus presents the topics in an order, that is, as logical as possible, this does not mean that the topics of a course in a certain year have to be taught in that order. The teacher is free to choose an order, though often *the structure of the subject* makes it necessary to teach certain topics before others." (Min O&W, 1984; translation and italics mine)

An initial solution of the problem of the structure of current school chemistry, stemming from the social and scientific roots mentioned above and given by De Vos and Verdonk (1990), laid the groundwork for my research. In the 1990 paper they arrived at the hypothesis of a *coherent* conceptual structure in school chemistry. The concept of the chemical reaction and the three reaction conditions mentioned above occupied therein a central place; (for an elaboration of this hypothesis, see also De Vos et al., (1994). Subsequently, it was decided to test the hypothesis on the *coherent* structure in current school chemistry against the curriculum experiences and views of both an International Forum and a Dutch Forum of chemical educators, developers, and researchers (see also1.2.3). To explore the international relevance of the problem of structure:

- We wanted to test our hypothesis against the curriculum experiences and knowledge of chemical educators in both our own country and other western countries in order to see whether it was grounded or valid at both national and international levels.
- We felt that if we could establish and describe the structure of current school chemistry as an international curriculum phenomenon, it would greatly enhance the urgency to change the current state of school chemistry, either locally or globally.
- We needed a valid description and analysis of the structure of school chemistry, but only as detailed as required for this chemical educational purpose since our ultimate goal was to contribute to reforms of school chemistry. Therefore, we refrained from embarking on an extensive and detailed historical study of school chemistry curricula.
- We also hoped to learn more about the mechanism that prevented reforms of school chemistry, at a national or international level, from realizing their newly set educational aims.

1.1.3 Personal relevance

What follows in this subsection is a personal case study, and as such is less objective than a case study performed on another subject. Its function is to introduce the problems, that will be discussed in this thesis in an abstract or empirical way, in a more personal way, and thereby hopefully make these problems more accessible. By sharing my curriculum experiences, the reader might recognize and be able to identify more readily with the problems discussed. These experiences can also serve as further illustrations of some of the general claims backed by empirical research I will arrive at in this thesis and discuss at the end of this study (Chapter 6).

Although I have followed chemistry at secondary school and studied chemistry as an undergraduate student at university and later in the context of a teacher-trainer course, these learning experiences did not give me a clear idea of the *conceptual structure* of school chemistry or, for that matter, the conceptual structure of university chemistry. I will now describe some current reflections on a few of these experiences that are relevant to the study at hand.

Secondary school

In 1963, I was introduced at age 15 to chemistry as a school subject in grade 9 of a secondary school, the so-called “Hogere Burger School” (HBS), a Dutch school-type at the time. Pupils who passed the HBS exam were admitted to any university in the country they wished to attend, provided they met certain requirements, like sufficient training, for the subject they chose to study. I received chemistry lessons from three teachers. The first teacher, who was quite an old teacher in my perception, often failed to get the ‘right’ results in the experiments he demonstrated to us. One time, though, he succeeded to engulf the classroom as well as the whole school in hydrogendisulfide (H_2S) smoke and smell. This event might have been one of the reasons why he left. His place was taken halfway through the school year by a much younger teacher who tried to relate to us more and to motivate us for his school subject, but without much success. He left at the end of the school year. After grade 9, we had to choose either HBS-A, a humanities-oriented exam course, or HBS-B, a science-oriented exam course. Having chosen the latter, I was fortunate to get as my third chemistry teacher, in both grades 10 and 11, an inspiring person who was able to motivate many of us, including me, for his subject. This resulted in better achievements in the classroom, in better marks on tests and final exams.

Textbooks

The textbook we used in grades 9 and 10 was written by Meurs and Baudet (1959), and entitled *Beginselen der Scheikunde, part I*. The first edition of this textbook appeared in 1921; it could be called a ‘systematic’ introduction to chemistry. The table of contents shows that it is organized around elements and groups of elements, that is, it consists largely of chapters of descriptive chemistry interjected with a few chapters on theoretical topics, such as combustion or valence. In my day as a student we used the nineteenth edition which did contain more theoretical chapters (about 10), although the descriptive, systematic chemical chapters still dominated (about 25). In their foreword to this edition the authors remarked on the addition of chemical theory:

> We think we have achieved in this way that students do not have to learn outdated concepts which otherwise have to be replaced with great difficulty by modern concepts (my translation).

This textbook did, however, include demonstration experiments for teachers to perform, but no practicals to be done by pupils. In any case, we did none that year. In my last year (grade 11) at the HBS, my chemistry teacher decided to use a new textbook written by Feis et al. (1962), and titled simply “Scheikunde” (Chemistry). This text presented a different, a more theoretical view on chemistry. The subject matter was organized around corpuscular theories, such as the atomic theory of Rutherford and Bohr. As the authors explained in their foreword:

> By putting theory first we have been able to strongly limit the space given to the systematic discussion of elements and compounds, and which is needed for the written final exam of the HBS (my translation).

As for experiments, most were again demonstrated by the teacher. In this last year, though, we ourselves performed some practical experiments, or rather exercises as they were called, in a room specially equipped for that purpose. I recently learned from an interview with my former chemistry teacher that his aim for letting us do these practical exercises in grade 11 was to give us some experience of those *chemical reactions we would probably come across in final exam questions* such as precipitation reactions and titration reactions. Looking back I found this rather revealing. The goals proposed in the 1970s for using 'pupil' experiments – to motivate pupils for school science, to introduce and/or verify chemical laws and theories presented in school chemistry textbooks, and to illustrate scientific method – were fully absent in this case. Instead, practical exercises were used as an additional asset to the textbook, lectures and demonstrations to help us to solve exam problems in order to prepare us for the final exam.

In sum, I got a rather 'textbookish' introduction to school chemistry, largely along 'systematic' chemistry lines, and only in grade 11 along theoretical, corpuscular lines. What we did, mostly, was to solve problems chapter-by-chapter from both textbooks, which prepared us for our exams. The few practicals we did were selected for that same purpose. Although I did pass my final exams for the subject chemistry, the relations between chemical theory and observation and experiments did not at that point become clear to me at all. I suppose this accounts for my ignorance at the time of the existence of a *conceptual structure* of school chemistry, a theoretical structure (as I learned much later) which could be used for describing, explaining and predicting chemical phenomena, and thereby give pupils an understanding of the nature and structure of chemistry as a science.

Undergraduate chemistry

This state of affairs did not improve much at university, I must say. I still had to study textbooks, but now more and bigger ones, introduced to us by several lecturers. By studying the lecture notes and textbooks it was fairly easy, however, to pass the required test to go on to the next course, and the next test. Admittedly, we had to attend much more practical courses as well, such as practical courses on organic chemistry, inorganic chemistry, physical chemistry, physics, and botany, but without seeing much relations between what was presented theoretically in lectures and textbooks and the topics offered in the practical courses.

Practical courses were organized as separate blocks as well, and were not really connected to, or in preparation for, each other; nor did they relate clearly to the theory or lectures we followed. As a rule the practicals had a certain format. First, we studied some 'relevant' theory, then we discussed this with a teaching assistant and performed the (related) experiment. The experiment was followed by a discussion of the results with the same assistant. Again, this process did not lead to any real theoretical understanding of what we had done in our practical work. After all, what we had to do, we could realize by following the given prescriptions, the recipes (De Jager, 1985). Following a number of these prescriptions as a rule led to the required experimental results and on to the next practical course. In brief, besides chemical formulas given in textbooks, we now had learned, or rather reproduced, chemical recipes as they were given in what could be called chemical 'cookbooks' (Van Keulen, 1995).

Thus, in the undergraduate chemistry courses I got a rather fragmentary view of chemistry as a discipline, as portrayed by several textbooks and 'cookbooks'. This did not give me a coherent picture of chemistry as a science. Something that could have provided an overview, such as a course in the history or philosophy of science or chemistry, was, not available, or at least not known to me, and it was certainly not mandatory.

An episode

Sometimes I could not take it all in. So, I twice had to do the subject 'organic chemistry' that was focused on organic name reactions. Since I failed both times, I could not pass the ensuing 'kandidaats' (bachelor) exam. As a last resort an oral examination could be taken. I prepared myself thoroughly for this with the help of a tutor, a member of the chemical faculty who seemed pleased with my progress in his hands. However, I did not pass the oral exam. The examiners, one of whom was a newly appointed professor in organic chemistry, did not examine me on the required subject matter of organic name reactions, the reproduction of which I had rehearsed for some months to the satisfaction of my tutor. Instead they decided to ask me some penetrating questions about the reaction mechanism of some organic reactions. They also wanted me to explain – concerning whatever I managed to suggest – a possible path of the reaction. I must say that I was not prepared for that type of organic chemistry thinking at all. Since I did not pass the oral exam, I could as a result not pass the bachelor exam either. However, by law students were allowed to take written tests again. At the next opportunity, I took the written test and finally passed, this time, though, on the usual topic of organic name reactions. As you can imagine, it was much later that I began to appreciate the mechanisms of organic reactions.

The structure of the undergraduate course in chemistry, consisting of a row of separate theoretical and practical courses, also meant that students were only dimly aware of such a thing as chemical research. Some of our practical assistants were as PhD's involved in chemical research, but I had no idea what this entailed. Chemical education and chemical research were at that time almost fully separated from the undergraduate level. Nevertheless, I decided to choose as my first minor biochemical research inspired by the reading of "The Double Helix", a popular book on the discovery of the structure of DNA by James Watson (1968).

Philosophy of science

It was at this point in my life, that I became interested, through discussions with friends, in the philosophy of science. And I decided, after a half-hearted and aborted attempt to do some biochemical research, to continue my studies with a course in the philosophy of the 'exact' sciences. Subsequently I studied history of science and history of chemistry.

It was in these courses that I began to understand that chemistry as a science aims at explaining and predicting chemical phenomena, and how that involves the generation and testing of knowledge (Popper, 1968). I learned about the structure of science and the structure of theories, for example, about the atomic-molecular theory, its relation to chemical and physical phenomena, and the empirical laws that it explained and predicted (Nagel, 1968).

I found out how hard it had been for scientists to arrive at an interesting hypothesis, how difficult it was to develop this into a valid theory, a theory which could explain and predict the known facts and also predict novel facts. Seen in this light, the purpose of experiments was not so much to introduce or illustrate a theory, as is usual in school science; rather, experiments were viewed as tests of a proposed hypothesis. When hypotheses withstood the tests, they could lead to theories, thereby furthering the growth of knowledge (Popper, 1965).

As sketched above, none of this transpired from my school chemistry or university chemistry. I felt rather alone in this, but later I found out that it was not an uncommon experience. Other students, at school or university, have experienced similar things, even including those who have gone on to do chemical research and become professors (Verdonk, 1995).

Teacher training

Some time after I graduated in philosophy of science, I decided to take a teacher-training course. This course consisted of a major in chemistry and a minor in chemical education. The latter consisted of period of teaching chemistry as a teacher-trainee at a secondary school and of a small research project in chemical education. At the end of the teacher training course, I came across a paper written by Wobbe de Vos and Adri Verdonk on the "Vakstructuur van het Schoolvak Scheikunde" (1990). This paper was a major eye-opener for me (see further the summary in section 1.2.2, section 1.2.3 and the reference given there). It gave me a first idea of the structure of chemistry as it pertained to *school chemistry*. Suddenly I saw that at the level of school chemistry a serious attempt can be made to teach students the explanation and prediction of chemical phenomena with regard to both chemical substances and chemical reactions.

De Vos and Verdonk (1990) pointed out that in essence there were two comprehensive theoretical structures involved in chemistry as a school subject. The first one was organized around chemical *substances* and the *corpuscular* theories which explained the structure and bonding of these chemical substances. The second theoretical structure was organized around chemical *reactions* and included the principle of the conservation of chemical elements, thermodynamic theory, and kinetics, which together offered a surprisingly coherent chemical reaction view on chemistry. From my studies in the history and philosophy of science, I was well aware of the existence and theoretical coherency of the first, the *corpuscular* point of view. The second theoretical structure, though, which De Vos and Verdonk described in some detail in their paper was quite new to me. I was receptive to this second theoretical structure because of the major I did in heterogeneous catalysis in my teacher-training course.

In sum, after my studies in the philosophy and history of science, I studied some chemistry in the context of a teacher-training course, and unexpectedly found out what the structure school chemistry was all about by reading the pathbreaking paper mentioned above by Wobbe de Vos and Adri Verdonk. I now had an idea of the conceptual structure of school chemistry.

Research in chemical education

My own struggle to arrive at this point made me conscious of a second issue involved, which we later called the *isolation* of the current school chemistry curriculum. Why had I not seen at least an outline of *a conceptual structure of school chemistry*? Maybe not at school, but at least at the university, or at the latest as I followed the teacher training course? I had not even grasped it when I was doing my chemical education research project on chemical equilibrium.

When I started in the 90s to teach chemistry at a secondary school, I experienced as a teacher that there existed more or less the same school chemistry curriculum that I had experienced when I was a pupil in the 1960s. This was despite the fact that, as I knew, there had been a major reform of school chemistry in the 1970s. Just as my teachers had done, I began to lecture and demonstrate experiments to my students at school, following the new textbook (Pieren, 1983). Admittedly, in line with the intent of the (then) recent curriculum reform, the pupils did more practical work, but again they performed the experiments as given by recipes. Besides lecturing, I spend most of the time on problem-solving which prepared pupils for the written tests I gave them. Full circle! Here I was giving pupils almost the same kind of chemistry teaching I had received, and to boot, had not liked. This kind of school chemistry was codified in textbook, tests, and exam. It apparently did not matter that I knew there was more to chemistry, such as its history or philosophy, which I had studied, and the chemical education research I had done. In that first year of teaching, I hardly had motive or opportunity to integrate such other content into my lessons, operating as I was under the demanding constraints of keeping ‘order’ and covering the required subject matter.

Not much later, I was fortunate to have an opportunity to do research in chemical education, this time on the problem of the *conceptual structure of school chemistry*, that is, on the same “Vakstructuur van het Schoolvak Scheikunde”, De Vos and Verdonk had recently written about. This way, I had a chance to learn more about this structure and its relation to textbooks and to the practice of teaching in this country and/or in other countries. Are there any differences across time or place? Why is the structure of school chemistry so invisible? How is it possible that despite major reforms, in this and other countries, the structure remains more or less the same? Why is it so rigid? This led to the two major problems mentioned before. First, what is the structure of school chemistry, that is, what are its elements, relationships and structure? Second, why is this structure so resistant to reforms in chemical education, or, as we later called it, why is school chemistry so rigid? Knowing what the structure is and how it blocks change might put us in a position to reform, or as we later called it, to *escape* from school chemistry.

1.2 Research design

First, I will explain the terms De Vos and Verdonk (1990) used to describe the problem of the structure of current school chemistry (1.2.1). Second, I will give an outline of their hypothesis on the structure of chemistry as a school subject, by focusing on the structural features of the school chemistry curriculum (1.2.2). Third, I will discuss the research methods used in my research: the method I used to test the initial hypothesis on the structure of current school chemistry, and the method I used to evaluate and analyze the attempt to escape from the prevailing school chemistry curriculum by an innovative school chemistry course called Salters’ Chemistry (1.2.3).

1.2.1 Analysis of the problem situation

In their attempt to describe the specifics of the structure of school chemistry, De Vos and Verdonk (1990, pp.19 -21), realized they had to be clear about the following points.

In their initial publication in The Netherlands on the structure of the current school chemistry curriculum, De Vos and Verdonk noted that the locution *the structure of the subject chemistry* does *not* refer to chemistry *as a scientific discipline*, but must be taken as a structure of chemistry *as a school subject*. The structure of chemistry as a school subject does not coincide with the structure of chemistry as a discipline (De Vos et al., 1991a, p.1), nor does the structure of chemistry as a university subject coincide with the structure of chemistry as a discipline (see 1.1.3). Secondly, they defined their general idea of structure by three features (1990, p. 20):

- a structure consists of a number of building blocks, i.e., chemical concepts;
- between these chemical concepts exist chemical relationships;
- a structure exhibits a certain demarcation from its surroundings.

De Vos et al. (1991a, p.1) added a fourth feature to this general idea of structure: structure is a “continuity in the way key concepts are mutually related”, that is, the property of a structure to repeat itself in place and/or time (Van Hiele, 1986).

In a later paper, De Vos et al. (1994, p. 743) summed up these features of the idea of structure by stating that “structure in this article refers to a more or less limited entity that consists of interrelated elements”. In view of the fourth feature mentioned above, this general idea of structure refers to an *enduring* entity, largely stable over time and place.

Thirdly, in their papers De Vos and Verdonk (1990, 1991) focused on the *chemical content* contained in the structure of chemistry as a school subject and on the relationships between chemical concepts. Furthermore, De Vos et al. (1994, p. 743) stressed that:

> In designing our structure we decided to limit it to the *chemical content* of the curriculum, leaving teaching strategies and theories of learning, important as they may be for actual implementation of a curriculum, aside. This allows the structure to be combined with various teaching strategies and learning theories.

As for the view on science underlying school chemistry, De Vos et al. (1994, p. 743) remarked that school chemistry:

> (…) is associated with a specific view of science and science education that seems to stem from the 19th century, that is, chemistry is taught in a strictly scientific context, one that sees science as providing descriptions, explanations and predictions of natural phenomena.

As for the general objective of the current school chemistry curriculum De Vos et al., (1994. p. 743) stated that:

> (…) students learn to explain and to predict chemical phenomena by studying the facts, theories and methods produced by predecessors.

This implies, that the intent of current school chemistry is to prepare pupils for further study in chemistry and eventually for university chemistry.

Analysis and discussion

Whereas De Vos and Verdonk were trying to describe the *specifics* of the current structure of school chemistry, my research problem became more and more at this stage one of trying to find *general* curriculum categories in terms of which I could analyze different specifications of the school chemistry curriculum including their version as a special case thereof (see Figure 1.1 below).

In the initial stages of my research, called at that time the Conceptual Structure of School Chemistry Research Project, I used the terms chemical, philosophical, and educational dimensions (Van Berkel, 1993, Van Berkel 1996). At a later stage of my research (Van Berkel etal., 2000), I decided to describe and analyze the structure of chemistry as a school subject in terms of three substructures: the substantive, philosophical and pedagogical structures, curriculum categories I derived from Schwab (1978). This reformulation of the problem of the structure of school chemistry brings in both the curriculum as a field of study and the possible relevance of curriculum theories for the domain of science (chemistry) education. In studying the science education literature I had often come across the term *structure-of-the-discipline* approach to science education (Bruner, Schwab). In particular Schwab's syntactical and substantive structures of a discipline were referred to frequently. About the same time a colleague, Fred Janssen, in his search for the fundamental principles of (school) biology, had come across a little booklet (Ford and Pugno, 1964) which contained two articles by Schwab on the structure of the natural disciplines. While studying these articles the relevance of Schwab's curriculum ideas for my research became clear. This led to my adoption of Schwab's theoretical curriculum framework in which the coordination of a substantive, syntactical, and pedagogical structure of a science curriculum holds a central place (see 1.3.2).

Briefly, the reformulation of the problem of the structure of school chemistry in Schwab's terms led to the following. The conceptual structure or chemical content to which De Vos and Verdonk had largely limited their study was treated by me as their specification of the substantive substructure of the school chemistry curriculum. The strictly scientific nineteenth century context of school chemistry, mentioned by De Vos and Verdonk (above), I interpreted as their specification of the syntactical substructure of the current school chemistry curriculum. And theories of teaching and learning, although left aside by De Vos and Verdonk (1990), I took to be a part of the pedagogical structure of the school chemistry curriculum, together with the aim of school chemistry which they *did* specify as *learning to explain and predict chemical phenomena*.

In section 1.3.2, I will elaborate on Schwab's curriculum framework which I adopted making some slight adaptations for my research purposes. It will be shown (Chapter 2), if and to what extent the *specific combination* of a substantive, philosophical, and pedagogical structure, posited initially by De Vos and Verdonk, had to be changed as a result of confronting this initial hypothesis on the current structure of school chemistry with the experiences and knowledge of chemical educators in The Netherlands and other western countries.

Figure 1.1 Sources and terms used at different stages of the research project

De Vos and Verdonk (1990, 1991)	**Van Berkel** (1993, 1996)	**Schwab** (1978)	**Van Berkel** (2000)
Specified chemical content around the concept of chemical reaction	Chemical dimension	Substantive structure	Substantive structure
19th century, positivistic view of science	Philosophical dimension	Syntactical structure	Philosophical structure
Specified aim; Teaching and learning strategies unspecified	Educational dimension	Pedagogical structure	Pedagogical structure

1.2.2 Initial hypothesis: Coherent School Chemistry

The introduction of De Vos et al. (1991) contains the following set of queries:

> Is there a hidden structure in secondary school chemistry curricula? An underlying structure that explains why chemistry school books from different countries and different periods look so remarkably similar? Most school books are based on exam/course syllabi or similar documents stating which concepts are to be taught and in which order. Do the chemical concepts and the order in which they are *normally* mentioned in these documents represent a widely accepted structure behind chemistry teaching that determines not only the contents of school books but also the teaching activities of chemistry teachers? And if such a structure exists, is it inherent to chemistry itself or is it a result of *choices* that have been made in the past for teaching purposes and that have for a long time remained unchallenged? (italics mine).

De Vos and Verdonk (1990, 1991) attempted to explicate a conceptual structure of school chemistry *as a whole* by focusing on chemical content or concepts in the tradition of the method of *content analysis* as performed by the Department of Chemical Education before on *parts or chapters* of the school chemistry curriculum (see 1.1.2). Textbooks and syllabi from various countries and periods were analyzed to yield a number of essential chemical concepts and relationships between them which add up to *fragments* of a conceptual structure. See References, the section on school chemistry textbooks and syllabi.[7]

Our aim was to formulate, by explication *and* construction, from these available fragments a *coherent* conceptual structure of school chemistry. De Vos et al. (1994, p. 743) defined “a curriculum structure as coherent if it is, in its entirety, in agreement with a specified objective.” In the process of *constructing additional relationships* between chemical concepts De Vos et al. (1994) adhered to the following design criteria:

- It must include all essential chemical concepts that appear in a standard secondary school syllabus.

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[7] De Vos and Verdonk were led to their hypothesis on Coherent School Chemistry by their research of the most representative Dutch (and English) textbooks. Their perusal of a book-case full of schoolbooks from different countries such as Sweden, Poland or China did not gave them grounds to change their claims.

- It must include essential relationships already described in standard textbooks and syllabi.
- It must present secondary school chemistry as a coherent and complete unity.

List, sequence or structure

In order for a conceptual structure to be coherent it should at least be more than a mere *list* of concepts, and also more than just *a sequence* of concepts.

Mere lists of topics, sometimes even alphabetical lists, can be found in exam syllabi for school chemistry and other educational documents (Figure 1.2). For example, a Dutch exam syllabus for upper secondary chemical education (Min. O & W, 1984) begins with the topic of analysis, continuing with the concepts of atomic structure, chemical bonding, and so forth.

Figure 1.2 Alphabetical listing of chemical concepts

Dutch list[a] (Min. O & W, 1984)	**IUPAC-CTC list** (Bradley & Sane, 1993)
analytical chemical methods	acid
atomic structure	atom
chemical bonding	chemical bond, compound
energy, entropy & equilibrium	element
industrial chemistry	mixture
organic chemistry	molecule
reaction rate	oxidation
reaction mechanism	physical change
reduction/oxidation	pure substance
stereoisomerism	reaction

[a] My translation did not change the alphabetical order in the original document

The list of chemical concepts on the right side of Figure 1.2 is taken from a publication of the IUPAC-CTC project, and also follows an alphabetical order. The latter list is actually a small selection taken out of a longer "alphabetical listing of concepts" (Bradley & Sane, 1993).

Of course, such an alphabetical order is often chosen because it is convenient for purposes of presentation. However, for purposes of teaching chemistry a different kind of ordering of chemical concepts is usually given. For example, in the Dutch course syllabus (Min. O&W, 1984), an educational document in which topics and concepts are described in more detail, a *sequence of concepts* is suggested for each grade (list somewhat shortened by me):

- substance, substance property, pure substance, reaction, atom (grade 9);
- periodic system, ions, chemical equilibrium, acids and bases (grade 10);
- energy, entropy and chemical bonding (grade 11/12).

Thus, for teaching purposes a different order, that is, a particular sequence, is recommended. The authors of the same document add, however, an important qualification (see section 1.1.2):

> Although it is true that a syllabus presents the topics in an order which is as *logical* as possible, this does not mean that the topics of a course in a certain year have to be taught in that *order*. The teacher is free to

> choose an order, though often *the structure of the subject* makes it necessary to teach certain topics before others. (Min. O&W, 1984b; translation mine)

It seems to be clear, at least to the authors of this document, that the criterion of logical presentation does not prevail over teaching criteria, while the criterion of "the structure of the subject" does. It is as if the structure of the subject acts as *a kind of internal constraint* on any chosen order of teaching.

What is not clear from this or any other known official educational document (national or international), is what exactly is meant by the structure of the subject. What does this structure look like? As De Vos et al. (1994, p. 743) remarked:

> We found no textbook or other document offering a coherent description of the essential concepts of the secondary school curriculum as well as their mutual relations.

Structural features of school chemistry

Based on De Vos et al. (1994), I will give here an outline of the hypothesis on the coherent school chemistry curriculum focusing on the following structural features (Figure 1.3):

- Demarcation;
- Relationships between concepts at the macroscopic level;
- Conditions for reactions;
- Theories of structure and bonding.

Figure 1.3: A Coherent Conceptual Structure of School Chemistry

Categories	Codes	Specifications from De Vos, Van Berkel, and Verdonk (1994)
Substantive structure	[Sub]	Reaction Chemical Approach (RCA)
Chemical concepts	[CC]	chemical reaction/classes of reactions (inorg./org.) chemical/pure substance/classes of substances (inorg./org.) substance properties: chemical and physical chemical element: as material principle/indecomposable substance periodic classification of elements; taxonomy of functional groups equilibria, energy and entropy; stoichiometrie, composition, structure, valency and bonds corpuscula: molecule/atom/ion/electron/quantum
Chemical relationships	[CR]	(i) demarcation from: common sense, physics, technology, society. (ii) interconnectedness of chemical concept, e.g. chemical reaction and pure substance concept presuppose each other (iii) three coherent reaction conditions: element conservation, decrease Gibbs energy and kinetic instability (iv) restrictions for substances, e.g. limited number of elements; limited combinations, periodicity, octet rule (all based on valency) (v) theory of reaction mechanisms/theory of absolute reaction rates (macro-micro explanation) (vi) theories of structure and bonding, e.g. Dalton, Kekulé, Lewis, Bohr, Hoffmann (structural explanation/structural formulae)
Chemical techniques	[CT]	separation techniques qualitative/quantitative analysis

Figure 1.3: A Coherent Conceptual Structure of School Chemistry (continued)

		Philosophical structure [Phil]
foundations of science	[FS]	basic science tentative, fallible nature of knowledge pragmatic view on explanation/reduction cohesive explanatory framework
methodology of science	[MS]	generation and testing of tentative, revisionary hypotheses/models description, explanation, prediction, experimentation
foundations of chemistry	[FC]	relative autonomy vis-a- vis. physics/biology; descriptive chemistry and stoichiometry physical chemistry (thermodynamics, kinetics) corpuscular theory as (a) explanatory framework and (b) background theory of representation/symbolic notation
methodology of chemistry hypotheses/models	[MC]	generation and testing of tentative, revisionary description, explanation, prediction, Baconian (explorative) experimentation and control; making substances/synthesis of products
		Pedagogical structure [Ped]
aims	[A]	develop an understanding for the mystery of chemical change gradually learn to argue and experiment: observe, describe, relate, explain, predict, model, interpret, experiment, measure, control, make
teaching approach	[TA]	guided discovery/simulation of research using empirically, iteratively researched chemical educational structures
theory of learning	[TT]	learn via direct experience to explain surprising phenomena interactive and reflective discourse

Demarcation of school chemistry

School chemistry is usually, and more or less explicitly, demarcated by three areas: (i) everyday life; (ii) school physics; and (iii) chemical technology.

Demarcation from everyday life

The common sense ideas students use in everyday life, such as their idea of ‘stuff’ when talking about chemical materials or their ideas about the way ‘stuff’ changes, are often regarded as *preconceptions* (or even misconceptions) in comparison with the correct chemical concepts, pure chemical substance and chemical reaction, as taught in school chemistry courses.

However, extensive research in science education on preconceptions and conceptual change emphasizes that it is very hard for students to overcome, or even to see the point of changing (Klaassen, 1995), their common sense ideas, preconceptions, or intuitions (Pfundt and Duit, 1987; Fensham, 1994). The scientific concepts of the natural sciences (biology, chemistry, physics) are often experienced as *counter-intuitive* concepts, as *unnatural* concepts or as *uncommon* sense (Wolpert, 1992; Cromer, 1993; Van Berkel, 1999).

Demarcation from school physics

The authors of a British school chemistry book (Clynes and Williams, 1960) stated that:

> A chemical change is accompanied by the formation of new substances, while a physical change is not. This is the really important point.

As soon as "this really important point" is made, students subsequently learn the 'proper' or correct names for the concepts of chemical change and chemical substance, that is,

> A chemical change is often called a chemical reaction, and substances taking part in it are called reagents or reactants (Mee, 1960).

As a consequence pupils tend to see chemistry and physics as completely separate subjects even when the same terms are used such as atoms, molecules, and/or electrons.

Demarcation from technology

The concept of chemical or pure substance is a scientific one, defined at the macro level in terms of fixed properties and reproducible procedures, and at the micro level in terms of identical molecules. But in a *technological* context a pure substance can mean something quite different, namely, a particular mixture. Although purified to a certain degree, tap water or purified water does, even must, contain essential additional ingredients which comply with specific societal and technological demands associated with health and taste. Hence, students visiting a water purification plant are likely to become confused. This example illustrates that 'pure' school chemistry as a rule does not deal with chemical activities in technological or industrial contexts.

This brief discussion on the threefold demarcation of coherent school chemistry raises the question of its function in relation to the general objective of the curriculum, that is, learning how to explain and predict chemical phenomena. In Chapter 2, I will come back to the question of why school chemistry has been demarcated the way that it has.

Relationships between macroscopic concepts

Whether a change should be classified as physical or chemical depends on understanding other chemical concepts, namely, on understanding the difference between the concepts of pure substances and mixtures. This understanding, in turn, depends upon the concepts of separation and isolation of pure substances from homogeneous mixtures using methods like distillation or chromatography. That is, it depends on ascertaining a difference in properties of the substances present in reaction mixtures before and after a chemical reaction.

This brief *conceptual analysis* shows that the meaning of the concepts of chemical reaction, pure substance, separation, and their counterparts (physical change, mixture, combination) are all connected to each other. This points to a first *structural feature* of school chemistry, which I will call the *interconnectedness* of chemical concepts.

The relationships among these macroscopic concepts can be elaborated upon. The definition of the concept of chemical reaction quoted above implies or presupposes a specific chemical concept of pure substance. The reverse also holds since a pure substance is defined in terms of its chemical properties, that is, properties or dispositions to react with other substances. For example, hydrogen is identified, and therefore also often defined, in school chemistry by its property, or rather its disposition, to react explosively with oxygen (under certain conditions).

The introduction of the concept of a chemical element in the conceptual structure of school chemistry follows that of the concept of a chemical reaction and the concept of a ‘chemical’ or pure substance, and is defined in terms of both (De Vos et al., 1991a).

The concept of element is defined in two ways. First, it is a substance which cannot be further decomposed by chemical or (ordinary) physical means. The reference to chemical substance is given explicitly; whereas, the expression ‘chemical means’ implies the concept of a chemical reaction. Second, the concept of chemical element can also be defined as a ‘principle’, that is, as the material principle which is conserved, both qualitatively and quantitatively, during a chemical reaction. In this case there is an explicit reference to the reaction concept. However, this definition of a chemical element also presupposes the chemical substance concept. Thus, in a cycle of copper reactions starting with copper, the element copper, taken as a chemical substance, disappears to reappear at the end of the cycle. In between, the element copper, taken as a ‘material principle’, has not disappeared but, rather, appears to have been conserved.

Thus the demarcation of school chemistry from school physics as described in the two quotes immediately above, that is, the distinction between physical changes and chemical reactions, can thus be elaborated in a set of connected chemical concepts. The concepts of chemical reaction, chemical substance, and chemical element form the heart of this set, while the concepts of substance property, separation, and their counterparts fulfill supporting functions.

Three coherent conditions for chemical reactions

In their hypothesis on the structure of the coherent school chemistry curriculum De Vos et al. (1991a, 1994) built their conceptual structure around the concept of a chemical reaction. The outcome of their conceptual analysis is that there are three conditions which must be fulfilled before a chemical reaction will take place, namely:

- Conservation of chemical elements
- Decrease of chemical or Gibbs energy
- Kinetic instability or perceptual reaction rate

This can be illustrated by the following example, based on De Vos et al. (1994). It is not possible, apart from being rather unwise, to change diamond (C) into sand (SiO_2). This is so because the first reaction condition, conservation of chemical elements, has not been fulfilled. It has not been observed that diamond (C), for example a diamond ring, reacts with water (H_2O) by changing into sugar ($C_{12}H_{22}O_{11}$), although in this case the first reaction condition has been fulfilled. In other words, it is possible to write a balanced equation for this reaction, namely: $12\ C + 11\ H_2O \longrightarrow C_{12}H_{22}O_{11}$.

The problem with this reaction is that the second reaction condition has not been fulfilled; that is, for this reaction a net *increase* of Gibbs energy for ambient circumstances can be calculated from thermodynamic data. But from the same thermodynamic knowledge follows a surprising, and if true, possibly, lucrative result. The *reverse* reaction, the chemical synthesis of diamond (and water), starting from sugar, must show a *decrease* in Gibbs energy: $C_{12}H_{22}O_{11}$ —> 12 C + 11 H_2O. However, since we know that diamond does not form spontaneously, and therefore cannot be made this way, a third reaction condition must be involved, one which has not been fulfilled. This points to the kinetics of a reaction, the reaction rate, which for all practical intents and purposes should have at least a detectable value.

As De Vos and Verdonk put it, for a chemical reaction to occur, the three reaction conditions mentioned above must be fulfilled simultaneously. They noted, however, that these three reaction conditions are not treated as a *coherent whole* in the traditional school chemistry curriculum, and therefore are not understood as such. That is, the conservation of chemical elements is usually treated in a chapter early on in the textbook, the decrease of chemical or Gibbs energy later on in another chapter (and separately, if at all), and the kinetics of chemical reactions, again separately, in still another chapter of the school chemistry textbook.

In brief, *if* we want students to understand the occurrence of chemical reactions fully, *then* we need to offer them a complete and coherent picture of these three reaction conditions in the school chemistry curriculum, or at least as complete a picture as possible given the current state of chemical knowledge with regard to these conditions.

As noted above, the aim of De Vos et al. (1994) was to formulate, by explication *and* construction, from the available fragments in textbooks a *coherent* conceptual structure of school chemistry. The first two structural features of school chemistry, demarcation and interconnectedness of concepts, could be formulated by making *explicit* and/or *consistent* certain relationships *of* current school chemistry and certain relations *within* current school chemistry. The third structural feature of school chemistry, though, the coherency of the three reaction conditions described above, could only be formulated by De Vos and Verdonk by *constructing* additional chemical relationships on top of available fragments in school chemistry textbooks. De Vos et al. (1994) arrived at the conclusion that:

> (…) We were only able to design a coherent conceptual structure after accepting two conditions that appeared to be unavoidable. The first condition was that (…) the structure had to cover not only secondary school chemistry *but also general chemistry at the level of tertiary education* in order to become a coherent whole. This suggests that [current] secondary school chemistry is not a complete subject in its own right but that it is inseparably linked to further education in chemistry (…). The second condition we had to accept was that school chemistry must be taught within a strictly scientific context, in which students are being treated as if they were future chemical researchers receiving the necessary education.

As we will see in Chapter 2, this quotation can be regarded as a first expression of the idea that a *specific conceptual structure* of a school chemistry curriculum, a structure built here around the coherence of chemical reaction conditions, is *coordinated* with a *specific philosophical structure* having a strictly scientific orientation towards general chemistry at the tertiary level, and with a *specific pedagogical structure* in which students are being treated as if they were future chemical researchers receiving the necessary education.

Theories of structure and bonding

This summary of the hypothesis on the structure of the coherent school chemistry curriculum has up to now treated only macroscopic or phenomenological chemical concepts. That is, no, or only occasional, reference has been made to a corpuscular view of chemical substances and chemical reactions, though the corpuscular view has received much emphasis in many current textbooks in tertiary as well as in secondary chemical education. All the concepts dealt with so far can be interpreted or even introduced in corpuscular terms. For example:

- A chemical reaction can be seen as a rearrangement of atoms and electrons.
- The concept of chemical element can be seen as an agglomerate of one kind of atom.
- The pure substance concept can be redefined in terms of identical molecules (or lattices).

Initially, Dalton's atomic-molecular theory of matter was used for such a purpose and became fruitful in the nineteenth century, for example, for organic chemists in developing the so-called structural theory (Franklin, Kékulé, Van 't Hoff). Structural theory was succeeded in turn by Lewis's electronic view of the structure and bonding of substances and by Bohr's theory of the structure of the atom. The latter theory was the first to use quantum mechanical ideas and was the beginning of a still evolving quantum-chemical interpretation of matter (Nye, 1993).

Chemistry as a discipline appears to consist of a hierarchical structure of successive layers of micro-theories in terms of which chemical phenomena and macro-theories are explained. Macro-theories include, on the one hand, empirical generalizations such as stoichiometric relations, trends in behavior of substances, and chemical classifications up to and including the periodic system; and on the other hand, they include sophisticated mathematically formulated theories such as chemical thermodynamics.

As for school chemistry, an attempt was made by De Vos et al. (1994), again starting from fragments in school chemistry textbooks, to formulate a set of conditions that substances must fulfill in order to exist, that is to be stable; just as an attempt was made by them to formulate the conditions necessary for reactions to occur.

In the context of school chemistry most of these *substance* conditions appear to be related to the concept of valence, a concept which was defined originally in terms of combining proportions of elements and later in terms of valence electrons. An example of such a condition is Lewis's octet rule. A *complete* set of conditions which includes Pauli's exclusion principle and classical and quantum mechanical constraints on stereochemistry and stability (e.g. Woodward-Hoffmann rules), has not been found in school or university chemistry textbooks, nor for that matter in chemistry as a discipline (Atkins, 1985; Hoffmann, 1995).

This means that, *if* we want students to understand the occurrence and stability of chemical substances, *then* we need to offer them a picture as complete as possible while at the same time teaching them the present incompleteness of chemistry in this area.

Again, as in the area of reaction conditions pertaining to chemical reactions, a complete and coherent treatment of *substance* conditions – at least as complete as is scientifically possible – would only have a point for a chemistry course in which students were being treated as if they were future chemical researchers (Fensham, 1984; De Vos et al., 1994).

1.2.3 Research methods

I will now discuss the research methods used. First, I discuss the method used to test the initial hypothesis on the coherent structure of school chemistry (1.2.2) involving the probing of a selected International Forum and Dutch forum of chemical educational experts. Second, I will discuss the method used to analyze and evaluate the attempt to escape from the current school chemistry curriculum by an innovative school chemistry course called Salters' Chemistry.

Testing the hypothesis on coherent school chemistry

In order to test the hypothesis on the coherent school chemistry curriculum, we did recast the hypothesis in the form of "Ten Statements" (Figure 1.4). Statements 2-8 were formulated in terms of "the chemical concepts which we consider as important elements of the structure of the discipline [and] are given boldface in the text" (De Vos & Verdonk, 1990, p. 21).[8] Statements 1, 9, and 10, also based on De Vos & Verdonk, were formulated to address the educational dimension of the structure of school chemistry, that is, the structure of the discipline as it pertains to school chemistry (see Figure 1.1). Statement 9 was reformulated at a later stage by the researcher to address the philosophical dimension of the structure of school chemistry, too (see also section 2.2.1).

These "Ten Statements" were used as a probe to elicit comments and criticisms from the members of an International Forum (IF), and also, using a Dutch translation ("Tien Stellingen"), as a probe to elicit comments and criticisms from the members of a Dutch Forum (DF). The IF members received as background material a paper entitled "A Structure in School Chemistry" (De Vos et al., 1991), an (unpublished) English version of the original Dutch paper called "Een vakstructuur van het schoolvak scheikunde" (1990), the paper which the DF members received (see also Chapter 2).

Formation of IF and DF

In August 1991 Adri Verdonk, Wobbe de Vos, and myself attended the Eleventh International Conference of Chemical Education (ICCE), held in York (UK). As it turned out, this added considerable momentum to the establishment of the IF which I had started by way of a literature search around the work of some colleagues of De Vos and Verdonk.

Firstly, the search for colleagues who might be interested in our project was greatly facilitated by the Book of Abstracts issued by the organizers of the conference. In particular, it became much easier to locate and approach any interested colleagues present and to engage with them in personal dialogue, which usually turned out to be very informative and inspiring. I concluded this by extending each one an invitation to participate in some way in my research project.

Secondly, one of us, Wobbe de Vos, had been given a chance to present the research project in a plenary lecture entitled, "The Hidden Structure in School Chemistry and How to Escape from It". At the end of the lecture he also extended an invitation to our colleagues in chemical education present, stating that the aim of our research project was:

> to get into contact with colleagues from abroad who are interested in the concept of a structure underlying the curriculum and who are willing to read our papers, comment on our work, answer our questions, and criticize our ideas. What we need is "*an international scientific forum*" (De Vos, 1992).

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[8] De chemische begripen die we als belangrijke elementen van de vakstructuur beschouwen zijn in de tekst vet gedrukt (De Vos & Verdonk, 1990, p. 21; my translation above).

Figure 1.4 Summary in Ten Statements of Coherent School Chemistry

1. From the moment chemistry was introduced as a subject in secondary education in the nineteenth century, it has always been taught *as a science*. It is made clear, often on the first page of the book or even in the first sentence, that chemistry is one of the natural sciences. Concepts to be taught are selected on the basis of their scientific relevance. The student is seen as a future scientist, who wants to specialize in chemical research and therefore has to become familiar with research methods and research results obtained by applying these methods. The use of chemical products and processes in society is presented as something that follows from scientific theory, not the other way around.

2. Chemistry is immediately distinguished from other natural sciences by its object of research, which is chemical 'phenomena' or chemical reactions. The reaction concept is introduced very early in the curriculum, and it is defined in a very general sense: it refers to a process in which one or more substances are converted into one or more other substances. Each substance is characterized by a set of substance properties. Besides, chemical phenomena are often said to be irreversible and more fundamental than physical phenomena (such as phase transitions). The definition of chemical reaction requires a specific chemical substance concept.

3. The reaction concept is illustrated by a series of examples (and usually also non-examples) of chemical reactions. These examples emphasize the fact that chemical reactions are spectacular, manifold and, as yet, unpredictable. From that moment on, the curriculum can be seen as an attempt to answer the question of *predictability of reactions*.

4. One way to predict chemical reactions is by developing an explanatory theory. The curriculum implicitly offers such a theory by demanding that a reaction must fulfill three conditions (see 4a, 4b, and 4c). Failure to meet one of these conditions is sufficient explanation for the non-occurrence of a reaction. A reaction therefore takes place only if it fulfills all three conditions.

    a. The first condition is element conservation. Conversion of substances A and B into C and D is impossible if C and D do not consist of the same elements as A and B, qualitatively as well as quantitatively. This explains why, for instance, mercury and sulfur cannot react to form sugar. The first condition implies that any reaction that does take place can be represented by a balanced equation.

    b. The second condition is a decrease in free energy of the reaction system (or an increase in entropy of the system and its environment) accompanying the reaction. Usually this thermodynamic condition is not formulated in these general terms in secondary school chemistry. It is, however, introduced implicitly in chapters on acids and bases, redox reactions and electrochemistry in terms of rules-of-thumb involving the equilibrium constant K or the standard reduction potential E^o, both of which are directly related to the change in free energy ΔG.

    c. The third condition is that a reaction is said to take place only if it occurs at a minimum reaction rate. A reaction that fulfills the first and the second conditions may still fail to occur because of its high activation energy. Explanations of why the activation energy is low or high are not given in general terms in secondary school chemistry, but in some specific cases differences or changes in reaction rate are explained.

Figure 1.4 Summary in ten statements of coherent school chemistry (continued)

5. Predictability of chemical reactions is achieved not only by means of theories but also through descriptive chemistry. Whereas theoretical chemistry sets the boundaries of the reaction phenomenon, descriptive chemistry gradually fills in the available space within these boundaries with concrete examples. Students learn individual reactions as well as groups of reactions and the circumstances under which they occur. The groups of reactions include, e.g. solubility rules of salts in inorganic chemistry and reactions of functional groups in organic chemistry.

6. Although the reaction concept is the most fundamental concept in school chemistry, it is closely linked to a specific chemical pure substance concept. This concept helps to distinguish between chemical and physical phenomena. Students have to understand that a phase transition and the formation of a mixture are not chemical reactions, even though a mixture does not have the properties of its components. As a pure substance is characterized by a set of substance properties, it is important to learn how to isolate and purify substances in order to be able to recognize them. This explains the chapter on separation techniques early in the curriculum.

7. The predictability question also applies to substances and, as in the case of reactions, it is answered along two lines: a theoretical line introducing valence as an important concept for predicting formulas, and a descriptive line dealing with substances individually and in groups. (We have not yet been able to identify a specific set of conditions that substances must fulfill in order to exist.)

8. A distinction is made between a level of phenomena and a level of corpuscula or particles such as atoms, molecules, or electrons. Once corpuscular theory is introduced, it provides explanations, e.g. of reactivities, of equilibrium (kinetic explanation), etc., as well as conventions, e.g. the nomenclature of substances such as 1,2-dichloroethane.

9. The conceptual structure in the curriculum does not imply a *specific* philosophy of science, e.g. inductivism or hypothetico-deductivism or a *specific* philosophy of chemistry, nor does it in itself prescribe a *specific* teaching approach. While some teachers (and books) aim at a direct transfer of knowledge, others prefer students to discover as much as possible by themselves. Both traditional and modern teaching methods may be based on the same curriculum structure.

10. In its historical development the traditional structure has shown a gradual shift of emphasis from descriptive to theoretical chemistry. This is a result of the enormous growth of chemical knowledge: the theoretical approach offers a more efficient way of organizing and presenting knowledge. However, at the same time it makes chemistry more difficult to understand for many students.

It became clear from these ‘piloting’ meetings that our colleagues not only recognized the problems discussed by us, but also acknowledged them as important problems. The discussion then revolved on possible ways to solve these problems, especially the problem of escape.

When I left the eleventh ICCE in York the IF had about thirty potential members, mostly from Western countries, who were researchers and developers of chemical education. About half had agreed to take part in the search for, as we called it, the hidden structure in school chemistry. Since then, the number of potential IF members increased (snowballed) to about sixty members: (i) through personal contacts made at conferences on science education (NARST, Atlanta, 1993; Summer School, Driebergen, 1993); (ii) because colleagues wrote or visited us; and (iii) by references from colleagues or the literature to other potentially interested researchers and/or developers of chemical education.

Starting in June 1992 I sent letters to IF members inviting them to comment on the "Ten Statements" and to indicate whether they agreed or disagreed with each of the ten statements presented to them (Figure 1.4). Twenty-six IF members (researchers **20**, developers **5**, and teachers **1**) responded by writing comments on the statements, of about 1-5 pages length. A few were also interviewed and recorded on tape (Appendix 3: List of international respondents).

The establishment of the IF was followed by the formation of a similar group in the Netherlands called the Dutch Forum on Structures in School Chemistry (DF). In this case, educators were approached who were familiar with the different sectors of the Dutch system of provision of chemical education, such as research, development, assessment, teaching, teacher training, implementation, and administration. Also approached were persons from the fields of history and philosophy of chemistry and research chemistry who were interested in secondary chemical education.

As noted above, DF members' understanding of our hypothesis on coherent school chemistry was probed in the same way as with IF members. Thus, starting in June 1993 letters were sent to DF members inviting them to comment on the "Tien Stellingen" ("Ten Statements") and to indicate whether they agreed or disagreed with each of the ten statements (Figure 1.4). Twenty-two (out of thirty) DF members actually responded by writing comments of 1-5 pages length (researchers **4**, developers **5**, teachers **6**, philosophers and historians of chemistry **4**, and persons from other sectors of chemical education **3**). (See Appendix 4: List of Dutch respondents.)

Analysis

The analysis of the IF and DF responses was first performed individually by the three researchers involved at this stage: Adri Verdonk, Wobbe de Vos, and myself. We arrived largely at similar results in our analysis, and in the ensuing discussions we resolved any remaining differences or unclear points in our analysis (see further Chapter 2).

As I will explain in greater detail in Chapter 2, the "Ten Statements" are not all of the same kind. Whereas statements 2-8 address the chemical conceptual dimension or structure, statements 1, 9, and 10 make claims about the relationship between the conceptual structure of school chemistry here posited, and the philosophical or educational dimension of school chemistry, using the terms *philosophy of science* and *teaching approach*.

In the course of the analysis of the IF data on the structure of the coherent school chemistry curriculum, it proved fruitful to categorize the curriculum data in terms of:

- the substantive, philosophical, and pedagogical structures, three substructures of the curriculum based on Schwab (1964c, 1978), replacing the three dimensions of school chemistry (chemical, philosophical, educational) that were initially used (see Figure 1.1 in subsection 1.2.1);

- the curriculum levels: the intended and formal curriculum levels, and the taught and learned curriculum levels based on Goodlad (1979), further explained in subsection 1.3.1.

The method of testing a hypothesis by trying to confirm its consequences is a well-known method used in the natural and social sciences, usually called the hypothetical-deductive method (Schwab, 1964b, p. 34; Popper, 1968). A special form of this method has been described as "structural explanation" (McMullin, 1978), since it is often used in research where it is necessary to construct a model of a possible structure, say of an atom or a gene. In this case we are dealing with an hypothesis on the *structure* of the school chemistry curriculum as formulated by De Vos and Verdonk (1990,1991). Schwab (1964b, p. 35) has remarked on the character of this kind of hypothesis:

> Further, each such hypothesis represents a major act of constructive imagination. The scientist takes account of a vast variety of data which must be accounted for. He treats each datum as a limitation on what may be conceived as accounting for the whole range of data, and within the boundaries of these complex limitations he conceives a solution to the problem.

Wobbe de Vos and Adri Verdonk did just that with regard to their original solution of the problem of the structure of school chemistry. The next step was then to ascertain whether their solution to the problem of the structure of school chemistry would stand the test.

The revision of the hypothesis on the structure of the coherent school chemistry curriculum (De Vos et al., 1994), in light of the scrutiny of the collected IF data, led to the formulation of the *currently dominant* structure of the school chemistry curriculum, in brief *Dominant School Chemistry* as described in Chapter 2.

The IF response to our probe "Ten Statements" was about 50% (28 out of 60 IF members reacted); the non-response having about the same representativeness as the response.[9] After a preliminary analysis of the IF responses we stated our preliminary position in an intermittent report, called "Position Paper" (Van Berkel & De Vos, 1994). This was sent, together with an article giving our latest views on the conceptual structure of the chemistry curriculum (De Vos et al., 1994) to the IF respondents prior to the 13Th ICCE in Puerto Rico. The workshop, which Wobbe de Vos and myself held there, was attended by a few IF members who made some interesting comments. Answering the question of one IF member about the validity of our structure of school chemistry, it became clearer that we preferred to find a description of the structure of school chemistry which was valid and not so much a description based on a consensus (which would have resulted from a Delphi-type of research). As we put it there:

> The structure is valid in so far as: (i) it is confirmed by data gathered from different sources such as content analysis of current curricula/textbooks, responses of forum members and teachers, historical analysis of school chemistry; (ii) it is considered by members of the chemical education community as an relevant and effective instrument for the analysis and design of new curricula.

Initially, we set out to perform two or three (what we called at the time) Delphi-rounds, but which are now better described as a *survey*, followed by two or more rounds of

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[9] The written response from the developers in York was low, probably because the focus of the interviews with them, as well as the focus of the developers themselves, was more on the problem of escape than on the problem of structure. A couple of developers, such as Garforth and Lazonby, were interested in the problem, though.

communication with IF members "who are willing to read our papers, comment on our work, answer our questions, and criticize our ideas." (De Vos, 1992).

In the period 2000-2002, I sent my paper on *Normal Science Education and its Dangers: The Case of School Chemistry* and five reports (Van Berkel 2000a,b,c, 2001a,b, 2002) which together comprised the first draft of my thesis, to the 28 IF members. About 50% acknowledged receipt and said they looked forward with interest to read the reports and the paper. Some members said they found the paper and reports "very valuable", "useful and stimulating", or commented favorably on my argument for a "non-normal science" approach to science education. No one raised objections to the claims made in the paper or in the reports, except for a number of the developers of the Salters' Chemistry course (see further Chapters 4 and 5). The thesis which I am presenting here will be sent to the IF members (and DF members) to inform them of the results of my research into the structure of the school chemistry curriculum.

Method of curriculum evaluation

The second problem I address in this thesis, the problem of escape, can now be reformulated as follows. Is it possible when designing a new school chemistry curriculum to escape from Dominant School Chemistry, and if so, to what extent?

As will be explained in Chapter 4, in 1991 I selected the society-oriented school chemistry course, Salters' Chemistry, as a good candidate to probe for answers to this question. At the time, the Salters' Chemistry course was viewed by many researchers and developers of chemical education, including the developers of the course itself, as a *radical* departure from traditional school chemistry. Later, it was classified by Fensham (1992) and Aikenhead (1994) as a "chemistry through technology and society" course. The radical nature of the Salters' Chemistry course was formulated by the developers in a set of design criteria used in the development of their new school chemistry course (see Chapter 4).

In Chapter 5, I will systematically *analyze* one of the units of this course, called Metals, to demonstrate the extent to which the design criteria of the unit are adhered to *consistently* by developers designing the lessons of the unit Metals, and by a teacher teaching the unit Metals.

On the basis of extensive data collected on the design and teaching of the unit Metals, I will analyze the extent to which the developers and the teacher involved escaped from *Dominant School Chemistry* in relation to the design criteria they set for themselves.

The data on the development of the unit were collected via in-depth interviews with a number of developers and by a thorough content analysis of the unit Metals, performed by Wobbe de Vos and myself, in the light of the design criteria laid down by the developers. The data on the teaching and learning of the unit Metals were collected by classroom observation and audio taping the lessons of the unit, by interviewing the teacher involved, and by administering a questionnaire to the students in the class. For this method of *consistency analysis* see further section 4.1.3 and section 5.1.4.

Thus, I gathered data on the visionary, designed, interpreted, taught, and learned curricula of Salters' Chemistry (Goodlad; see 1.3.1). Drawing also on the relevant research literature, I will conclude my domain-specific evaluation of the Salters' Chemistry course with a discussion of the degree of escape of Salters' Chemistry from *Dominant School Chemistry* (see 5.5). This will be followed by an explanation of the curriculum data, including the degree of escape, in terms of my curriculum framework (for Schwab, see 1.3.2; for Goodlad, see 1.3.1).

1.3 Curriculum framework

Science curricula are a very complex field of study (Jackson, 1992). In the course of my research into the structure of school chemistry, the curriculum frameworks of Goodlad (1979), Schwab (1962), Roberts (1982), and Kuhn (1970) helped me to understand the structure of school chemistry curricula, that is, these frameworks appeared to be fruitful for describing, ordering, analyzing and explaining the curriculum data I gathered in this research.

First, following Goodlad (1979), I will distinguish, depending on the practice and study at hand, several curriculum *levels* in school chemistry curricula (1.3.1). Second, following Schwab (1962), I will subdivide the curriculum structure of school chemistry curricula in three related *substructures* (substantive, philosophical, and pedagogical) that can pertain to *each* level of school chemistry curricula (1.3.2). Thirdly, I use Roberts' (1982) concept of curriculum *emphasis* to characterize, in terms of seven different emphases for science curricula, the school chemistry curricula I am dealing with in this thesis (1.3.3). Finally, Kuhn's view on scientific training makes it possible to single out, characterize, and explain the *dominant* emphasis and structure of the current school chemistry curriculum (1.3.4).

1.3.1 Goodlad's framework of curriculum levels

Following Goodlad's "*Curriculum Inquiry, The Study of Curriculum Practice*" (1979), many researchers, performing curriculum studies, analysis, and/or evaluation, consider a curriculum as being composed of several curriculum levels. Goodlad (1979, p. 50), describes the final aim of his studies into the practice of the curriculum as follows:

> … our intent is to draw attention to the *study* of curriculum planning, processes and products, to the ongoing nature of praxis in all domains, and to the delineation, and ultimately, understanding of the phenomena.

In his article on the science curriculum in the *International Handbook of Science Education*, Van den Akker (1998, pp. 421, 422) distinguishes the following curriculum levels:

- the *ideal* curriculum: the original vision underlying a curriculum (basic philosophy, rationale or mission);
- the *formal* curriculum: the vision elaborated in a curriculum document (with either a prescribed/ obligatory or exemplary/voluntary status);
- the *perceived* curriculum; the curriculum as perceived by its users (especially teachers);
- the *operational* curriculum: the actual instructional process in the classroom, as guided by previous curriculum representations (also often referred to as the curriculum-in-action or the enacted curriculum;
- the *experiential* curriculum: the actual learning experiences of the students;
- the *attained* curriculum: the resulting learning outcomes of the students.

More or less differentiation in curriculum levels is possible (Goodlad, 1979; Van den Akker, 1998). It depends on the particular practice and study which curriculum levels are distinguished, how they are described, and which are focused on. On the other hand as we will see below, sometimes slightly different words or terms are used for essentially the same level. For example, the well-known TIMMS study (Rosier and Keeves, 1991) focuses on the intended (cp. the term *ideal* above), the implemented (cp. the term *operational* above), and attained curriculum (same as above; Van den Akker (1998).

Application of framework of curriculum levels

Applying the framework of curriculum levels makes it possible to:

- collect with the appropriate methods the relevant data at each curriculum level;
- find out the discrepancies between two curriculum levels (Goodlad, 1979, p. 64);
- determine the relationships between various curriculum levels;
- explain the curriculum data, discrepancies and relationships between curriculum levels

As we will see in this study in Chapter 2, the IF responses to the "*Ten Statements*", a summary of Coherent School Chemistry, are taken as referring to the following curriculum levels of school chemistry:

- *intended* curriculum: formulation of a number of aims by textbook writers and developers;
- *formal* curriculum: operationalization of aims in textbook, teaching units, and syllabus;
- *taught* curriculum: execution of formal curriculum by teachers in the classroom;
- *learned* curriculum: learning of taught curriculum by students in the classroom (exams)

The IF responses to our *Ten Statements* probe were analyzed and interpreted as referring mainly to the *intended* and *formal* curriculum, but sometimes also, as we will see, in relation to the *taught* and *learned*, or the realized curriculum of school chemistry.

In Chapters 4 and 5 on the evaluation of the innovative school chemistry curriculum, Salters' Chemistry, I have used the following curriculum levels and terms:

- *visionary* or *intended* curriculum: the formulation by the developers of a number of design criteria (cp. the term ideal curriculum above; Van den Akker, 1998);
- *designed* curriculum: the first operationalization of the design criteria by the developers in prototypical teaching materials;
- the *written* curriculum: the follow-up of the designed curriculum which is realized by elaborating or revising prototypical teaching materials after trials or testing in the classroom;
- *formal* curriculum: the official codification of the designed curriculum product in a syllabus by the developers in collaboration with the staff of an exam board;
- *interpreted* curriculum: the curriculum (units) as perceived by teachers (cp. the term perceived curriculum above);
- *taught* curriculum: teachers in the classroom executing the curriculum units;
- *experienced* curriculum: students in the classroom experiencing the teaching of the curriculum units (cp. the term experiential curriculum above).

The slightly different terms I have used for the curriculum levels above refer, I take it, to essentially the same curriculum levels as those described by Van den Akker. In the context of the evaluation of the *process* of the development of units in the Salters' Chemistry course, however, I was led to distinguish another curriculum level, namely, the *designed* curriculum, that is, the operationalization of the design criteria by the developers in the prototypical teaching materials during the trials of these teaching materials. This is as a rule followed up by the written curriculum, the next phase (or phases) of the designed curriculum (see Chapters 4 and 5).

An important relationship that may hold between several curriculum levels, and which, as I will show, pertains to the curriculum development process of the Salters' Chemistry course, is:

> (…) the slippage from any ideal formulation to what reaches the student, or of working backwards from what the student perceives to what the formal curriculum intended for him or her (Goodlad (1979, p. 64).

Curriculum levels and corresponding methods of data collection

As I will describe in detail in Chapters 4 and 5, the following methods were used for collecting data, and for analysis of these data, appropriate for the curriculum levels investigated.

For the visionary and designed curriculum were used: content analysis of relevant documents produced and interviews with the developers who envisioned and started the project. For the written curriculum were used: content analysis at the level of the lessons of a particular teaching unit produced. For the interpreted and taught curriculum were used: observation, audio-taping, and interviewing, thus collecting data on both the behavior and opinions of the teacher. For the experienced curriculum were used: observation, audio-taping, and a questionnaire, thus collecting data on both the behavior and opinions of the students.

In sum, by performing a curriculum study of the currently dominant school chemistry curriculum and a curriculum evaluation of the innovative school chemistry curriculum, Salters' Chemistry, in terms of Goodlad's framework of curriculum levels, I have collected data on the curriculum *products* as well as on the *behavior* and *opinions* of teachers and students. Also, the process of curriculum development was gauged by interviews with developers.

In Chapter 6, I will come back to the relationship between curriculum levels and the methods appropriate to study them – methods which address the realized curriculum products or the behavior (such as activities performed in the classroom) or the opinions of the actors involved.

1.3.2 Schwab's curriculum framework for the natural sciences

In my research into the structure of school chemistry I have adopted, a*nd adapted to the purposes of my research*, Schwab's framework on science curricula (1962, 1964a,b,c; Westbury and Wilkof, 1978). This means that, throughout this thesis, I will describe and analyze the school chemistry curricula I am dealing with in terms of three curriculum substructures composing a curriculum structure, namely, the *substantive* structure, the *philosophical* structure, and the *pedagogical* structure of the curriculum.

Before I describe and explain the adaptations I made in the context of my research to

Schwab's curriculum framework, I will first give a brief summary of Schwab's curriculum framework for the natural sciences, and of the concepts and terms he used.

Schwab's view on the organization of the disciplines

Schwab's *general* curriculum views originated from his work on the "problems of the *organization* of the disciplines" (Schwab, 1964b, p. 7) in the 1940s in the practical context of the development of the so-called "Three-Year Program in the Natural Sciences" (Westbury and Wilkof, 1978), a college curriculum which embodied a liberal form of science education at the University of Chicago in that period. Later on during the 1960s Schwab contributed from this background to the structure-of-the-disciplines movement (Westbury and Wilkof, 1978, p. 25) at the high school level. Schwab's view of the structure of the curriculum of the natural sciences (Schwab, 1964a) is therefore part of his overarching view of the structure and organization of the disciplines which include natural, social, and humanitarian sciences.

According to Schwab the structures of a discipline consists of two *related* components, namely the s*ubstantive structure of the discipline* and *the syntactical structure of the discipline*. These two central concepts of Schwab's curriculum framework for the natural sciences (discussed below) turned out to be relevant for my research into the structure of the school chemistry curriculum. It is important to note that Schwab discussed these two concepts in the context of science education, that is, "for purposes of instruction" (1964a, p. 47).

Substantive structures of the disciplines

Schwab (1964b, p. 12) gives the following description of the function of a substantive structure of a discipline, or conceptual structure as he calls it alternatively.

> In general, then, enquiry has its origin in a conceptual structure, often mathematical, but not necessarily so. It is this conceptual structure through which we are able to formulate a telling question. It is through the telling question that we know what data to seek and what experiment to perform to get those data. Once the data are in hand, the same conceptual structure tells us how to interpret them, what to make of them by way of knowledge. Finally the knowledge is formulated in the terms provided by the same conception.

Schwab mentions three important characteristics which substantive structures of the natural science disciplines acquired more and more in the twentieth century.

First, the substantive structures of a discipline are not one, but many. Schwab, himself a biologist, gives some specific examples from the science of biology such as the taxonomic, functional, and evolutionary substantive structures. In Chapter 2 we will come across the plural character of chemistry as a discipline. An example of a substantive structure from chemistry as a discipline is thermodynamics, a research area which focuses exclusively on macroscopic magnitudes like P, V, and T to the exclusion of microscopic models while searching for the laws of thermodynamics. Another example is in the atomic-molecular theory, a theory which focuses on submicroscopic entities such as atoms and molecules and their mechanisms, in order to explain macroscopic phenomena and relations in its terms (Vollebregt, 1998; Van Berkel, 1999).

Second, substantive structures are not only elaborated on during the course of enquiry, but also tested and, eventually, revised. Third, the scientific knowledge gained in terms of a substantive structure stems from selected abstractions or idealizations of the subject matter or referent in question and is, therefore, always partial and incomplete.

Syntactical structures of the disciplines

Schwab (1964b, p. 14;1964c, p. 11) describes "the problem the *syntactical* structure of the disciplines" as follows:

> There is, then, the problem of determining for each discipline what it does in the way of discovery and proof, what criteria it uses for measuring the quality of its data, how strictly it can apply canons of evidence, and in general, of determining the route or pathway by which the discipline moves from its raw data through a longer or shorter process of interpretation to its conclusion.

Further, Schwab (1964c, p. 10,11) emphasizes that to each of the possible, many substantive structures of a discipline there corresponds a distinctive syntactical structure of the discipline.

> If different disciplines pursue knowledge of their respective subject fields by means of different substantive structures, it follows that there may be major differences between one discipline and another in the manner and the extent to which each can verify its knowledge (…). Further, the kind of evidence, and the degree to which it is evidential, required by different researches within the natural sciences differ markedly from field to field (biology against physics, for example) and even within researches within a field.

In chemistry, for example it is the case that to the different substantive structures of thermodynamics and the atomic-molecular theory there correspond different syntactical structures in terms of "the manner and the extent to which each can verify its knowledge (…) the kind of evidence, and the degree to which it is evidential" (Schwab 1964c, p. 11).

This makes the syntactical structures of a discipline also plural, as well as specific to the domain involved. As Schwab (1964c, p. 31) puts it:

> Of greatest importance perhaps, in view of the present state of education in this regard, is that syntax effectively does away with the embarrassing divorce of "method" and "content". A syntax cannot be described except through reference to the concrete subject matter involved in concrete enquiries.

Discipline structure and pedagogical structure

As noted above Schwab discusses the problems of the structures of the disciplines, and its sub-problems: the problem the *substantive* structure of the disciplines and the problem of the *syntactical* structure of the disciplines in the context of education or pedagogy, listing and emphasizing each time the educational significances of his concepts (Schwab, 1978).

> Both of these – the conceptual and the syntactical – are different in different disciplines. The significance for education of these diverse structures lies precisely in the extent to which we want to teach what it is true and have it understood.

In a long paper titled "Education and the Structure of the Disciplines" written in 1961 but published in 1978 (Westbury and Wilkof, 1978, p. 241, 242), Schwab elaborates on the relationship between the (substantive) structure of the discipline and the *pedagogical structure* – the latter a term he used only once as heading of a subsection of this paper – as follows:

> We also have the task of learning to live with a far more complex problem – that of realizing that we will no longer be free to choose teaching methods, textbook organization, and classroom structuring on the basis of psychological and social considerations alone. Rather, we will need to face the fact that methods

> are rarely if ever neutral. On the contrary, the means we use color and modify the ends we actually achieve through them. *How* we teach will determine *what* our students learn. *If a structure of teaching and learning is alien to the structure of what we propose to teach, the outcome will inevitably be a corruption of that content. And we will know that it is* (my italics).

The structure of a discipline does not have, as such, a pedagogical structure, but it does *take on* a relationship to a pedagogical structure in the context of education, that is, in relation to teaching methods, curriculum materials, and learning. Thus, in the context of education, the substantive and syntactical structures of a discipline assume a specific relationship to the pedagogical structure of a curriculum.

Adaptations of Schwab's curriculum framework

Let me discuss now the ways in which I have adapted Schwab's views to the purpose of my research (see also Chapter 2).

First, there is my *explicit* use of the pedagogical structure in my analysis of school chemistry curricula in relation to the substantive structure and the syntactical (or philosophical, see below) structure of chemistry as a discipline as embodied in the school curriculum. In the light of the discussion immediately above, this seems to be an appropriate use of the concept of pedagogical structure in the context of education. As components of the pedagogical structure of a curriculum I have taken: the aims of teaching, teaching approach, and learning approach (see further Chapter 2).

Second, I have, mostly for practical reasons as will be explained in Chapter 2, used the concept of the *philosophical structure* of a curriculum, by adding to the methodological principles contained in the syntactical structure as defined by Schwab, fundamental principles of a discipline as used in a school curriculum (taken them out of the substantive structure, as it were; see further Chapter 2).

Consequently, I have analyzed my curriculum data from the point of view of each of these three substructures and from the point of view of the interrelationship of the these three substructures, that is, the *substantive, philosophical, and pedagogical* structures of the school chemistry curriculum.

In his later essays on *The Practical*, Schwab (1978) argues strongly for the *coordination* of four topics or common places of education. These are: the subject matter, the learner, the teacher, and what he calls the milieu. The idea of coordination entails that we should strive for *coherence* in the four common places. If we do not achieve this, it will lead to ineffective teaching or alienation of learners. To repeat Schwab (1978, p. 242):

> If a structure of teaching and learning is alien to the structure of what we propose to teach, the outcome will inevitably be a corruption of that content.

Schwab seems to use here the same idea of coordination but now in connection with the substantive, syntactical, and pedagogical structure of a curriculum. I will come back to this point in section 1.3.3 and Chapter 3 in my discussion of the work of Roberts.

So, in this thesis, I will describe, analyze, and discuss school chemistry curricula also from this point of view, that is, in my case, in terms of the *coordination of the substantive, philosophical, and pedagogical structure* of a school chemistry curricula.

I use the curriculum framework, adopted and adapted from Schwab, in this thesis mainly for analyzing school chemistry curricula as products and as a process of development, and to some extent in Chapters 3 and 6 also for the purpose of contributing to a model for the development of school chemistry curricula.

Finally, it is to be noted that the curriculum categories discussed here – the substantive, philosophical, and pedagogical structures – can be assigned to *each* level distinguished for school chemistry curricula in section 1.3.1.

1.3.3 Roberts's concept of curriculum emphasis

Doug Roberts, a Canadian science educator, and his colleague Graham Orpwood began to develop in the late 1970s a science curriculum framework centered around the concept of curriculum emphases (Roberts & Orpwood 1978, 1979, 1980). The concept of curriculum emphases is defined by Roberts (1982, p. 245) as:

> [A] coherent set of messages to the student about science (rather than within science). Such messages constitute objectives which go beyond learning the facts, principles, laws and theories of the subject matter itself - objectives which provide an answer to the student question: "Why am I learning this?"

And the framework around the concept of curriculum emphasis should be seen as:

> [A]n analytical framework for understanding what is involved for policy makers, and for science teachers, when they shape answers to the question: What counts as science education? (Roberts, 1988, p. 27).

Thus, the "conceptual lens of curriculum emphases" (Roberts (1982, 254), as it has aptly been called, has to be considered as a framework for both analysis and development. That is, to analyze, characterize and categorize (innovative) *science* curricula and to develop, sustain, and evaluate in a systematic way a *vision* on new science curricula.

Based on historical research on science curricula in North America from 1900-1980, Roberts (1982, 1988) distinguished seven curriculum emphases for science curricula (Figure 1.5).

Figure 1.5 Seven curriculum emphases

SOLID FOUNDATION:	Stresses science as cumulative knowledge
STRUCTURE OF SCIENCE:	How science functions as a discipline
SCIENCE/TECHNOLOGY DECISIONS:	The role scientific knowledge plays in decisions which are socially relevant
SCIENTIFIC SKILL DEVELOPMENT:	The 'science as process' approach
CORRECT EXPLANATIONS:	Science as reliable, valid knowledge
PERSONAL EXPLANATION:	Understanding one's own way of explaining events in terms of personal and cultural (including scientific) influences
EVERYDAY APPLICATIONS:	Using science to understand both technology and everyday occurrences

Application of concept of curriculum emphasis

In Chapter 3, I will describe in more detail the concept of curriculum emphasis and its functions in research and development of science curricula. This will also lead into a preliminary discussion of the conditions necessary to escape from Dominant School Chemistry.

In Chapters 4 and 5, I will use the 'conceptual lens' of curriculum emphasis to characterize the innovative school chemistry curriculum, Salters' Chemistry, as well as the currently dominant school chemistry curriculum from which it tries to escape.

Finally, in Chapter 6 I will come back to the conditions necessary to escape from Dominant School Chemistry. This will lead to recommendations to escape from Dominant School Chemistry formulated in terms of the structure of current school chemistry, and of a vision and method of development, based on the curriculum theoretical framework I develop in this thesis of which the concept of curriculum emphasis forms an important part.

1.3.4 Kuhn's views on science education

In Chapter 2, I will discuss Kuhn's views on scientific training that form an important part of his well-known theory of the dynamics of the natural sciences, in which the concepts of normal science, paradigm, and puzzle-solving occupy a central place (Kuhn, 1970a).

Kuhn's views on science education will be used, firstly, to explain the resistance encountered in reforms of school chemistry, that is, to explain the two crucial characteristics of the currently dominant school chemistry, namely, rigidity and isolation.

Secondly, the analysis, in terms of Kuhn's theory, of the empirical results of my research into the structure of school chemistry leads to a recommendation for the prevention of the tacit import of, what I call, the concept of *Normal Science Education*, at all the relevant curriculum levels concerned: the visionary, designed, formal, interpreted, taught, and experienced curriculum (see Chapter 6).

Kuhn and Popper on science education

In order to set the scene for the (following) studies of the structure of school chemistry, the problem of the structure, and the problem of escape, it seems useful to give the reader a general idea of the views of Kuhn on science education as contrasted with those of Popper and Schwab.

The views of Thomas S. Kuhn, an ex-physicist famous for his work in the history and philosophy of science, are well known, especially those views pertaining to the dynamics of science. Since the publication of his book *The Structure of Scientific Revolutions* (1962, 1970a), terms like *normal science* and *revolutionary science, paradigm* and *anomaly* have entered common usage in meta-science as well as in science circles (Horwich, 1993; Nye, 1993; Hoffmann, 1995).

According to Kuhn (1959), the characteristic problems a normal scientist has to deal with in pure or basic science are "almost always repetitions, with minor modifications, of problems that have been undertaken and partially resolved before". Kuhn (1970b) further elaborates on this:

> [A normal scientist's] object is to solve a *puzzle*, preferably one at which others have failed, and *current theory* is required to define that *puzzle* and to guarantee that, given sufficient brilliance, it can be *solved*.

Thus, normal science is about puzzle-solving: "an enterprise which accounts for the overwhelming majority of the work done in basic science" (Kuhn, 1970b).

At an international colloquium held in London in 1965, one of the symposia was devoted to Kuhn's work. The chairman of the symposium, Sir Karl R. Popper, an ex-science teacher renowned for his work in the philosophy of the natural and social sciences, took issue with Kuhn's characterization of science. In his contribution, entitled "Normal Science and Its Dangers", Popper (1970) admitted that he had been:

> (…) only dimly aware of this distinction between normal science and revolutionary science.

However, Popper admitted, that: "what Kuhn has described does exist (…), it is a phenomenon which I dislike (because I regard it as a danger to science)". And he continued:

> The normal scientist, in my view, has been taught badly. I believe, and so do many others, that all teaching on the University level (and *if possible below*) should be training and encouragement in *critical thinking*. The 'normal' scientist as described by Kuhn has been badly taught. He has been taught in a *dogmatic* spirit: he is a victim of indoctrination. *He has learned a technique which can be applied without asking for the reason why,* (…) he is, as Kuhn puts it, content to solve 'puzzles'.

In Popper's view, training students for normal science leads to scientists who "merely want to know the facts, and who have just learned a technique". This results in an uncritical or dogmatic attitude which is "a danger to science and, indeed, to our civilization".

Thus, whereas for Kuhn (1970b): "it is precisely the abandonment of critical discourse" which characterizes mature, productive science; for Popper it is critical thinking which is essential for the growth of scientific knowledge. Please note that the marked differences between Kuhn's and Popper's philosophies of science are associated with equally different views on science education.

Schwab's view on secondary science education

As we saw in section 1.3.2, Schwab's thinking on matters of curriculum is subtle and complex. Therefore, I will now insert a rather large quotation which will make clear in what way Schwab analyzed the school science of his day.

> These three properties of scientific knowledge, its special reference, its revision, its plurality, confer on the scientific enterprise a character alien to that conceived in the nineteenth century. The latter was naively literal. Science was supposed to study a permanent, inflexible, given world. Research was taken as a matter only of seeing what was there, recording and codifying as it went. Science, therefore, was supposed to seek and find inalterable truths. The education appropriate to such a view of science was clear enough: mastery of the true facts as known by science. For such an education, the best possible material was one kind only: a clear, unequivocal, coherent organization and presentation of the known: a pure rhetoric of conclusions. For neither doubt nor ambiguity characterized what was known. A declarative rhetoric of conclusions, omitting all evidence, interpretation, doubt, and debate, sufficed. For, presumably, no interpretation was involved, no doubt existed. The conclusions of science merely presented what the scientist had seen. For such an education the proper method was equally clear: inculcation and exercise. First, the conclusions were to be learned and remembered as given. Then, in the laboratory, their subjects were to be identified and their predicates seen to be true. For this purpose precise and exact instructions told the student what to look at and what to look for. Then came exercises inviting the application of these truths. These, too, would

> be inculcative, for application of scientific truths to particular instances involved neither adaptation of truths to the instance nor to each other. Any practical, particular problem exemplified precisely the general truth of which it was an instance.
>
> *A dogmatic education, then, embodied in authoritative lecture and textbook, inflexible laboratory instructions, and exercises presenting no problems of choice and application was the education appropriate to this nineteenth-century view of science* (Schwab, 1958, p. 375-376; my italics).

Thus, there appears to be a remarkable agreement in the diagnosis or characterization of (school) science education by Kuhn, Popper, and Schwab. It is also clear from this brief review that Popper and Schwab were strongly in favor of a thorough reform of current school science education, while, as I will argue in Chapter 2, Kuhn was not.

1.4 Overview of thesis

This thesis deals with two central questions of the current school chemistry curriculum: the question of the structure of current school chemistry and the question of the escape from the traditional structure of school chemistry. These two main research questions are subdivided here in the seven subquestions listed in Figure 1.6. The first three of these questions deal with the *problem of structure*, the last four with the *problem of escape*, It is good to bear in mind, though, that these seven subquestions differ with respect to their character or status.

The questions 1 and 5 are *empirical* research questions answered by empirical means. The questions 2 and 6 are *theoretical* research questions, arising from the empirical research performed, and asking for an explanation. They are answered in terms of the curriculum theoretical framework developed in this thesis based on the work of Goodlad, Schwab, Roberts and Kuhn. The questions 3, 4 and 5 also have a *theoretical* character, albeit more tentative. In the case of question 3, the answer will lead us into a normative discussion in terms of the means and ends of science education, informed by the empirical and theoretical considerations discussed in this thesis. In the case of question 4 and 7, the answer consists of an argued elaboration of three conditions of escape, which in the latter case will lead to a discussion on recommendations for more successful attempts to escape.

Figure 1.6 Research questions

1. What is the structure of the current school chemistry curriculum?
2. Why is this structure the way it is?
3. Is this structure a desirable structure?
4. What are conditions for escape?
5. To what extent does the Salters' Chemistry curriculum escape from this structure?
6. Why is it so hard to escape from this structure?
7. How can attempts to escape from this structure be more successful?

I will now indicate which sub-question is answered where in this thesis, using some of the key terms of the curriculum framework and the research methods introduced above.

A preliminary answer to *research question 1* has been given above (1.2.2) in the form of the initial hypothesis on the Coherent Structure of School Chemistry based on the work of De Vos and Verdonk (1990, 1994). This hypothesis, summarized in Ten

Statements, has been put to an empirical test by submitting it to both an International and a Dutch Forum on the structure of school chemistry. The comments and criticisms made by the members of these two forums – experts in chemical education: researchers, developers, teachers – led to a major revision of the initial hypothesis and to the reformulation of the structure of the current school chemistry curriculum, that is, to what I have called Dominant School Chemistry.

In Chapter 2, I will describe in further detail the research design used in the testing of the hypothesis on Coherent School Chemistry and the theoretical curriculum framework used in the analysis of the research data. I will also describe Dominant School Chemistry in the form of five revised core statements of Coherent School Chemistry.

Research question 2 is also answered in Chapter 2 by giving an explanation of the characteristics of Dominant School Chemistry in terms of Kuhn's theory of science and science education.

This leads then to a discussion of *research question 3*, that is, whether the structure of school chemistry, thus described and explained, is a desirable structure from the point of view of teaching chemistry for understanding chemical phenomena and from the point of view of teaching chemistry to future citizens.

In Chapter 3, I will reflect on the findings and conclusions of Chapter 2 in order to find a first answer to *research question 4*: "What are conditions for escape?", that is, conditions for a radical reform of the current school chemistry curriculum which would provide a relevant and meaningful chemical education to *all* students of secondary schools, whether they are potential future chemists or future citizens living in an increasingly scientific and technological world in which chemistry occupies an important place. I arrive at a preliminary formulation of three conditions for escape which revolves around the keywords *structure*, *vision*, and *method* (3.4). These conditions will be informed by the empirical research on the current structure of school Chemistry as reported in Chapter 2. They and are given in Chapter 3 a theoretical interpretation in terms of the concept of curriculum emphasis as put forward by Roberts (1988) and in terms of the concept of normal science education based on Kuhn's work (1970).

Research question 5 and research question 6 are answered in Chapter 4, respectively in Chapter 5, where I report on the extent to which an innovative, society-oriented school chemistry curriculum, Salters' Chemistry, succeeds in escaping from Dominant School Chemistry. In a research design which combines document analysis, interviews, and classroom observation of the taught and experienced lesson materials, it becomes visible to what extent the visionary, designed, interpreted, taught, and experienced curricula of Salters' Chemistry deviates from the traditional concept-oriented school chemistry curriculum. In Chapter 6, I will try to answer *research question 7* by reflecting on the empirical findings and conclusions of Chapters 4 and 5 in combination with the findings and conclusions of Chapter 2. I will also return to the preliminary conditions for escape as put forward in Chapter 3. This will result in a further elaboration of these conditions for escape, and to a number of recommendations for escaping from Dominant School Chemistry taken as a form of Normal Chemistry Education.

2 Normal Science Education and its dangers: The case of school chemistry

The following chapter appeared in 2000 as an article published in a special issue of "Science & Education" on: "Thomas Kuhn and Science Education".[1] With the kind permission of the publisher it has been reproduced here with some minor changes. The chapter can therefore be read as a self-contained whole. In this chapter, I argue that the currently dominant school chemistry curriculum can be interpreted as a form of Normal Science Education. Some of the topics, more fully discussed in Chapter 1 such as my research design (section 1.2) and my curriculum framework (section 1.3), are briefly summarized here. Other topics such as Kuhn's and Popper's views on science education have been elaborated upon here.

The article in "Science & Education" started with an *abstract* which follows immediately below. In the text of abstract and the main body of the article I have made some small changes such as the numbering of sections and figures. If and when necessary, I have added explanatory notes in order to relate the argument developed in Chapter 2 with the methods and framework introduced in Chapter 1.

We started the Conceptual Structure of School Chemistry research project, a part of which is reported on here, with an attempt to solve the problem of the hidden structure in school chemistry. In order to solve that problem, and informed by previous research, we performed a content analysis of school chemistry textbooks and syllabi. This led us to the hypothesis that school chemistry curricula are based on an underlying, coherent structure of chemical concepts that students are supposed to learn for the purpose of explaining and predicting chemical phenomena (2.1). The elicited comments and criticisms of an International Forum of twenty-eight researchers of chemical education, though, refuted the central claims of this hypothesis (2.2). This led to a descriptive theory of the currently dominant school chemistry curriculum in terms of a rigid combination of a specific substantive structure, based on corpuscular theory, a specific philosophical structure, educational positivism, and a specific pedagogical structure, involving initiatory and preparatory training of future chemists (2.2). Secondly, it led to an explanatory theory of the structure of school chemistry, based on Kuhn's theory of normal science and scientific training, in which Dominant School Chemistry is interpreted as a form of Normal Science Education. Since the former has almost all characteristics in common with the latter, Dominant School Chemistry must be regarded as Normal Chemistry Education (2.3). Forum members also formulated a number of normative

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[1] Van Berkel, B., De Vos, W., Verdonk, A.H. and Pilot, A. (2000). "Normal Science Education and its Dangers: The Case of School Chemistry". Science & Education, Vol. 9, Nos. 1-2, 123-159.
Adri Verdonk and the late Wobbe the Vos were my former supervisors who gave many valuable comments and constructive criticisms on earlier versions of this paper. They also contributed to other parts of the research into the current structure of school chemistry as I have indicated in Chapter 1.

criticisms on dominant school chemistry, which we interpret as specific dangers of Normal Chemistry Education, complementing Popper's discussion of the general dangers of normal science and its teaching (2.4). On the basis of these criticisms, it is argued that Normal Chemistry Education is isolated from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research (2.5).

2.1 Introduction

In this introductory section I will briefly describe the rationale of the research reported on in this thesis (2.1.1), the chosen research design (2.1.2), and the curriculum theoretical framework used (2.1.3). In subsection 2.1.4, I will give an overview of what will be discussed in the sequel of this chapter. See also the relevant sections in Chapter 1: sections 1.1.2, 1.2 and 1.3.

2.1.1 Rationale

Most of the studies performed, from 1985 onwards, by members of the Department of Chemical Education, Center for Science and Mathematics Education, Utrecht University, concerned the *parts* of the current school chemistry curriculum in the Netherlands which addressed topics such as chemical reactions (De Vos and Verdonk, 1985/86/87), chemical equilibrium (Van Driel, 1990), chemical bonding (Van Hoeve-Brouwer, 1996) and electrochemistry (Acampo, 1997).

After a conceptual analysis of these topics in representative Dutch textbooks, new teaching material was designed and trialled in the classroom. The feedback from students and teachers was used to redesign each teaching unit in order to match the proposed educational structure of activities to the aims set by the respective researcher, such as how and why a particular topic of school chemistry must be taught and learned.

The completion of a number of these small-scale research projects led to the problem of the *hidden structure* of school chemistry, as we initially called it (De Vos, 1992). We began to wonder why school chemistry textbooks from different countries look so remarkably similar. What does the school chemistry curriculum *as a whole* look like? How can we arrive at a valid description of it? Further, why is school chemistry so *resistant* to reforms? Is the structure of the school chemistry curriculum a support or a hindrance to the quality of chemical education?

In 1991 the Department of Chemical Education started the Conceptual Structure of School Chemistry (CSSC) research project in order to find out whether it would be possible to arrive at a curriculum theory or framework (see 1.3) in terms which we could: (1) describe, analyze, and criticize the structure of school chemistry curricula, traditional as well as innovative ones; (2) answer relevant curriculum questions such as the ones raised above, and (3) contribute to the ongoing reforms in secondary education in chemistry. In brief, the project set out to develop a chemistry-specific curriculum framework (Van Berkel and De Vos, 1993; Van Berkel, 1996).

2.1.2 Research design

The phases of our research design are formulated in general categories which stem from Popper.[2] These phases are specified for the International Forum (IF) part of the CSSC project, and correspond to sections of this chapter (Figure 2.1).

Figure 2.1 Research design for the IF part of the CSSC project

Popper's categories	**Research phases of CSSC project**	**Sections in this chapter**
Initial problem (P1)	Problem of hidden structure	Introduction (2.1)
Tentative theory (TT1)	Coherent CSSC, summarized in *Ten Statements*	Introduction (2.1)
Error Elimination (EE1)	Probing International Forum	IF response to core statements (2.2)
New problem (P2)	Many IF responses are inconsistent with statements of coherent CSSC	Analysis of IF response to core statements (2.2)
Revised Theory (TT2)	Dominant school chemistry: *descriptive* theory of school chemistry	Analysis of IF response to core statements (2.2)
	Normal chemistry education: *explanatory* theory of school chemistry	Normal science education (2.3)
Critical Discussion	Specific and General Dangers	Normal chemistry education and its dangers (2.4)

In order to solve the first problem (P1), the problem of the hidden structure of school chemistry, and informed by our previous research, we performed a content analysis of textbooks and syllabi. The analysis contained chemical, philosophical, and educational dimensions and was applied to current and post-war textbooks and syllabi representative of secondary chemical education in mostly Western countries (see 1.2.2). This led to our initial *hypothesis* that school chemistry curricula are based on an *underlying, coherent* structure of chemical concepts that students are supposed to learn for the purposes of explaining and predicting chemical phenomena (De Vos, Van Berkel and Verdonk, 1994).

In the next phase of the IF part of the CSSC research project, we tried to test or validate the *hypothesis* on the *coherent* conceptual structure of the school chemistry curriculum (TT1). For that purpose the hypothesis was summarized in *Ten Statements* of a *general* nature (See Chapter 1, Figure 1.4), which were used as a probe with an International Forum (IF) of twenty-eight experts in chemical education: researchers, developers and teachers. About half of them were enrolled in the IF during the 11th International Conference on Chemical Education in York (Kempa and Waddington,

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[2] Popper (1972, 1994) describes science, as well as life, as a *revisionary* spiral of problem posing and problem solving, using terms as mentioned in the left column of Figure 2.1.

1992), while others were approached through other conferences or during work visits of the first author.[3] If people showed interest in the research project (self-selection), we asked them to formulate the extent to which they agreed or disagreed with each of the *Ten Statements*, and to give written comments on some of our papers containing necessary background and detail. As anonymity of *responses* was guaranteed to respondents, we assigned randomly-generated numbers to individual respondents for the purpose of publication.

The IF responses were analyzed by the three authors of that paper, at first individually and then jointly, to arrive at the findings reported in section 2.2. The following procedure was used:

(i) For each respondent, analyze the response to *one* particular statement in connection with relevant comments made by the same respondent to *all* ten statements.
(ii) Analyze the response to a particular statement by *one* respondent in the light of *all* IF responses to this statement (including relevant comments to other statements).
(iii) Consider the IF response to a statement in the light of relevant research evidence, either taken from the research literature or from our own research.
(iv) Decide on the basis of (i – iii) how many respondents agree or disagree with a particular statement and how many respondents do not respond or address the statement in question.[4]

2.1.3 Curriculum framework of analysis

After the exploratory phase, posing the problem and formulating the initial hypothesis, we have adopted, and *adapted* to our research purposes, a curriculum theoretical framework introduced by Schwab (1964a/b/c, 1978) in the context of the 'structure of the disciplines' movement. Schwab (biologist, philosopher, and educationalist) distinguished in science curricula the following structures, which we take as specifications of the dimensions (chemical, philosophical, and educational) that we used before (see Figure 1.1 in Chapter 1, and Figure 2.2. below).

- *Substantive* structure: scientific concepts, relationships and techniques;
- *Syntactical* structure: changed into *philosophical* structure, containing the methodology as well as the foundations of science and chemistry;
- *Pedagogical* structure: aims of and approaches to learning and teaching.

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[3] See Appendix 3 for a list of International Forum respondents. In another cycle of the CSSC project we tested the hypothesis on coherent school chemistry with a Dutch Forum (DF) of twenty-two experts in chemical education (see section 1.2.3 and Appendix 4)

[4] As a final step should be added: (v) Decide on the basis of (i – iv) how to reformulate the original statement by weighing the evidence in the light of the principle mentioned by Schwab (1964a, p. 35): "The scientist takes account of a vast variety of data which must be accounted for. He treats each datum as a limitation on what may be conceived as accounting for the whole range of data, and within the boundaries of these complex limitations he conceives a solution to the problem." (see also section 1.2.3).

Figure 2.2 Categories and codes for analyzing school chemistry curricula

Substantive structure	[Sub]	Philosophical structure[a]	[Phil]	Pedagogical structure	[Ped]
Chemical concepts	[CC]	Foundations of science	[FS]	Aims	[A]
Chemical relations	[CR]	Methodology of science	[MS]	Teaching approach	[TA]
Chemical techniques	[CT]	Foundations of chemistry	[FC]	Learning approach	[LA]
		Methodology of chemistry	[MC]		

[a] Reason for subdivision is given in subsection 2.2.2 below.

The categories and subcategories of Figure 2.2 proved to be fruitful for the authors of this article in the analysis of school chemistry curricula. Where appropriate in this article, in the text and in quotations, the codes corresponding to these categories are provided in brackets in order to allow readers to make their own judgment as to their usefulness.

The main problem which the CSSC project tried to resolve can now be reformulated in terms of Schwab's categories as follows: to describe, analyze, and critique the *relationships* between the specific substantive, philosophical, and pedagogical structures that together were found to comprise current school chemistry curricula.

Following Goodlad (1979, 1994) many researchers performing curriculum studies (e.g. Van den Akker, 1998, p. 422) see curricula as composed of several curriculum levels. In this study we use the following curriculum levels and terms:

- intended curriculum: formulation of a number of aims by textbook writers and developers;
- formal curriculum: operationalization of aims in textbook, teaching units, and syllabus;
- taught curriculum: execution of formal curriculum by teachers in the classroom;
- learned curriculum: learning of taught curriculum by students in the classroom (exams).

It is to be noted that the curriculum categories mentioned above – the substantive, philosophical, and pedagogical structures – can be assigned to *each* level of school chemistry curricula. IF responses to our *Ten Statements* probe were analyzed and interpreted as referring mainly to the *intended* and *formal* curriculum, and also, as we will see, in connection with the *taught* and *learned*, or the realized curriculum of school chemistry.

2.1.4 Preview

The elicited IF response refuted the central claims of our hypothesis on the structure of *coherent* school chemistry. This led to a new problem situation (P2) which we have resolved as follows. Firstly, we acknowledge that the coherency of structure and aim *ascribed* by us to the intended / formal school chemistry curriculum does not validly *describe,* according to IF respondents, the *realized* school chemistry curriculum, that is, the taught and learned curriculum. Secondly, the refutation of coherent school chemistry leads to the characterization of the currently *dominant* form of the school chemistry curriculum as a *rigid* combination of *specific* substantive, philosophical, and pedagogical structures (section 2.2).

Subsequently, using Kuhn's (1970a) theory of normal science and scientific training, we *interpreted* dominant school chemistry as a form of *normal science education* (NSE). The latter has the following characteristics: (i) NSE prepares future scientists for normal science; (ii) NSE is the dominant or normal form of science education in the natural sciences at the tertiary *as well as* at the secondary level; (iii) NSE contains implicit norms with respect to science and its philosophy and pedagogy (section 2.3).

As we will show, dominant school chemistry shares almost all of its characteristics with NSE. More specifically, it must be regarded as *normal chemistry education*. Thus, on the basis of our empirical findings, we will argue that Kuhn's view on normal science education is *confirmed*, in particular for *chemistry* as taught in schools. Figures 2.3, 2.4 and 2.5 give a summary of the structure of dominant school chemistry (left side) and a summary of the structure of normal science education (right side).

IF respondents also formulated a number of *normative* criticisms on dominant school chemistry, that is, criticizing what is realized de facto in the school chemistry curriculum. These criticisms point to specific *dangers* of normal chemistry education and complement Popper's (1970) discussion of the general dangers of normal science and its teaching. On the basis of these criticisms, it is argued that *normal chemistry education* is isolated from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research (section 2.4).

2.2 Analysis of response International Forum

In section 2.2.1, I will describe how I categorized the *Ten Statements*, as given in Figure1.4, in terms of my curriculum theoretical framework in order to analyze the responses given by IF members. In section 2.2.2, I will analyze what I have called the *core* statements (statements 1, 2, 3, 8 and 9) taken as representing the *core* of our hypothesis on coherent school chemistry. This analysis is followed by a concluding discussion in section 2.2.3.

2.2.1 Methodological introduction

Initially, we ordered the *Ten Statements* using the following dimensions: chemical (Statements 2 – 8), philosophical (Statements 9 and 10), and educational (Statements 1 and 10). During the analysis of the IF response to the *Ten Statements* we thought it fruitful to replace these dimensions with Schwab's categories (Figure 2.2).

Statement 1 is taken as addressing the *pedagogical* structure [Ped], the aim and the teaching approach of school chemistry. IF respondents responded accordingly, while some also pointed to components of the philosophical structure (see below).

Statements 2 – 8 address the *substantive* structure [Sub], which is further ordered as follows: Statements 2 and 3 address the three basic, *phenomenological* concepts of school chemistry: pure substance, chemical reaction, and chemical element. Statements 4 and 5 are elaboration's of Statement 3, while Statements 6 and 7 are elaboration's of Statement 2. Several IF respondents responded to these same combinations of statements.

Statement 8 focuses on corpuscular explanations of phenomenological concepts mentioned in Statements 2 – 7. Many IF respondents commented that corpuscular explanations prevail in *current* school chemistry.

Statement 9 addresses the *philosophical* structure [Phil], as well as part of the pedagogical structure, especially the teaching approach [TA] of school chemistry. IF respondents responded by pointing to relationships between the substantive, philosophical, and pedagogical structures. Finally, Statement 10 adds an historical dimension to Statement 9 as well as to Statement 1.

Thus, while probing the IF, it became clear that Statements 1, 2, 3, 8 and 9 could be considered as the *core* of our hypothesis on coherent school chemistry, therefore, this section is restricted to these five *core* statements. (Illustrations of these general core statements, taken from school chemistry textbooks, are given in Appendix 1).

2.2.2 Analysis of core statements

We begin our analysis by presenting the original formulations of each of the core statements. Second, we briefly summarize the IF response to each core statement and quote respondents who agree or disagree with its *central* claim, that is, the substatement containing an italicized keyword. Third, we reformulate the central claims as *universal statements* in order to emphasize their theoretical character and their refutation by IF responses. Fourth, we give a revised formulation of the central claims, which taken together constitute the core of the currently *dominant* structure of the school chemistry curriculum (Figures 2.3, 2.4 and 2.5).

Statement 1 Our original formulation was:

> From the moment chemistry was introduced as a subject in secondary education in the nineteenth century, it has always been taught *as a science*. It is made clear, often on the first page of the book or even in the first sentence, that chemistry is one of the natural sciences. Concepts to be taught are selected on the basis of their scientific relevance. The student is seen as a future scientist, who wants to specialize in chemical research [Ped/A] and therefore has to become familiar with research methods and research results obtained by applying these methods. The use of chemical products and processes in society is presented as something that follows from scientific theory, not the other way around.

Almost all IF respondents disagree with the claim that school chemistry is taught *as a science* [Ped/A], an activity equated here with prediction and explanation of chemical phenomena (cf. Statement 3). The next quote epitomizes the IF view that in fact *current* school chemistry gives an incorrect picture of chemistry as a science:

> We tend to teach chemistry by using certain well established *standard items of dogma ... theoretical propositional* knowledge often *dominates* school chemistry and *symbolic notation* becomes a *reified* account of many facts which have never been observed (R4).

Ten respondents address the claim of Statement 1 directly, using in their responses terms such as *algorithms*, *rules*, *techniques*, and *rote learning* [Ped/LA] to characterize current school chemistry. Several other respondents (5) can be taken to disagree since they deny that the aim of prediction and explanation of chemical phenomena refers de facto to school chemistry. Another ten IF respondents disagree implicitly, by pointing to *relevant* chemistry courses which instead try to teach chemistry as an *applied* science. A few respondents do not address the central claim of Statement 1, and only one respondent (R12) appears to agree with it.

Besides relevant society-oriented curricula, such as Salters' Chemistry and ChemCom, IF respondents mention process-oriented curricula such as Nuffield Chemistry, but these curricula are mentioned as actual or desirable *alternatives*, not as part of the mainstream development. Some respondents (R1, R8) point out that different forms of science education, emphasizing societal relevance or scientific processes, have been viable *before* 1900.

In sum, IF respondents appear to say that the currently dominant school chemistry curriculum is mainly oriented towards the imparting and recall of results [Ped/A], that is, to the propositions and algorithms of chemistry. Thus, the IF response leads to a revision of the central claim of Statement 1:

CENTRAL CLAIM STATEMENT 1	All school chemistry curricula are being taught *as a science* to students seen as future chemists.
REVISION STATEMENT 1	All school chemistry curricula belonging to the dominant version are being taught and learned as *propositions and algorithms* to students seen as future chemists.

One should bear in mind here that the original statement1 refers mainly to the formal and taught curriculum of school chemistry, while the revised statement refers to the dominant curriculum *as realized*, according to IF respondents, in the taught *and* learned curriculum. The same applies to Statements 2, 3 and 8. We return to the *pedagogical* structure and its relation to the philosophical and substantive structure of school chemistry when we analyze the IF response to Statement 9 below (Figure 2.5).

Statement 2 Our original formulation was:

> Chemistry is immediately distinguished from other natural sciences by its object of research, which is chemical 'phenomena' or *chemical reactions*. The reaction concept is introduced very early in the curriculum and it is defined in a very general sense: it refers to a process in which one or more substances are converted into one or more other substances. Each substance is characterized by a set of substance properties. Besides, chemical phenomena are often said to be irreversible and more fundamental than physical phenomena (such as phase transitions). The definition of chemical reaction requires a specific chemical substance concept (see Figure 1.4, Statement 6).

Together with Statements 3 and 8, Statement 2 forms the core of the substantive structure of school chemistry (Figure 2.3).

Many respondents (15) agree *prima facie* with our claim that *chemical reactions* play a fundamental role in school chemistry. The agreement of other respondents seems more implicit, but when we consider the response to Statement 6, we see that most at least acknowledge, and some stress, the point that the 'fundamental' concept of chemical reaction is 'closely linked to a specific chemical *pure substance* concept', as we stated. For example, R21 emphasizes that 'the notions of reaction and substance are closely interrelated'.

However, R1 remarks, ‘nor is it clear that *greater* weight should be placed on reactions than on substances’. Some respondents (8) specify their disagreement by pointing to other foci of school chemistry, such as properties of substances (4), the products of synthesis (2), or the existence of *plural* foci (2). The following quote elaborates the latter point:

> ... *three approaches* to the beginning of chemistry teaching have been advocated, and, indeed, have been the basis of published curricula. The focus of each is I believe different, namely, *substances* and their properties, *atomic structure* as the basis of chemical substances and their properties, and *chemical reactions* (R8).

As we will see below (Statements 3 and 8), of the many foci existing or possible, the corpuscular one, in which school chemistry is based on atomic structure, applies to dominant school chemistry. The IF response thus leads to revision of the central claim of Statement 2:

CENTRAL CLAIM STATEMENT 2	All school chemistry curricula are focused on *chemical reactions,* the reaction concept being closely linked to a specific chemical substance concept.
REVISION STATEMENT 2	All *current* school chemistry curricula belonging to the dominant version have a *corpuscular theoretical* focus on chemical substances and their properties.

Statement 3 Our original formulation was:

> The reaction concept is illustrated by a series of examples (and usually also non-examples) of chemical reactions. These examples emphasize the fact that chemical reactions are spectacular, manifold and, as yet, unpredictable. From that moment on, the curriculum can be seen as an attempt to answer the question of *predictability of reactions*.[5]

Some respondents (4) agree with us, but their comments seem to concern more the *intended* curriculum than the realized curriculum of school chemistry. That is, they agree but only in the sense that school chemistry *can be seen* as an attempt to answer the question of predictability of reactions.

Most respondents (16), though, disagree with our position, that is, they deny, to a greater or lesser extent, that current school chemistry *is*, de facto, devoted to this aim. For example, R8 remarks that ‘very few school chemistry courses set out explicitly to predict reactions or to provide explanatory theory as you claim’, and R27 comments that ‘this is definitely not the declared framework’. Some respondents (4) say that it applies partly to the upper secondary level; others (3) are of the opinion that we overstate the emphasis on predictability, certainly with regard to reactions. The explanatory theory needed for this purpose, several respondents (5) point out, is not really addressed in school chemistry,

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[5] I add here also the original formulation of the first part of Statement 4:
One way to predict chemical reactions is by developing an *explanatory theory*. The curriculum implicitly offers such a theory by demanding that a reaction must fulfill three conditions (4a, 4b, and 4c in Fig.1.3). Failure to meet one of these conditions is sufficient explanation for the non-occurrence of a reaction. A reaction therefore takes place only if it fulfills all three conditions.

i.e., the three reaction conditions are *not coherently* treated, but only addressed in an isolated, implicit, and often incomplete way.

In line with the corpuscular theoretical focus referred to above, the IF sees school chemistry as dealing largely with *corpuscular* explanations and predictions of properties of chemical *substances*: 'prediction of formulae of substances is I think more common in schools than is prediction of reactions' (R27). In this context, R4 emphasizes *systematization* rather than explanation:

> Valence and the more refined concept of oxidation number provide one of the most useful *systematization* schemes in the whole of chemistry. The link between oxidation number, elements, the periodic table, atomic structure and stoichiometry, I believe, is *absolutely essential to achieve a rational base* (emphasis R4) for the reaction concept. This is intimately connected to what you refer to as *corpuscular theory*.

Similarly, R16 questions whether the theme of prediction and explanation pertains at all to current school chemistry:

> I think that the emphasis on 'predictability' is overstated here. Instead, I would argue that much effort focuses on *patterns of behavior* of chemical substances. Although such patterns, once recognized, may be used for predictive purposes (by extrapolative processes based on, e.g., the Periodic Table), they frequently serve as ways of rationalizing and *systematizing large amounts of chemical information*.

Thus, the school chemistry curriculum deals, according to IF members, not so much with prediction and explanation of aspects of chemical reactions, but rather with the explanation and systematization of patterns and trends in properties of chemical substances. For instance, it is customary to explain properties of substances, such as acidity and boiling points, and to use chemical formulae in the representation of substances, in terms of corpuscular theories about composition, atomic structure, and bonding.

The IF response thus leads to revision of the central claim of Statement 3. (The original formulation shows that it refers to the *intended* curriculum of school chemistry.)

CENTRAL CLAIM STATEMENT 3	All school chemistry curricula *can be seen as* aiming at *predictability* of chemical reactions using explanatory theory.
REVISION STATEMENT 3	All current school chemistry curricula belonging to the dominant version deal with the explanation and systematization of chemical information largely in terms of *corpuscular theory*.

Statement 8 Our original formulation was:

> A distinction is made between a level of phenomena and a level of *corpuscula* or particles such as atoms, molecules or electrons. Once corpuscular theory is introduced, it provides explanations, e.g. of reactivities, of equilibrium (kinetic explanation) etc., as well as conventions, e.g. the nomenclature of substances such as 1,2-dichloroethane.

All respondents agree that the corpuscular explanation of chemical phenomena is an important part of the *intended* school chemistry curriculum, with some (4) strongly in favor of the dominant focus on corpuscularity while a few others (3) are critical.[6] For example, R5 remarks, 'The consequence of concentration on the molecular is that it diverts attention away from the macro [level].' At the same time, many respondents emphasize that the distinction mentioned above between corpuscula and phenomena is only partially realized in teaching. They give examples of the problems with the translation of this distinction from the intended curriculum to the formal curriculum level, i.e. textbooks, and to the levels of the taught and learned curricula, respectively:

> The distinction between the macroscopical and microscopical levels of description certainly exists. However, it is not adequately stressed in school chemistry books. Indeed, the descriptive language used in these books does not maintain that distinction. Phrases such as 'nitrogen has a triple bond' illustrate the point: nitrogen is a colorless, odorless unreactive gas; the nitrogen *molecule* has a triple bond. The triple bond provides the explanation of the unreactive nature of the substance. (R27)
>
> Often language is used inaccurately, e.g., you speak of iron when you have to speak of iron-ions. (R2)
>
> I agree that the corpuscular theory provides explanations for phenomena but am unsure how far these are internalized by students. Many continue to reason in macroscopic terms about events, even after being taught corpuscular theory. (R13)
>
> ... students ascribe properties of substance to particles: They melt, they grow etc. (R2)

Again, the IF response leads to a revision of the central claim of Statement 8.

CENTRAL CLAIM STATEMENT 8	All school chemistry curricula make a distinction between a level of *phenomena* and a level of *corpuscula*. Once corpuscular theory is introduced it provides explanations of macroscopic phenomena and relationships.
REVISION STATEMENT 8	All *current* school chemistry curricula belonging to the dominant version make a distinction between a level of *phenomena* and a level of *corpuscula*. The introduction of corpuscular theory in books and classroom is neither consistent nor accurate, and hence not effective.

Finally, it is to be noted that the choice for a substantive structure of school chemistry in terms of corpuscularity has implications, as pointed out by R8 above, for the scope and sequence of concepts developed in the curriculum, choices which reflect views on philosophy and pedagogy of chemistry. With Statement 8 we conclude our analysis of the IF view on the substantive structure of school chemistry as such (Figure 2.3).

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[6] According to the Dutch Forum (DF), the currently dominant school chemistry curriculum in the Netherlands introduces corpuscular theory after a phenomenological introduction of one or two semesters. Apart from this, the DF gives a similar characterization of dominant school chemistry as does the IF.

Figure 2.3 Substantive structure of dominant school chemistry and normal science education

Category	**Dominant School Chemistry** (based on International Forum response)[a]	**Normal Science Education** (based on Kuhn's work)[b]
Chemical concepts	- chemical (pure) substances and their properties, elements, simple reactions - stoichiometry, balanced equation, formulae - taxonomy of substances and reactions - periodic system - atoms, valence and bonds	- concepts (pencil and paper), facts
Chemical relations	- demarcation, mostly implicit, from: common sense, everyday life and society, technology, history/philosophy of science, physics, and research	- insulation, mostly implicit, from: common sense, everyday life and society, technology, history/philosophy of science, related sciences, and research front
	- implicit (partly incomplete) relations between chemical reaction, chemical substance, and chemical element - reaction conditions often implicit, incoherent, and partly incomplete[c] - conditions for substances are presented only as fragments[c]	- definitions, laws, theories are presented briefly, precisely, and systematically
	- the relationship of descriptive/systematic chemistry with theoretical/physical chemistry often lacks coherence - corpuscular theory dominates: symbolic notation; balancing equations (number of atoms/charges/electrons)	- as separately and seriatim as possible
Chemical techniques	- school laboratory, using simple reactions; separation techniques	- laboratory experiments, techniques, measurement

[a] The points in this column are taken from IF responses; the same applies to Figures 2.4 and 2.5.

[b] Most of this column is quoted directly from Kuhn (substantive structure follows latest paradigm, that is, for school chemistry corpuscular theory); the same applies to Figures 2.4 and 2.5

[c] We refer here, of course, to reaction conditions and conditions for substances as far as they are known. After all, chemistry, as a science, is still incomplete in some of these respects (De Vos, Van Berkel, and Verdonk, 1994).

Relationship between substantive, philosophical and pedagogical structure

We will now review the IF response to statement 9, and analyze and discuss the relationships between the substantive and the philosophical structures of school chemistry on the one hand, and the pedagogical structure of school chemistry on the other. Where appropriate we review the IF response to Statement 10 and Statement 1.

Statement 9 Our original formulation was:

> The conceptual structure in the curriculum does not imply a *specific* philosophy of science, e.g. inductivism or hypothetico-deductivism; or a *specific* philosophy of chemistry. Neither does it in itself prescribe a *specific* teaching approach. While some teachers (and books) aim at a direct transfer of knowledge, others prefer students to discover as much as possible by themselves. Both traditional and modern teaching methods may be based on the same curriculum structure.

A number of respondents (11) agree in general, though some add that ‘the content of a traditional syllabus’ (R13) is *retained*, or that ‘similar content’ (R23) is used, which is ‘OK for able, motivated students’ (R28). Those who agree mostly refer in their responses to the *content* of school chemistry [Sub], that is, to the conceptual or substantive structure, as we specified it later, taken as a *part* of the school chemistry curriculum. About an equal number of respondents (12) disagree, most of them quite explicitly:

> Contrary to what you imply I believe that the *conceptual structure of the curriculum* [Sub] does prescribe a specific teaching approach [Ped/TA]. Until the 1960s, *descriptive chemistry* [Sub] ... students learned much of this *by rote* [Ped/LA] ... then replaced in the late 60’s by the *physical chemists’ approach* [Sub] in which explanatory theory [Phil] was given paramount importance. Practical work was aimed at students to *discover*, via the experimental method, theoretical relations between facts for themselves [Ped/TA]. (R4)

> I do not see any evidence for the first sentence, indeed I believe the reverse. I would argue that the *conceptual structure of the curriculum* [Sub] is as value-laden as science itself and *implies* a philosophy of science [Phil], the philosophical roots go back to F. Bacon and the beginning of European Science. (R5)

> While the *structure of the text* does not prescribe a specific teaching style [Ped/TA], *it has traditionally implied one*. First of all, in the ordering of the content [Sub], secondly, in the emphasis it places on laboratory work versus book work [Ped/TA], some texts only describe experimental procedures; others insist the students perform certain techniques. (R1)

It is to be noted that most respondents who *disagree*, refer, as does R1, to the *curriculum structure as a whole* or to the *current* school chemistry curriculum by using terms such as ‘book’ (R26), ‘text’ (R11) or ‘chemistry taught’ (R8). Remaining IF respondents do not, or say they cannot respond, because of our unclear or ambiguous terms. Some rightly point out that the claim of Statement 9 is to be taken as ‘an empirical matter’ (R21).

Looking at the further IF response, especially to Statements 1 and 10, we come to the conclusion that most respondents disagree, at least implicitly, with Statement 9 taken as a claim pertaining to *current* school chemistry. Thus, the IF contends that the currently dominant school chemistry curriculum comprises a specific substantive structure, a *physical chemists’ approach* to school chemistry, which is combined with a *particular* philosophical structure and a *particular* pedagogical structure (see Figures 2.4 and 2.5).

Discussion

Some respondents (4) disagree with Statement 9, both in the sense of referring to the curriculum structure *as a whole* and to the substantive structure *in or of* the curriculum. The latter response lays bare the fact that school chemistry has used more than one substantive structure. This confirms the point made by R8, in connection with Statement 2, about the existence of three different approaches to school chemistry.

Furthermore, the first quotation of R4 (given above) makes clear that the choice for a particular substantive structure – descriptive chemistry or physical chemistry – is at least *intended* to have consequences for the choice of pedagogical structure – rote learning or discovery learning – as well as for the choice of philosophical structure – inductivism or hypothetico-deductivism. Whether these last two choices have left much traces in the *realized* curriculum is another matter, and doubted by many IF respondents. Recent research confirms that little has persisted of the reforms of the 60s and 70s (Fensham, 1992; Duschl, 1993; Matthews, 1998).

On the basis of IF comments to Statement 9, we thought it useful to replace Schwab's syntactical structure with an extended and specified philosophical structure consisting of four coded subcategories: foundations of science [FS], methodology of science [MS], foundations of chemistry [FC], methodology of chemistry [MC]. See Figure 2.2. The most important reason for the substitution is that the IF response to these statements reveals, besides methodological assumptions, several implicit philosophical foundations in school chemistry.

In order to determine the *specific* components of the philosophical structure and the pedagogical structure of current school chemistry, we treat the IF responses towards Statement 9 as directed to three substatements expressing the following central claims:

- the substantive structure does *not* imply a *specific* philosophy of science (9a1);
- the substantive structure does *not* imply a *specific* philosophy of chemistry (9a2);
- the substantive structure does *not* imply a *specific* teaching approach (9b).

Substatement 9a1

There are relatively few IF respondents (4) who explicitly address specific components of the philosophical structure, though some respondents implicitly address the philosophical structure in responding to other relevant statements (Statements 1 and 10).

The comments and criticisms on substatement 9a1 fall under four points. The first is exemplified by respondent R26, who says that in school chemistry, 'Science appears like the key to solve *all* our problems: it is neutral, pure, aseptic.' But while R26 gives an apt description of *scientism* [FS], R5 points to a different aspect of scientism, namely, 'Humankind's considerable power over matter ... hides from discussion our lack of knowledge.' As for the other three points, R26 feels that 'the philosophy of science in the vast majority of the books is *positivism*' [FS], R5 points to 'reduction to the atomistic level' [FS], and to 'predictability, nature being brought under control' [FS].

Thus, contrary to what we claimed in Statement 9a1, and without explicitly addressing the *foundational* issue, these respondents claim that the substantive structure of current school chemistry entails a *specific* choice for a philosophy of science, which consists of the following assumptions: (1) scientism, (2) positivism[7], (3) reductionism, and (4) predictability as control (Figure 2.4).

A few IF respondents (3) also address the issue of the methodology of science as

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[7] Chalmers (1980, p.1, 2) describes the common-sense view of science briefly as follows: “Scientific knowledge is *proven* knowledge. Scientific theories are *derived* in some rigorous way from the facts of experience acquired by observation and experiment”. He argues in his book that this “naive inductivist” methodology and positivistic account of science “is quite mistaken and even dangerously misleading”.
Van Aalsvoort (2000) explicates in detail the positivistic assumptions in current Dutch school chemistry textbooks.

portrayed de facto in school chemistry textbooks. R26 feels that ‘the scientific method of the first page is the old positivist physics method’ [MS]. R11 elaborates on this:

> The opening chapter of most texts gives a brief and inaccurate description of the scientific method [MS], but the student is not asked to apply this approach in later pages. Moreover, the historic experiments described later are all successful, and their *interpretation is always correct*, using the hindsight of many decades. There is *no uncertainty of conclusions* [MS].

The relative scarcity of explicit IF responses testifies to the partially *hidden* nature of the philosophical structure of school chemistry. In the last decade there has been a renewed and systematic interest in the philosophical assumptions underlying school science, as is evident from many articles, books and studies, and from substantial sections on history and philosophy of science (HPS) in encyclopedias of science education (Duschl, 1993; Matthews, 1998).

Substatement 9a2

Again, there are few explicit comments and criticisms of IF respondents on substatement 9a2. They fall under three points. First, some respondents, for example R18, point to a theory-driven orientation of school chemistry: ‘We teach the chemical theories first and then we collect some examples illustrating theories.’ Second, as noted above, in the 1960s the substantive structure of school chemistry changed to a ‘physical chemists’ approach’ (R4). Third, this led to a corpuscular oriented curriculum for school chemistry, where ‘atomic structure is the main subject, sometimes the only one and [where] chemistry appears like something less than physics’ (R26).

Thus, contrary to what we claimed in substatement 9a2, and without explicitly addressing the *foundational* issue, these respondents claim that a *specific* philosophy of chemistry is implied in the substantive structure of school chemistry. This philosophy consists of the following assumptions: (i) primacy of chemical theories/concepts, (ii) dominance of physics, and (iii) a corpuscular curriculum emphasis (Figure 2.4). Few respondents comment explicitly on the issue of a methodology of chemistry as portrayed de facto in school chemistry.

If we take the criticisms of IF respondents to substatements 9a1 and 9a2 together, we must conclude that the content of current school chemistry is largely presented in textbooks, and taught and learned in classrooms, as consisting of established and definitive facts with little regard either to their generation or testing. Dominant school chemistry appears to entail a positivist philosophy and methodology of science (Duschl, 1993, p. 446) which we will call from now on *educational positivism*. The influence of educational positivism [Phil] explains to a large extent why the content of school chemistry has been *persistently* presented, taught, and learned as *propositions and algorithms* (see analysis Statement 1), or using Schwab’s terms, as a *rhetoric of conclusions* (Schwab, 1962).[8]

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[8] Schwab (1962, p. 24), in a section called “The Teaching of Science as Dogma”, argues that science has for a long time been taught as a “*rhetoric of conclusions* (...), a structure of discourse which persuades men to accept the tentative as certain, the doubtful as the undoubted, by making no mention of reasons or evidence for what it asserts, as if to say, “*This*, everyone of importance knows to be true.” “(italics Schwab). As we show in this paper, the teaching of school chemistry has, alas, not changed much from this picture. See also Duschl (1993, p. 450), who characterizes this curriculum phenomenon “final form science”.

Figure 2.4 Philosophical Structure of Dominant School Chemistry and Normal Science Education

Code[a]	**Dominant School Chemistry** (based on International Forum responses)	**Normal Science Education** (based on Kuhn's work)
FS	- scientism (pure, certain, neutral) - positivism - reductionism - predictability and control	- pure or basic science - outcomes/accepted knowledge - development-by-accumulation - solvable normal science problems
MS	- no uncertainty of conclusions: interpretation always correct, reified account, models as facts - positivism of physics	- paradigmatic puzzle-solving: obtain/articulate/concretize the known - not to uncover/explore the unknown, either by discovery or confirmation
FC	- primacy of chemical theories/concepts - emphasis on physical chemistry and physics - corpuscular orientation: atoms/molecules/atomic structure as basis for stoichiometry, formulae, and equations	- foundations implicit in latest paradigm - chemistry as one of the physical sciences
MC	- systematization of substances and reactions - description of patterns of properties of substances and reactions (periodic table)	- criteria implicit in latest paradigm - methodology of the physical sciences

[a] See Figure 2.2

Substatement 9b

The IF contention that dominant school chemistry combines a specific substantive structure, based on *corpuscular theory*, with a *specific* pedagogical structure raises the question regarding the properties of that pedagogical structure. A number of respondents, especially those disagreeing with *Statement 9b,* mention *specific* components of the pedagogical structure of school chemistry. Two characteristics have already been addressed in the discussion of Statement 1: (i) teaching and learning science as propositions and algorithms, and (ii) initiation and preparation of future chemists. The IF responses following elaborate on and add to these characteristics (Figure 2.5). With regard to the first characteristic, there is a tendency in school chemistry to encourage *rote learning* by presenting 'well established standard items of dogma mainly because this can be conveniently reproduced within the confines and limitations of school' (R4). And, there is also a tendency to teach models as facts since 'it is *not uncommon* to find that students have learned to regard a *conceptual model* such as the ionic bond *as an established fact*' (R4). As for the training of future chemists, some respondents (4) point to the crucial role of teachers in the initiatory and preparatory training of future chemists, that is, 'the desire of chemistry teachers to *role play* what *professional* chemists do' (R5).

Figure 2.5 Pedagogical Structure of Dominant School Chemistry and Normal Science Education

Code[a]	**Dominant School Chemistry** (based on International Forum responses)	**Normal Science Education** (based on Kuhn's work)
A	- initiation and preparation for university chemistry/future chemist - learn systematization of chemical information: learn explanation/ prediction of properties, formulae, valence, and bonding by applying simplified corpuscular rules	- pre-professional curriculum; dogmatic initiation into pre-established problem-solving tradition - increasing understanding of known and/or similar puzzles in terms of latest scientific paradigm/language
TA	- established standard items of dogma: theoretical propositions and algorithms are conveniently reproduced within the limitations of school - role play what professional chemists do	- textbook and exemplar conducted: students solve puzzles, paper/ pencil or laboratory, closely modeled in method and substance on a given exemplar or text
LA	- rote learning of propositions and algorithms (distinctions, facts, definitions, theories, techniques)	- providing students, in the most economical and easily assimilable form, the outcomes of research

[a] See Figure 2.2

IF respondents seem divided in their views on the persistence, or as we call it, the *rigidity* of the current combination of the substantive, philosophical, and pedagogical structures of school chemistry. For example, has the *substantive* structure of school chemistry been largely *retained*, as one group of respondents (10) say, or has it been modified as a result of its combination with the new pedagogical and philosophical structures introduced in the 60s and 70s? Another, second group IF respondents (11) seem to be more optimistic on this point , that is, they feel that different forms of *pedagogical* structure are, or at least *should be*, compatible with approximately the same conceptual structure.

The changes in the curriculum structure of school chemistry that IF respondents perceive extend on the one hand from 'a major paradigm shift', as instigated by the 'applications first approach: relevance and student motivation to learn is now the guiding force' (R4); and on the other hand to the 'ideologically controlled' (R5) curriculum entailing a traditional didactic or transmissive pedagogy. Between these extremes respondents point to various variables such as (i) ordering and organization (linear vs. spiral) of content; (ii) curriculum emphasis on e.g. experimental work, theory, or problem solving; (iii) a new teaching approach, e.g. the context-led approach of Salters' Chemistry or ChemCom; and (iv) a new learning approach such as constructivism.

Thus, the second group of IF respondents perceive a greater variation in pedagogical structure, compatible with largely the same substantive structure, at least greater than the variation in philosophical structure which, as we have seen above, reduces de facto to educational positivism. The first group thinks, however, that at least for the variations in pedagogical structure tried in the past, it can be said that they reduce as a rule de facto to the *initiatory and preparatory training* of future chemists. Relevant research reviewed by Fensham (1992), Duschl (1993), and Matthews (1998) amply confirms the latter claim.

Therefore, we conclude that, contrary to what we have claimed in substatement 9b, the substantive structure of school chemistry does imply, as a rule, a specific pedagogical structure.[9] The IF response to substatements 9a1, 9a2, and 9b taken together leads to the following revision of the central claim of Statement 9:

CENTRAL CLAIM STATEMENT 9	All school chemistry curricula have a conceptual structure which does not imply a specific philosophical or a specific pedagogical structure.
REVISED STATEMENT 9	All *current* school chemistry curricula have a dominant substantive structure, based on *corpuscular theory*, which is *rigidly* combined with a specific philosophical structure, *educational positivism*, and a specific pedagogical structure, *initiatory and preparatory training* of future chemists.

2.2.3 Discussion

We did not foresee, nor did we intend, that there would be so many IF responses which strongly refuted our hypothesis. Apparently our IF probe, a summary of our hypothesis on *coherent* school chemistry, triggered respondents to be candid in expressing their views on the *currently dominant* school chemistry curriculum. We had expected criticisms on the *degree* of explicitness and coherency of our hypothetical curriculum structure of school chemistry. What we found, though, was an explicit *refutation* of the *central* claims of coherent school chemistry, which led to a specification of the substantive, philosophical, and pedagogical structures of *dominant* school chemistry (Figure 2.3, 2.4 and 2.5).

Further, probing the IF revealed that the *coherent* school chemistry curriculum does not refer to the *realized*, taught and learned, school chemistry curriculum but rather it must be taken as our *interpretation* of the *intended and formal* school chemistry curriculum. In other words, coherent school chemistry is to be regarded as an *idealization* of school chemistry *constructed* on the basis of a content analysis of a number of representative textbooks and syllabi *in the light of* our views on chemistry, science, and pedagogy, and their coherency. The resulting description of the structure of dominant school chemistry receives empirical support in the majority of IF responses, which in turn are likely to be informed by relevant research on the school chemistry curriculum, including research performed by the IF respondents themselves.

The *choice* for a *corpuscular* substantive structure in dominant school chemistry entails a preference for a particular kind of chemical content and for the scope and order in which this content must be taught. This substantive structure is, as a rule, combined with a specific philosophical structure, called educational positivism, and a specific pedagogical structure involving initiatory and preparatory training of future chemists.

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[9] In forming this conclusion, I have used the principle mentioned by Schwab in note 4, as I did at other places in section 2.2 in the process of revising the original central claims of statements 1, 2, 3, 8 and 9.

Thus, we arrive at an important characteristic of the currently *dominant* school chemistry curriculum, namely, that there exists a *rigid* relationship among specific substantive, philosophical, and pedagogical structures.

Finally, many respondents strongly disagree, *de jure*, with the actual situation of school chemistry, as described above. Although dominant school chemistry *is* the case, it *should* not be so. That is why several respondents endorse existing alternative process-oriented or society-oriented curricula, and why some other respondents welcome our proposal for a more coherent school chemistry.

2.3 Normal Science Education

In this section we will first discuss Kuhn's views on scientific training (2.3.1), which I have dubbed Normal Science Education. In subsection 2.3.2, I will show that the currently dominant school chemistry curriculum must be seen as a form of Normal Science Education, which is followed by a brief discussion (2.3.3).

2.3.1 Kuhn's views on scientific training

Kuhn underpinned his famous theory of the dynamics of *normal science* with a less well-known theory on the structure and function of tertiary and secondary science education (Siegel 1990). Reading Kuhn (1963, 1970a/b/c, 1977a/b) from the perspective of a researcher in science education, one obtains a specific view of science education which we have called, in Kuhn's vein, *normal science education* (NSE). Subsequently, we interpret *dominant* school chemistry as a form of NSE, since the former has almost all characteristics in common with the latter.

In a symposium on 'The Structure of Scientific Change', Kuhn presented a paper with the provocative title, 'The Function of Dogma in Scientific Research', which also contains a clear statement of his views on 'scientific pedagogy' (Kuhn, 1963, pp. 350, 351):

> The single most striking feature of scientific education is that, to an extent quite unknown in other creative fields, it is conducted through *textbooks* [TA], works written especially for students. Even books that compete for adoption in a single course *differ mainly in level and in pedagogic detail* [Ped], *not in substance or conceptual structure* [Sub].
>
> ...apparently scientists agree, about what it is that every student of the field *must* know. That is why, in the design of a *pre-professional curriculum*, they can use textbooks instead of eclectic samples of research (italics Kuhn, 1963, p. 351).

Kuhn is best known for his analysis of the structure and role of *paradigms* as (i) disciplinary matrices and (ii) *exemplars*. In his later work Kuhn (1970a, pp. 182, 187) gives the greatest emphasis to paradigms as exemplars, which he describes as standard examples shared by a community of (future) scientists, on which other (end-of-chapter) problems are modeled. Through a textbook's exemplars the student is initiated into the disciplinary matrix: current theory, methods, and criteria of a normal science. Kuhn's analysis of the structure of science textbooks, especially of the *techniques of textbook presentation* [Ped/TA], leads him to the following conclusions:

> Except in the occasional introductions that students seldom read, science texts make little attempt to describe the *sorts* of problems that the professional may be asked to solve or to discuss the *variety* of techniques that experience has made available for their solution. Instead, these books exhibit, from the very start, concrete problem-solutions that the profession has come to accept as paradigms [as exemplars], and they then ask the student either with a pencil and paper or in the laboratory, to solve for himself problems very closely modeled in method and substance upon those through which the text has led him (italics Kuhn, 1963, p. 351).

The pedagogic function of the textbook presentation is to accomplish:

> ... a relatively *dogmatic initiation* into a *pre-established* problem-solving tradition that the student is neither invited nor equipped to evaluate (ibid p. 351).

It is equally revealing to see what, according to Kuhn, is *not* included, in science textbooks:

> The objective of a textbook is to provide the reader, in the most economical and easily assimilable form [Ped/TA], with a statement of what the contemporary community believes it knows and of the principal uses to which that knowledge is put [Sub]. Information about *how that knowledge was acquired (discovery)* and about *why it was accepted by the profession (confirmation)* would at best be *excess baggage* [Phil]. Though including that information would almost certainly increase the 'humanistic' values of the text and might conceivably breed more flexible and creative scientists, it would inevitably detract from the ease of learning the contemporary scientific language. To date only the last objective [Ped] has been taken seriously by most writers of textbooks in the natural sciences (Kuhn, 1977b, p. 186).

Kuhn emphasizes in various places that the 'misdirection supplied by science texts is both systematic and *functional*' (1977b, p. 187). The dogmatic *initiation* into a normal science tradition by creating among students a misleading picture of the nature of science, a *textbook image of science* as Kuhn calls it, enhances 'the research *efficiency* of physical scientists' (p. 187). The systematic textbook presentation described by Kuhn will therefore *initiate and prepare* students for the handling of normal science problems, that is, for the activity of *puzzle-solving* as set within the current paradigm or disciplinary matrix, which is all that future normal scientists need in order to *function* successfully.[10]

Thus, Kuhn's view on science education, *normal science education*, stands for a specific view on science [Phil], i.e. normal science, in combination with a specific view on education [Ped], i.e. the teaching of normal science through textbooks-cum-exemplars to future scientists while using the current paradigm as a substantive structure.

2.3.2 Dominant School Chemistry as a form of Normal Science education

The characterization of the currently dominant school chemistry curriculum in terms of a *rigid* relationship among specific substantive, philosophical, and pedagogical structures (section 2), has led us to interpret the structure of *dominant* school chemistry curricula as a form of normal science education, that is, as *normal chemistry education* (NCE).

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[10] See Kuhn (1970b, p. 237) for the logic of the functional argument which he uses to explain 'how and why science works', that is, why *normal* science and *normal* science education work. See also section 6.1.2.

Conversely, Kuhn's theory of the nature and function of science teaching, although referring predominantly to tertiary education, has been confirmed for the secondary level by the IF response, in particular for school chemistry.[11] A comparison of our findings in terms of the substantive, philosophical, and pedagogical structures of dominant school chemistry and normal science education reveals a number of interesting commonalities (Figures 2.3, 2.4, 2.5).

Concerning the substantive structure, Kuhn (1970a, p. 140) remarks that scientific knowledge is presented in textbooks as an *accumulation* of 'experiments, concepts, laws, and theories of the *current* normal science (...) as *separately* and as nearly *seriatim* as possible'. In other words, the structure of a science, as portrayed in a textbook, resembles 'the addition of bricks to a building' (p. 140). Furthermore, textbooks tend to make scientific revolutions *invisible*, transforming them into a development-by-accumulation pattern which disguises any changes in the development of paradigm components, such as theories, concepts, methods, techniques, criteria, and aims. As we have seen above, some IF respondents also comment upon the anti-historical character of the substantive structure of school chemistry, but (*pace* Kuhn) without endorsing the latter.

Other conspicuous similarities are to be found in the philosophical and pedagogical structure of school chemistry. With regard to the philosophy of science, *within* a paradigm of normal science *and* in the textbook based on it, positivism still appears to reign uncontested, despite the successful critiques of Popper and of Kuhn himself.[12] As shown above, the positivistic philosophy and methodology of science is still present in school chemistry. Following Kuhn's functional argument (1970b, p. 237), we have called this phenomenon *educational positivism*.

With respect to the pedagogical structure, there are strong similarities between a 'pre-professional curriculum' (Kuhn) and the initiation and preparation for university (IF), and between 'easily assimilable *outcomes* of research' (Kuhn) and rote learning of propositions and algorithms (IF). Finally, conveniently reproduced standard items of dogma (IF) are perfectly amenable to puzzle-solving (Kuhn).

2.3.3 Discussion

Thus, dominant school chemistry shares many of its characteristics with *normal science education*. The existence of *normal chemistry education* as a training for normal chemists helps to answer two questions mentioned in section 2.1.1. The first of these is, why do school chemistry textbooks from different countries look so remarkably similar? This is because the substantive structure of most textbooks follows the latest paradigm. The second question, regarding the resistance of the dominant school chemistry curriculum to reforms, we can now reformulate in terms of why it is so hard to *escape* from the

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[11] Barnes (1982, p. 6) feels that Kuhn's theory of scientific training is 'the most weakly substantiated part' of his work. However, the empirical research reported in this paper substantiates Kuhn's theory for chemical education at the secondary level.

[12] Kuhn, both in his philosophical work on the dynamics of science and in his articles and books on the history of science, is at great pains to convey "a quite different concept of science" (1970a, p. 1) that goes beyond the standard positivistic philosophy of science.

rigidity of dominant school chemistry. Such an escape would involve the analysis, criticism, and *coordinated replacement* of a rigid combination of (i) a specific substantive structure, i.e. the current corpuscular paradigm; (ii) a specific philosophical structure, i.e. normal science and educational positivism; and (iii) a specific pedagogical structure involving the teaching of normal science through textbooks-cum-exemplars to future chemists.

As the history of reforms in science education shows, modifying only one of these structures in response to a set aim, for example, updating the substantive structure without a *coherent* coordination in the philosophical and pedagogical structures, will not do (DeBoer, 1991; Fensham, 1992). Furthermore, the existence of NCE can explain the resistance of school chemistry to reforms (e.g. its *rigidity*), since the pedagogical structure of NCE determines to a great extent the substantive structure and thereby also implicitly the philosophical structure of school chemistry. In brief, aim determines content and form.

Finally, the existence of NCE answers another question brought forward by our analysis, namely, why school chemistry textbooks contain such a misleading picture of the history and philosophy of chemistry. This is because it is thought educationally functional for training future chemists to provide them with such a (misleading) picture.

2.4 Normal Chemistry Education and its dangers

In the last section we concluded that school chemistry is a form of normal chemistry education. In this section we deal with the question of whether this *should be* the case. Let us return for a moment to Kuhn's views on science and science education.

According to Kuhn (1977a, p. 233), the characteristic problems a scientist is *ordinarily* confronted with in *pure* or basic science are 'almost always repetitions, with minor modifications, of problems that have been undertaken and partially resolved before'. Kuhn (1970a, p. 5) elaborates on the task of the *normal* scientist, saying that:

> ...when engaged with a *normal* research problem ... his object is to solve a *puzzle*, preferably one at which others have failed, and *current theory* is required to *define* that puzzle and to guarantee that, given sufficient brilliance, it can be solved.

In his 'Normal Science and its Dangers', Popper (1970, p. 52) admits that what Kuhn describes does exist, but he adds, 'it is a phenomenon which I dislike'.

> The normal scientist, in my view, has been taught badly. I believe, and so do many others, that all teaching on the University level (and *if possible below*) should be training and encouragement in *critical thinking*. The 'normal' scientist as described by Kuhn has been badly taught. He has been taught in a *dogmatic* spirit: he is a victim of indoctrination. *He has learned a technique which can be applied without asking for the reason why*, ... he is, as Kuhn puts it, content to solve 'puzzles' (Popper 1970, p. 53).

Hence, Popper feels that 'normal' science teaching results in an uncritical or dogmatic attitude which is 'a *danger* to science and, indeed, to our civilization' (ibid. p. 53). Thus, for Kuhn, 'it is precisely the abandonment of critical discourse' (1970a, p. 6) which characterizes mature, productive science, whereas for Popper it is critical thinking which is essential for the growth of scientific knowledge. As we will see, the marked differences between Kuhn's and Popper's philosophies of *science* entail equally different views on *science education*.[13]

2.4.1 Sevenfold isolation of Dominant School Chemistry

In this subsection the boldfaced characters (**a-g**) put in parentheses will denote, firstly, fields from which physical science is *insulated*, according to Kuhn, and, secondly, fields from which school chemistry is *isolated*, according to IF respondents.

An important factor besides puzzle solving which, according to Kuhn (1970a, p. 164), *explains* the special efficiency of normal science and its training is:

> ...the unparalleled *insulation* of mature scientific communities from the demands of the [a] *laity* and of [b] *everyday life*. (...) Even more important, the insulation of the scientific community from [b] *society* permits the individual scientist to concentrate his attention upon problems that he has good reason to believe he will be able to solve.

Although Kuhn's work does not address this point explicitly, the 'educational initiation' (Kuhn, 1970a, p. 165) into normal science implies that students give up or replace their pre-scientific conceptions with the scientific concepts accepted in normal science. In other words, students must supersede (**a**) their common sense views (Cromer, 1993). Because normal science is focused on *pure* science, the scientific community and its future practitioners are insulated not only from (**b**) everyday life and society, but also from (**c**) technology, with respect to both applied research and invention (Kuhn, 1977a, p. 238). Furthermore, as Hoyningen-Huene (1993, p. 186) states in a comprehensive study on Kuhn's philosophy of science:

> ... the *dominance* of textbooks in *training* for normal science leads, first of all, to the almost complete *insulation* of *students* from the *primary* literature, from those publications in which scientists originally communicate, or communicated their results.

This implies that during the training for normal science students are also insulated from (**d**) the research *front* as well as from (**e**) the history or foundation of a discipline. Kuhn has emphasized the latter by arguing that textbooks give, and for good functional reasons *should* give, a distorted picture of the history of a discipline. Hence 'the textbook-derived tradition in which scientists come to sense their participation is one that, in fact, *never* existed' (Kuhn, 1970a, p.138). Textbooks are rewritten after a scientific revolution. Further, normal science education is insulated from (**f**) the philosophy of science, that is, from the context of discovery *and* the context of confirmation (Kuhn 1977b). Finally, having an established paradigm insulates chemistry, per definition, from (**g**) other physical sciences, such as physics, which have their own specific paradigms.

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[13] Independent of Kuhn and Popper, Schwab (1962, 1964a/b, 1978) developed his views on the dynamics of science and science education in terms of *principles of stable and fluid enquiry*. It is remarkable that he did this in the context of the study, research, and development of science (biology) curricula. Schwab's pair of concepts: stable enquiry / fluid enquiry strongly resembles Kuhn's concepts of normal science and revolutionary science (Duschl, 1993). Schwab and Popper, one could say, both regret the dominance of stable enquiry or normal science, especially the dogmatic science education based on it. Schwab, again as Popper, wanted to *teach science as enquiry*, especially as fluid enquiry (see also Siegel, 1990, p. 101).

In Kuhn's view, the practice of normal science is insulated from these seven dimensions *in order* to concentrate the attention and energy of students, the future practitioners of normal science, upon problems which the scientific community has good reasons to believe are solvable, that is, on *puzzles* of a *specific* domain defined by a particular paradigm. The question we now want to address is whether IF respondents report on the *isolation* of dominant school chemistry along the same dimensions, and how they feel about this.

(a) Common sense.

An important problem mentioned by respondents (5) in this context is the resistance of students' common sense ideas to the conceptual change that NCE tries to induce: 'many continue to reason in macroscopic terms about events, even after being taught corpuscular theory' (R13). In turn, such resistance leads to naive realism, to the unintended pedagogical result that 'students ascribe properties of substances to particles: they melt, they grow etc.' (R24). School chemistry's reputation of being inaccessible and incomprehensible may have much to do with a covert transition from common sense beliefs to textbook science. Recent research on preconceptions has unearthed many other examples of difficulties which students have in relating textbook-based scientific knowledge to their own common sense knowledge. Thus, while a normal scientist can assume that his colleagues and advanced students 'share his own values and beliefs' (Kuhn, 1970a, p. 164), the teacher in the classroom cannot do so with regard to his or her pupils. As R19 remarks, 'The language I normally used in a chemistry class often did not have the same *meaning* for many of my students.'

(b) Everyday life and society

Several respondents (14) point to the lack of societal relevance of current school chemistry, e.g. R18 notes that in school chemistry there is a 'lack of everyday life experience', but most respondents 'see significant changes in chemistry curricula' (R20). For example R15, referring to the Salters' Chemistry course, remarks that 'there has been a marked trend in the last six years to the inclusion of scientific knowledge on the basis of its relevance to society'.[14]

(c) Technology

These respondents also point to the lack of craft- and science-based, technology. For example, R26 remarks that 'there is a lot of *pragmatic* knowledge in chemistry that does not appear in books (...) our science textbooks forget the [local] chemistry tradition'. R4 mentions a number of dimensions including technology: 'School chemistry often fails to show how the reaction concept is also of fundamental importance to related sciences, *technology*, and society.'

(d) Research front

Some respondents (5) comment on the fact that school chemistry fails to give an account of recent developments in chemical research. For example R4 says, 'Biochemistry despite its *relevance* and the fact that it has been the most fruitful area of research in

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[14] In the second part of the research project we investigated to what extent an innovative course in school chemistry, Salters' GCSE Chemistry Course (1987), managed to *escape* from NCE. See Chapters 4 and 5.

recent years is sadly neglected in school chemistry.' And R26 notes that in school chemistry books 'the emphasis is ... never on the non-existing compounds'. As we saw above, a number of respondents (9)
stated explicitly that current school chemistry does not prepare students for science *as enquiry*.

(e) History of science

Several respondents (8) comments concern this dimension. Thus, R18 thinks, 'It is important that students after having finished secondary school know something about the history of *chemistry* as part of history of human culture, e.g. the major periods of chemistry, the main reasons of chemistry development steps, the famous scientists, and useful inventions.' On the other hand, as R26 remarks, 'I do not know – like Aarons or Hecht in physics – a secondary textbook that shows chemistry like a historical process.' Historic experiments in school chemistry are, as R11 says 'all successful ... interpretation is always correct'.

(f) Philosophy of science

Several respondents (7) comment along this dimension. The last quotations also touch upon the way the nature of science or chemistry is, or is not, dealt with in school chemistry books. Here is a clear statement to this effect from R4, reminiscent of Schwab's view on science education:

> We often fail to teach through school chemistry *the nature of our scientific enterprise* (...) We need to show in school chemistry the relationship between scientific method, important for hypotheses *generation and testing* theories, and theoretical propositions aimed at providing a cohesive explanatory framework for observations.

And, R6 makes an important methodological point: 'Students (...) must be made aware of the fact that the currently accepted theory with which they are being *indoctrinated* is merely the successor of the previously accepted theory and also the predecessor of the next theory which will be adopted at some future date.'

(g) Related sciences: physics and biology

Some respondents (4) argue explicitly against the demarcation of school chemistry from school physics (see also Figure 2.3). For example, R19 makes the point: ' "Chemistry", "physics", and "biology" are concepts which have been historically subjected to an *artificial separation*. There is no point at which one can say that chemistry stops here and physics begins there.' Several other respondents (8) discuss, in connection with Statements 2 and 6, the difficulties in teaching and learning the distinction between chemical and physical changes.

Finally, some respondents (3) point more specifically to the irrelevance of current school chemistry to *ecological* problems. One respondent (R10) does not believe in the idea that school chemistry could 'gradually change', and favors therefore 'the abolition of school chemistry and reconstruction of a topic like perhaps *material environments and their changes*'. Eight respondents do not make any remarks along the dimensions mentioned above.

Conclusion and discussion

It thus appears, that most of the IF response on the isolation of school chemistry (De Vos et al., 1993; Van Berkel, 1996) and Kuhn's remarks on the insulation of normal science can be characterized by the same dimensions. In sum, normal chemistry education is isolated from common sense, everyday life and society, history of chemistry, philosophy of chemistry/science, school physics, and chemical technology, and from chemical research. The discipline of chemistry as a normal science, especially its 'unparalleled insulation', accounts for the isolation of school chemistry along the same dimensions. After all, the latter is regarded as an initiation and preparation for the former.

Thus, here the existence of NCE explains a second important general feature of dominant school chemistry: its isolation or its current inaccessibility to reforms. Whereas the first general feature, its *rigidity* or its resistance to reforms, characterizes the *internal* structure of dominant school chemistry, the second general feature, its *isolation*, characterizes the (lack of) external relations of dominant school chemistry (see also Figure 2.3).

But does the exclusion of these dimensions from scientific training – which according to Kuhn enhances the research efficiency of normal scientists – also enhance the puzzle-solving skills of (secondary) students aspiring to be scientists, i.e. chemists? In brief, is NCE effective? As we showed for the secondary level (section 2.2), NCE fails to realize its own set goals of initiating and preparing future chemistry students by teaching them the processes of understanding, explanation, and prediction of chemical phenomena (Figures 2.4, 2.5). The opinion of R11 reflects in a candid way the views expressed by a number of respondents (9):

> Not only does the theoretical approach make chemistry more difficult to understand, it also transforms it into a plugging of numbers into inaccurate formula for students to get answers to questions while *understanding neither the question nor the answer*.

The seven-fold isolation of dominant school chemistry has not been efficient in promoting its set goals. Instead, its isolation has led to the teaching and learning of *propositional knowledge and algorithms,* to which the 'unparalleled insulation' of normal chemistry has contributed.

2.4.2 General dangers of Normal Science Education

The latter conclusion with regard to normal chemistry education at the secondary level resembles a *parody* of what normal science education should be. To use Kuhn's terms, neither the puzzle set, nor the solution defined by the paradigm are understood by students. Instead, scientific results are simply reproduced as propositional knowledge and algorithms or as *a rhetoric of conclusions*.[15] Also contributing to this state of affairs is the pressure of the current poor forms of testing students' knowledge and skills, which seem to select the most routinized forms of puzzle solving (De Vos, et al., 1993).

It should be noted that just before the curriculum wave in the 1960s, Kuhn deplored such a 'parody of what scientific education should be' (1963, p. 390) as it pertained to, for example, the secondary level of science education in American high schools and colleges. As we have argued in this article, in the 1990s a similar parody of NSE still exists as NCE and is equally deplored by IF respondents, and many other researchers in science education (Fensham, 1992; Duschl, 1993; Aikenhead, 1997; Matthews, 1998). However, Kuhn insists in his reply to comments of B. Glass, one of the NSF curriculum reformers 'that it is a parody, i.e., that it is not irrelevant' (ibid., p. 390). The discussion between Glass and Kuhn shows clearly that Kuhn thinks his theory of scientific training *also* applies to secondary education. But Kuhn had one reservation about the discovery and process oriented reforms of the 1960s, though he welcomed them as a whole:

> In particular, I wonder to what extent the facts (whether 'authoritative' or not) can be dispensed with in favour of 'methods of investigation' (emphasis Kuhn). I suspect that students will learn *both together* as samples of *accepted* achievement, which is only to say that I suspect they will learn *paradigms* (Kuhn, 1963, p. 391).

Kuhn appears to be saying that, although there is an urgent need to improve bad forms of NSE, such as the parodies mentioned above, any reform should be in the direction of NSE. Furthermore, Kuhn points here to an important characteristic of NSE not discussed so far, namely, its *domain specific* nature which entails that methods cannot be taught separately from facts. On the contrary, science methods, and/or processes and facts, and/or conceptual content should be taught and learned together while using exemplary problem-solutions solvable within the context of the current paradigm.[16]

The same authors on whose work we have drawn for our Kuhnian interpretation of school chemistry (Popper, 1970; Barnes, 1982; Ziman, 1980; Hodson, 1988; Siegel, 1990; Duschl, 1993; Matthews, 1994) have also pointed to *general* dangers associated with NSE. In particular, they take issue with Kuhn's view on the initiation into normal science as a 'narrow and rigid education' (1977a) which requires or instills a *dogmatic* attitude. The gains of this initiation, that is, efficient puzzle-solving, befall mostly to the scientific *group*, says Kuhn, while the 'loss due to rigidity accrues *only to the individual*'

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[15] Schwab (1962 pp. 24, 39) describes this state of affairs as follows: 'Our teaching laboratories invite students to discover the satisfaction of *techniques* mastered. (...) Our classrooms are imbued with the same dye of established law and *accepted* knowledge. This is obvious in the premium put on "learning the lesson". It is most poignantly seen in the well-nigh universal reference to the phrase "problem solving". This is currently a popular phrase in the schools and is supposed to mark a new and higher conception of means and ends in education. But when the problems posed are examined and the "solving" inspected, "problem solving" turns out to be little more than *meticulous application of given procedures to situations which follow strictly the model problem on which the procedures were learned*.' It is noteworthy that Schwab anticipates Kuhn's idea of puzzle-solving, while observing that the practice of school science is reduced to the most routinized form of it, that is, to 'problem solving'.

[16] Schwab (1962, p. 102) equally deplored the tendency 'to divorce "content" and "method" ' and warned against the danger of treating thereby '*both* of them as orthodoxies by a rhetoric of conclusions'. Schwab, of course, wanted to teach science as enquiry, especially as fluid enquiry, which involved 'a treatment of scientific knowledge in terms of its origins in the *united* activities of the human mind and hand which produce it'.

(ibid., p. 166). But, as these critics of Kuhn say, in order to further the growth, not only of scientific knowledge but also of personhood and democracy, a *critical* attitude is called for. The following arguments have been brought forward to support this claim.

(i) The twentieth century has seen increasingly more 'fluid enquiry' (Schwab, 1962), both in terms of the extent and 'the duration of a revisionary cycle of stable enquiry' (p. 18) or, in Kuhn's terms, of normal science. In an age where 'the modal rate of revision is probably of the order of fifteen years' (p. 20), tertiary science education should largely aim for the training of more fluid enquirers, while secondary science education should be concerned mostly with teaching *about* fluid enquiry (p. 38).

(ii) Up to the 1940s, fluid enquiry or critical science (Popper, 1994, p. 76), or in Kuhn's terms, revolutionary science, has been much more important for the growth of scientific knowledge than stable enquiry or normal science. Popper (*pace* Schwab) sees increasingly more specialization and 'scientific "*routine*" ' (p. 76) since then, but in his opinion this calls all the more for the encouragement of a critical attitude; otherwise 'it will be the end of science as we know it – of great science' (p. 72).

(iii) Whereas in normal science (education) 'the loss due to rigidity accrues *only* to the individual', for the sake of the presumed effectiveness of the *collective* practice of normal science, in critical science (education) the critical abilities learned accrue to the *individual*, that is, not only for the sake of critical science, but also for the sake of personhood and democracy.

Furthermore, these scholars argue that critical abilities acquired in critical science education contribute to other important educational goals regarding future citizens and/or the public need, for example, the growth or development of democracy (Popper, 1950, 1970; Schwab, 1962); the growth or development of personhood (Koertge, 1996); autonomy, open-mindedness, pluralism, and respect for evidence (Siegel, 1990); the growth or development of culture, both the scientific and the humanistic culture (Snow, 1959; Ziman 1980; Matthews, 1994); and the maintenance and the sustainable development of the natural environment.

On the other hand, the rigidity or dogmatism inherent in normal science education seriously impedes the realization of these goals because such rigidity entails both a distortion of the history of science and a grossly misleading picture of the nature of science (Medawar, 1963; Popper, 1983, p. 50), thereby encouraging blind commitment and dogmatism in the name of professional training.

(iv) A more fluid or critical science education would motivate students by involving them actively in processes of enquiry, such as reasoning, observing, and experimenting (Verdonk, 1995). As such it would also be in line with humanistic values like autonomy and open-mindedness.

(v) Finally, many researchers in science education (Ziman 1980; Garforth 1983; Fensham 1992) point to the fact that only a minority of students continue to study chemistry and of them only a few actually become professional chemists. Nobel laureate chemist Roald Hoffmann (1995, p. 228) concurs and suggests that chemistry courses 'must be aimed primarily at the nonscience student, at the informed citizen, not toward the professional'.

2.4.3 Discussion

These arguments (i – v) lead us to the view that a critical science education is both desirable and urgently needed. The next question is whether it is feasible and effective. It is Kuhn's contention that only normal science can be the basis for an effective scientific training (NSE), and he seriously questions the possibility of a training for revolutionary or critical science. Schwab and Popper, as we have seen, disagree, as do many researchers in science education.

Ultimately this is an *empirical* matter: whether we can *escape* from NSE can only be settled by empirical research in science education. Classroom-based research, for example that performed by our group in the last decade (Van Driel, 1990, Van Hoeve-Brouwer, 1996; Acampo, 1997; Van Aalsvoort, 2000) shows that modest forms of critical chemistry education are feasible as well as effective on a *small scale* under specific, researched conditions. Also there have been some successful large scale attempts to realize forms of critical science education, e.g. Harvard Project Physics and the Biological Sciences Curriculum Study, the latter led by B. Glass and J.J. Schwab in the 1960s (Matthews, 1994, p. 6). But the question remains: why is it that critical science education, although it has been shown to be both feasible and effective at the secondary level, has not yet managed to replace normal science education except marginally and temporarily (Fensham, 1992; Duschl, 1993; Matthews, 1998). See on this topic futher Chapter 3.

We have tried to explain in this article why it is so difficult to escape from NCE, rigid and isolated as it is. Such an escape must entail the *coordinated replacement* of the currently rigid combination of specific substantive, philosophical, and pedagogical structures of school chemistry, not only at the level of the intended and formal curriculum, but also at the level of the realized curriculum. Furthermore, such an *internal* change in the structure of school chemistry can only succeed if school chemistry also overcomes its isolation, that is, if all those involved in school chemistry seek to enlist the seven dimensions it is now lacking. This will also involve a major change in pre-service and in-service teacher education aimed at increasing the competence of teachers to recognize, analyze, criticize, teach, and develop teaching materials emphasizing different combinations of substantive, philosophical, and pedagogical structures.[17]

2.5 Conclusion

The structure of the currently dominant school chemistry curriculum is accurately described as a *rigid* combination of a specific substantive structure, based on *corpuscular theory*, a specific philosophical structure, *educational positivism*, and a specific pedagogical structure, *initiatory and preparatory training* of future chemists. The

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[17] I would now formulate the claims I make in this paragraph less absolutely. As I did in Chapters 3 and 6 of this thesis, I would reformulate them in terms of three necessary conditions, without implying that these are sufficient conditions for the escape from Normal Chemistry Education.

structure of dominant school chemistry as a whole suffers from a sevenfold *isolation*: from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research.

These general features of dominant school chemistry, rigidity and isolation, are explained in terms of the concept of *normal chemistry education* (NCE). Escape from NCE is only possible through a *coordinated replacement* of the currently rigid combination of substantive, philosophical, and pedagogical structure of school chemistry.

NCE fails to realize its own set goals, that is, teaching and learning (for all pupils) the prediction and explanation of chemical phenomena; instead it teaches / learns a set of propositions and algorithms. Neither the effectiveness of NCE nor its superiority over more critical forms of secondary chemistry education has been conclusively demonstrated. It is not possible to justify, *by argument or experiment*, an NSE based chemistry course that is suitable for *all* pupils. Maybe this can be done with regard to the small minority of students who will study chemistry at a further level, some of whom might become chemists. NCE cannot be regarded as a form of chemistry education *appropriate* for *all* pupils, *exactly because* it consists of a dogmatic, domain-specific training for future chemists.

Therefore, at the secondary level, the *initiation* into normal chemistry should be largely *replaced* by an education *in or through* fluid, critical, or revolutionary chemistry (HPS-education, Matthews, 1994), together with an education *in or about* the relations between chemistry, technology, and society (STS-education, Solomon and Aikenhead, 1994).

3 Conditions to escape from and to escape to

In Chapter 2, I have arrived at a description of the rigid and isolated structure of the currently dominant school chemistry curriculum. Subsequently, I have explained the structure of, what I call Dominant School Chemistry in terms of the concept of *Normal Science Education*. Finally, I have argued that this state of affairs is undesirable, if and when a general aim such as ‘Chemistry for All’ is to be met.

In this chapter I begin by summarizing the argument so far by giving brief answers to research questions 1, 2 and 3 as they have been listed in Figure 3.1 (section 3.1). After this introductory section, I focus in this chapter on question 4: “What are the conditions for escape?” in order to arrive at a first description of the *necessary* conditions for escape.

A brief review of some attempts to reform the dominant school science curriculum, in terms of the concept of Normal Science Education provides an idea of the many difficulties involved when trying to realize a desirable reform, that is, to escape from Dominant School Science. An analysis of reasons for the difficulty to escape from Dominant School Chemistry, given its rigid and isolated character, leads then to the first condition for escape which has to do with the structure of the dominant school chemistry curriculum (section 3.2).

A discussion of the concept of *curriculum emphasis* developed by Roberts (1982), a concept which functions as a “view affording” lens on the nature of science curricula, leads us to two other conditions for escape. The second condition concerns the development of a vision on new science curricula, while the third has to do with the method one *chooses* to escape from Dominant School Science (section 3.3).

Finally, I discuss some problems with the implementation of new curriculum emphases, and the relationship between the concept of curriculum emphasis and the concept of Normal Science Education. I also discuss the three conditions of escape in connection with the concept of *developmental research*, which combines systematic research with strategies for development of innovative science curricula (section 3.4).

Chapter 3 sets the stage for the following two chapters, in which is given a detailed analysis of my evaluative research into the innovative attempt by the Salters’ Chemistry Project to escape form Dominant School Chemistry as it existed in England in the 1980s. In Chapters 4 and 5 the focus is on the Project’s vision, its method, and the resistance it met. In Chapter 6 I come back to the three conditions for escape and the concept of developmental research in light of my empirical findings on the development and realization of the Salters’ Chemistry curriculum.

3.1 To escape from Dominant School Chemistry

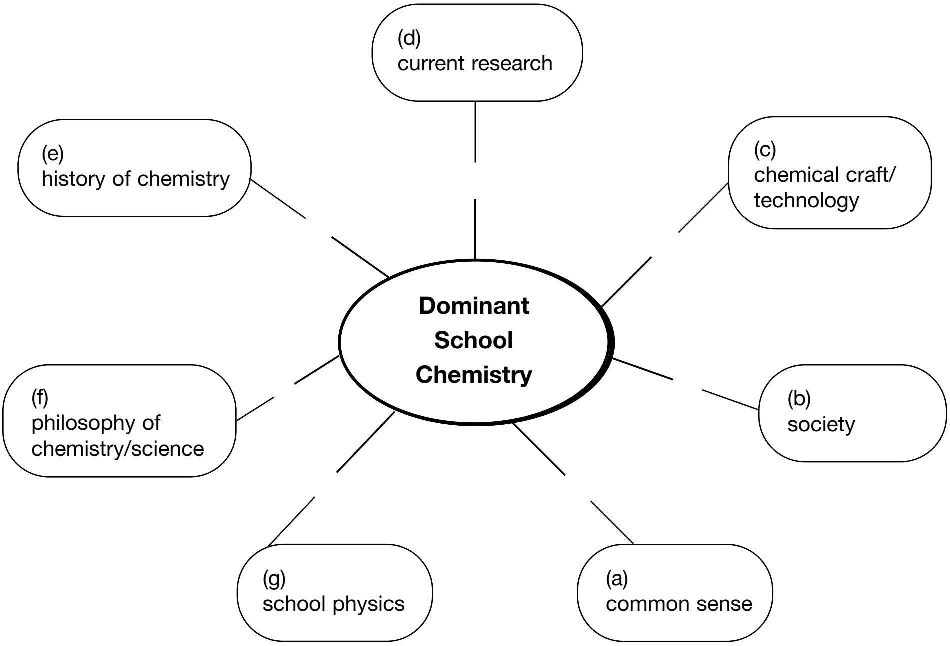
The research questions I am trying to answer in this thesis (first listed in Figure 1.6) are reproduced in Figure 3.1 below. The first three questions have been answered in Chapter 2, while the last three questions will be dealt with in Chapters 4, 5 and 6. The question which concerns us in this chapter is question 4: “What are the conditions for escape?”

Figure 3.1 Research questions

1. What is the structure of the current school chemistry curriculum?
2. Why is this structure the way it is?
3. Is this structure a desirable structure?
4. What are conditions for escape?
5. To what extent does the Salters' Chemistry curriculum escape from this structure?
6. Why is it so hard to escape from this structure?
7. How can attempts to escape from this structure be more successful?

Let me first give a short summary of the answers to the questions 1, 2 and 3, as discussed in Chapter 2. As argued in Chapter 2, the currently dominant school chemistry curriculum has to be taken as a rigid combination of a specific substantive structure based on corpuscular theory, a specific philosophical structure called educational positivism, and a specific pedagogical structure involving initiatory and preparatory training of future chemists. Whereas this first general feature, its *rigidity*, characterizes the *internal* structure of dominant school chemistry, the second general feature, its *isolation*, characterizes the external relations, or rather the lack of them, of dominant school chemistry with other domains or fields (Figure 3.2).

Figure 3.2 Sevenfold isolation of Dominant School Chemistry



The strong similarities between the substantive, philosophical, and pedagogical structures of Dominant School Chemistry (DSC) and Normal Science Education (NSE) lead to the conclusion that DSC must be considered as a form of NSE, in this case the form is Normal Chemistry Education. Dominant School Chemistry has a curriculum structure serving similar functions to those of Normal Science Education, namely to initiate and prepare pupils at the secondary level for scientific training. This means that Dominant School Chemistry has a pre-professional curriculum structure like that of Normal Chemistry Education as it is usually practiced at the tertiary or university level. Furthermore, the Normal Chemistry Education concept explains why Dominant School Chemistry is an inappropriate or undesirable curriculum orientation for the majority of students who do not aim to study chemistry at the tertiary level.

The essential features of Dominant School Chemistry, rigidity and isolation, imply a number of undesirable consequences affecting students and teachers of school chemistry alike. The prevailing curriculum emphasis of Dominant School Chemistry, that is, of chemistry as a body of knowledge consisting of propositions and algorithms, gives a rather one-sided view of the rich activities of chemists perform in scientific research, technology, and society. Teaching school chemistry this way instills a dogmatic attitude to science. Furthermore, it appears that this mode of teaching is ineffective with regard to understanding chemistry as a science for the majority of students, and probably also in part for the minority of students who go on to study chemistry at university.

Finally, given the global consensus on a general aim for school chemistry, epitomized in the slogan “Chemistry for All”, Dominant School Chemistry is surely inappropriate for the majority of students seen as future citizens, and maybe also inappropriate for the few who aim to be future students of chemistry. In brief, Dominant School Chemistry is ineffective as a means and largely undesirable as an end. This calls for the development – for the majority of students, if not for all, at the secondary level – of a new school chemistry curriculum which escapes from the currently dominant structure of the current school chemistry curriculum.

The first condition of escape

The revision of our initial hypothesis on the current structure of school chemistry, Coherent School Chemistry, leads to the formulation of a first condition of escape:

- Perform a domain-specific analysis of the structure of the currently dominant school chemistry curriculum, using the curriculum framework developed here.

In the process of developing a new school chemistry curriculum it is to be recommended to be aware of, anticipate, and avoid, or at least eventually deal with, any difficulties related to the currently dominant school chemistry curriculum and all curriculum levels involved. In other words, to take be necessary preventive or corrective measures in order to avoid marginal or superficial changes in the currently dominant school chemistry curriculum, changes such as the introduction of a new rhetoric of teaching or a new curriculum emphasis on top of Normal Science Education (NSE). In brief, while attempting a radical reform of school chemistry, we have to resist what I call the *NSE reflex*. In Chapters 4 and 5, while reviewing the attempt of the Salters’ Chemistry Project to escape from Dominant School Chemistry, we will see this NSE reflex in action.

Thus, from the main findings of Chapter 2, the rigidity and isolation of Dominant School Chemistry and their explanation in terms of Normal Science Education, can be inferred specific measures on what *not* to do. That is, do *not* import the structure of Dominant School Chemistry in new curriculum projects, and take all necessary measures to prevent and/or correct this if it begins to happen. Having detailed knowledge about what *to escape from* enables those involved in a developmental project to reform school chemistry where to expect difficulties or points of resistance, and to take specific measures to prevent or at least deal with these difficulties if and when they are met.

It is to be noted, that these measures, derived from the first condition for escape, apply to all curriculum levels involved and to all curriculum actors involved at these levels, from the members of the steering group to the team of developers and teachers, and the researchers. For example, it will have implications for the selection, training, and coaching of the teams of teachers and developers who design and trial the new curriculum.

In section 3.2 I will review some of the past attempts to escape from Dominant School Science, and also from Dominant School Chemistry, in order to discuss, firstly, whether developers' lack of success in doing so can be attributed to a failure in fulfilling condition one, and secondly, whether curriculum reforms which did fulfill condition one succeeded, and if not, which other conditions should have been met in order to do so. This will bring us to a discussion in section 3.3 of two other conditions for escape, conditions having to do with the development of a vision and a method to escape from Dominant School Science, more specifically from Dominant School Chemistry.

3.2 A brief review of attempts to escape

There have been many attempts to change, by optimizing or reforming, the practice of traditional school science (what I have called here Normal Science Education) since this tradition came to prevail at the end of the 19th century (Layton, 1973; De Boer, 1991; Just, 1989). For example, in Chapter 2, several IF members mentioned Salters' Chemistry and ChemCom as examples in the 1980s of alternative Science, Technology and Society (STS) oriented curricula, while others mentioned Nuffield Chemistry and ChemStudy as examples of alternative History and Philosophy of Science (HPS) oriented curricula in the 1970s. The latter courses were part of the so-called structure-of-the-disciplines approach to science education. This has been the most systematic attempt to reform school science so far, often described as a curriculum wave that began in the USA in the early 1960s following the launching of Sputnik.

3.2.1 Appraisal of the structure-of-the-disciplines approach

The structure-of-the-disciplines approach to science curricula set itself the task to realize, in a new and better way, teaching students the understanding of scientific phenomena by way of:

- modernizing and sequencing the content of school science curricula along the lines of the structure-of-the-disciplines;

- developing new teaching and learning approaches, mostly forms of discovery learning and enquiry teaching (Bruner, 1960; Schwab, 1962).

In different ways the projected science curricula – for chemistry ChemStudy and CBA, for physics PSSC and Harvard Project Physics, and for biology the BSCS curricula in the Blue, Yellow, and Green versions – were meant to replace the unintended and unwanted reproduction of facts with meaningful understanding of scientific knowledge, theories, and methods. In particular, Schwab (1962, pp. 21-24) argued strongly against the "*teaching of science as dogma*", which he saw as the dominant tradition of school science teaching students science as "a rhetoric of conclusions". This tradition should be replaced, he felt, by a *teaching of science as enquiry* which would "show some of the conclusions of science in the framework of the way they arise and are tested" (Schwab, 1963, p. 23).

Despite the major efforts performed during the post-Sputnik curriculum wave which spread to many other countries, the results were rather disappointing. One major evaluation study said:

> In spite of new curricula, better trained teachers, and improved facilities and equipment, the optimistic expectations for students becoming inquirers have seldom been fulfilled (Welch, 1981).

Only a few curricula are mentioned as an exception, notably the Harvard Project Physics course and the Yellow version of the BSCS High School Biology course (Matthews, 1994, pp. 6,18). Science educators (Fensham, 1992; Duschl, 1993; Matthews, 1998) reviewing the evaluative research of these new curricula (new compared to the preceding traditional curricula) likewise concluded that students' understanding of science had not improved in a significant way. The reproduction of facts and methods still reigned and continues to reign, a conclusion confirmed for school chemistry by the research described in Chapter 2.

3.2.2 Factors involved in school science reform

Curriculum reform projects are very complex processes (Chapter 1), consisting of several curriculum levels (Goodlad) and curriculum categories (Schwab) in which many factors as well as actors are involved. Matthews (1994, p.18) said in this regard:

> Now in the 1990s, when school science reform is once more on the agenda, it is timely to know how much of this failure and confusion was due to the curriculum materials, how much to teacher inadequacies, how much to implementation and logistic factors, how much to general anti-intellectual or anti-scientific factors and how much to a residue factor of faulty learning theory and inadequate views of scientific method that the schemes incorporated.

It is to be expected that the factors attributed by researchers of science education to the failure of the structure-of-the-discipline curricula are many and diverse. In order to emphasize the *systemic* character of curriculum reform, I have categorized in Figure 3.3 the factors discussed below in relation to the (transition of) curriculum levels (described in section 1.3.1).

Firstly, in a recent publication Duschl and Osborne (2002) point to: (i) the misplaced goals of the actual projects: "final form" science instead of teaching science as inquiry;

(ii) resistance of science teachers because of their previous training (p. 62); and (iii) lack of theory of instruction which combines cognitive with social situation (p. 43). Duschl and Osborne also mention Novak (1977) who attributed the failure to a lack of theory of learning (p. 42). They see these factors as barriers which have to be overcome if, as they argue, the aim of science courses is to be "to engage [students] in argumentation, the construction of explanations and the evaluation of evidence" (p. 41).

Secondly, Aikenhead (2000), in a paper titled: "*Changes Need to Succeed Where We Previously Failed*", mentions some other points, namely (i) curriculum developers failed to involve teachers in policy making and developing; (ii) a failure to offer teachers "practical on sight experience" (p. 340); (iii) a general lack of research and development.

Figure 3.3 Factors of failure involved in science education reform

Curriculum levels	**Failure attributed to factor by author**
Visionary curriculum	• Misplaced goals (Duschl & Osborne 2002; Welch 1979) • Lack of involvement of teachers in policy making (Aikenhead 2000) • Inadequate views of scientific method (Matthews, 1994)
Designed curriculum	• Lack of consistency between vision and teaching materials [this thesis] • Texts do not reflect vision (Herron, 1971; Diederich, 1969) • Exercises do not reflect idea of enquiry ((Herron, 1970) • Lack of involvement of teachers in development process (Aikenhead 2000) • Lack of cognitive and social theory of instruction (Duschl & Osborne 2002) • Lack of theory of learning (Novak, 1977)
Formal curriculum	• Transformation of school science into proto-university science or the professionalization of school science (Matthews, 1994, p.16)
Interpreted curriculum	• Lack of consistency, vision, and in-service training (Herron, 1971) • Lack of "practical on sight experience" for teachers (Aikenhead 2000)
Taught curriculum	• Lack of consistency between vision and views of teachers [this thesis] • Resistance of teachers (Duschl & Osborne 2002, Herron, 1970)
Experienced curriculum	• Resistance of students • General lack of research and development (Aikenhead 2000)

Thirdly, Herron **(**1970), at the time a student of Schwab, evaluated a number of the newly developed curriculum materials, PSSC, ChemStudy, and BSCS *Blue version*, in order to:

> … determine the clarity and coherence with which the doctrine [i.e., teaching of science as enquiry] is set forth and to determine to what extent the doctrine is incorporated in the actual structure of the textual materials (ibid., p. 172).

Herron found that the texts portray, in Schwab's terms, stable enquiry rather than fluid enquiry, that they fail to emphasize properly the “ideational” factor of science, and the self-corrective nature of science. Similar conclusions are reached by Diederich (1969).

As for enquiry-oriented exercises, only a few have been categorized as really open, while most are categorized as closed, that is, “problem area, methods of solution, and “correct” interpretations are given” (Herron, 1971, pp.197-203).

From the interviews of 60 teachers who were giving these courses at the time, Herron concluded that very few of them had an understanding of the theme of *science as enquiry* on the level of the textbook used, whether they had attended the teachers' institutes associated with the movement, or not. In fact, the lecture mode used by college specialists might have reinforced their traditional way of teaching at the expense of learning to teach science as enquiry.

Thus, the results of these curriculum projects (PSSC, ChemStudy, BSCS) were not consistent with the vision of teaching science as enquiry as reflected in the designed curriculum, in text or exercises, or in the interpreted curriculum by teachers.

Interestingly, Herron (ibid., p. 209) noted: “Ideally the present study should be followed up by an attempt to observe teachers in their classrooms and to identify and analyze whatever views of enquiry may or may not be entailed as logical consequences of their activities”, that is, Herron suggested to perform an evaluation of the taught curriculum, as I will describe in detail for the Salters' Chemistry course in Chapter 5.

3.2.3 Relevance of the first condition of escape

Performing a domain-specific analysis of the structure of the dominant school science / chemistry curriculum (first condition of escape, mentioned in section 3.1) has relevance both prior to as well as integral to the actual development process. Regarding the latter, the preventive and corrective measures taken in accordance with the results of a domain-specific analysis are relevant to all curriculum levels depicted in Figure 3.3, or rather, they are relevant to all *transitions* of curriculum levels. Only extensive curriculum study can reveal if and to what extent curriculum projects such as PSSC, ChemStudy or BSCS did perform a domain-specific analysis of their respective science curriculum, and if and to what extent the developers were able to take appropriate measures. Even though not many curriculum projects were able to perform a detailed domain-specific analysis, it seems likely that the first condition of escape would be considered by the actors involved as relevant. As Rutherford (1964, p. 80) stated:

> When it comes to the teaching of science it is perfectly clear where we as science teachers, science educators, or scientists stand: *we are unalterably opposed to rote memorization of the mere facts and minutiae of science* (my italics).

In the terms of this thesis, the actors involved would probably be all opposed to Normal Science Education, whether they analyzed Dominant School Science in detail or not.

BSCS and the first condition of escape

For one curriculum project, the BSCS project, it is relatively easy to determine, at least in a global way, whether or not a prior analysis of the nature and structure of the dominant school science curriculum, in this case, the school biology curriculum, was performed.

As already noted above, prior to the BSCS project, a domain-specific analysis of the nature and structure of the dominant school *biology* curriculum was performed by Schwab (1962), as well as by Brownson and Schwab (1963), and by Hurd (1962), the latter appearing in the BSCS *Bulletin series*. Further, through many other publications, including the *BSCS Newsletter*, and at several conferences, Schwab communicated to a large audience, his analysis of the teaching of science as dogma and his idea of what should replace it, the teaching of science as enquiry. Finally, as supervisor of the "Biology Teachers Handbook" (1963), an integral part of the BSCS materials, Schwab addressed the specific needs of biology teachers themselves. Thus, he began his description of the origin of the BSCS texts with a summary of his analysis of the basic model of the conventional science textbook. He formulated as his conclusion that:

> It failed to provide a liberal, general education for all precisely because it was designed for students who would go on to college. Its design seemed to *assume* that this further education would take place for it provided not a general and well-rounded education, but prerequisite courses, "propadeutics", preliminaries. It required the college to complete its work" (ibid., p. 4).

Thus, in the case of the BSCS project, a domain-specific analysis of the nature and structure of the dominant biology curriculum was performed, and therefore, condition one was fulfilled.

BSCS and other conditions of escape

As noted above, in general terms the second condition of escape concerns the development of a vision on new science curricula, while the third condition has to do with the method one chooses in order to escape from Dominant School Science.

In many publications and at conferences, Schwab contributed greatly to the formulation of a vision of new science curricula, or in this case, of school biology curricula. During Schwab's participation in the Biological Science Curriculum Study (BSCS) project, BSCS produced from 1958 onwards *four versions* of a beginning biology course for the high school student. Three versions were aimed at the average student, the so-called Blue version (molecules to man), Yellow version (inquiry into life), and Green version (ecology); also one version for the below average student, "Biological science: patterns and processes" (ibid., pp. 54, 60, 76). While these four versions had in common the science-as-enquiry theme as propounded by Schwab (1962), each version did select a different emphasis from the structure of biology as expounded by the BSCS project.

In the *Biology Teachers Handbook*, Schwab elucidated, apart from explaining the educational philosophy of enquiry, the structure and content of biology "as that science now exits" (ibid., p. 8) in terms of seven levels of biological organization and nine biological themes (p.14). The latter included seven biological themes, as well as theme eight "Science as enquiry" and theme nine "The history of biological conceptions". Interestingly, one of his suggestions for teachers' preparation was for them to take a philosophy of science course, as "an excellent background for the Blue version" (ibid., p. 59). The *Biology Teachers Handbook* also offered *contextual* chemistry and physics, that is, chemistry and physics needed in the context of biological enquiry. Thus, in terms of Figure 3.2, Schwab was addressing here a number of 'broken' relationships, especially the relationships of school biology to past and current research (d in Figure 3.2), to history and philosophy of science and to other sciences (e, f and g in Figure 3.2). Technology (and society) was seen by the BSCS project as something distinct from science and was therefore not treated in the materials.

The BSCS texts were field tested, went through many editions, and reached in the period from 1959-1990 as many as ten million students. As we saw above, however, the results of the BSCS project, at least for the Blue version, were not found to be consistent with the educational philosophy of enquiry, either as reflected in the designed curriculum, in text or exercises, or in the interpreted curriculum by teachers (Herron 1970). In their introduction to Schwab's selected essays on *Science, Curriculum and Liberal Education*, Westbury and Wilkof (1978, p. 25) remarked that "the texts themselves were very different from what he would have wanted".

Apparently, the analysis performed by Schwab and others on the conventional biology textbook and the vision formulated on the teaching of biology as enquiry were not sufficient. These two conditions should therefore be seen as *necessary* conditions. As we saw in Figure 3.3, many other factors also appear to be relevant in order for innovation projects to succeed. Many of these factors can be summarized, I think, under the heading of a *method* of development, a method which consists of two kinds of measures:

– measures taken in accordance with the results of a domain-specific analysis;

– measures taken to safeguard the realization of the chosen curriculum vision.

In a systematic curriculum project both type of measures pertain to all curriculum levels from the visionary curriculum down to the learned curriculum, that is to all transitions of these curriculum levels. Another way to put this point is to add to the curriculum levels listed in Figure 3.3 another curriculum level, the researched curriculum. Welch (1979), for example, pointed to the lack of effective testing of the teaching materials, while Aikenhead (2000) pointed to the need for more research in combination with the development of teaching materials. Evaluative research, ideally, should pertain to all levels, from top to bottom. It should be formative and not just summative, that is, cyclic or spiral, and not linear.

In sections 3.3 and 3.4, after discussing the concept of *curriculum emphasis* as developed by Roberts (1982), I will give a further characterization of the third of escape, the *method* of development, as well as of the second condition of escape, the development of a vision. Finally, in Chapter 6, I will come back to the systemic nature of curriculum development in order to add some additional points based on my empirical findings on the Salters' Chemistry curriculum with regard to conditions supporting innovative curriculum reform.

3.2.4 A new society oriented science curriculum movement

Partly as a reaction to the sobering evaluation of the structure-of-the-disciplines curricula, there has emerged in the 1980s a new curriculum movement which attempts to reform current school science curricula in a different and possibly more radical way. Thus, it was realized that there was an urgent need to set a new, more appropriate and inclusive aim for school science, epitomized in the slogan 'Science for All', that would lead to curricula in which the *societal* and *technological* dimensions of school *science* (STS education) would find an important place. In terms of Figure 3.2, the STS movement is addressing another set of 'broken' relationships, especially the relationships of school science to technology and society (b and c in Figure 3.2).

Thus, while the movement in the 1960s tried to realize the traditional aim of understanding science by modernizing the structure and teaching of traditional, science-oriented curricula, the STS movement of the 1980s tried to articulate and operationalize a new aim leading to society-oriented curricula which would imply the development of new *content*, as well as of new forms of teaching and learning (Aikenhead, 1994).

Attempts at articulating a new vision for chemistry

Different authors have put forward different formulations for the aim of articulating a new vision for chemical education. For example, Fensham (1984, p. 209) lists a number of goals for a school chemistry curriculum which could lead to a form of chemical education effective and worthwhile for *all* students (Figure 3.4).

Figure 3.4 Some outcomes and experiences for more effective chemical education

GOALS OF CHEMISTRY FOR ALL

Every student should be able to:

- Explain a chemically-based application
- Explain how the substances of everyday live can be regarded as chemicals
- State (with relevant details) the sorts of people who find employment in the field of chemistry

Every student should have:

- Practice in the application of chemistry to real (domestic, leisure, community, etc.) problems
- Meaningful experiences of each of the major activities of chemists
- Experience, with joy and excitement, of phenomena that attract people to chemistry
- Some experience of the power of chemical knowledge

These goals do justice to the “very rich diverse conglomerate on which the word CHEMISTRY confers a common identity” (ibid., p.208, emphasis Fensham), that is, of chemistry as a field of human endeavor which includes “the processes and procedures chemists use for their purpose” (p. 208), but also includes “learning about chemical applications [and] chemicals as the substances of everyday life” (p. 211), and about “the historical development of the subject and the contributions of its historical persons” (p. 208). In terms of Figure 3.2, Fensham is addressing the relationships of school chemistry to craft, technology, and society (b and c) as well as the relationships of school chemistry to past and current research (d, e, f in Figure 3.2).

De Vos et al. (1991a, p. 8) argued for a citizen-oriented view to the school chemistry curriculum, stating that: “[t]he main aim of modern school chemistry must be to prepare students for life in a society in which chemical products and processes play an important role”. One of his tentative ideas (De Vos, 1992, p. 81) was: “to situate chemical education entirely within the context of the role played by matter and energy in our society. This includes three aspects: production, use, and waste disposal thereby integrating environmental and safety problems with the subject as a whole”. In his later work (De Vos et al., 2002) generalized his ideas and addressed what he called the neglected faces of chemistry: *technology, craft and magic* (cp. relationships b, c, d, e & f in Figure 3.2). Each face of chemistry incorporates a specific role which students should learn to take in De Vos’s view of chemical education (see further section 6.4).

It can be inferred from the work of Fensham and De Vos, and also from the views of the large majority of researchers and developers in chemical education composing the IF and DF (Chapter 2), that these researchers all want to depart from something like the traditional, theoretical, or abstract “learning sequence for conceptual knowledge”, as Fensham (1984, p. 205) puts it (see also the work of several researchers in science education mentioned in Figure 3.3 above). That is, they all want to escape from Dominant School Chemistry as I have characterized traditional science education. Likewise, in their attempt to develop a new 16+ chemistry curriculum, the developers of Salters’ Chemistry clearly had the intention to:

> ...produce a *radical* rather than a piecemeal or cosmetic revision [of existing 16+ chemistry syllabuses characterized as academic and abstract from too early a stage (Garforth, 1983, p. 29).

However, De Vos points out that the realization of a new aim for school chemistry will require the development of new content as well as *the development of a new educational structure to organize this new content in a coherent way*. This has to be considered as the fundamental problem of chemical education. As De Vos (1992, p. 81) has put it: “the problem of an alternative structure is still on the agenda”.

Only by providing a solution for this fundamental problem will it be possible to escape from the currently dominant school chemistry curriculum, as against merely changing the traditional curriculum in a marginal or superficial way (De Vos et al., 1991, p. 8). It is to be hoped that in the end and after much developmental and research effort, this would lead to a new curriculum structure by which the new aim of school chemistry, “Chemistry for All”, would be fulfilled.

Van Aalsvoort (2000, p. 60), a Dutch researcher in chemical education, working in the cultural historical tradition, distinguishes between a gradual and a fundamental curriculum change. In her research-based attempt to develop a new elementary chemistry curriculum, Van Aalsvoort defines “a gradual change as one which leaves the core of the subject, consisting of aims, contents and teaching strategies, intact ...”,

> A fundamental change, on the other hand, consists of *an alteration of aims, contents and teaching strategies in concert,* due to their being founded in a different representation of reality (my italics).

Recently, from the 1990s onwards, there has emerged a new curriculum movement in science education which revives and articulates in new ways the emphasis on the structure and nature of the disciplines of science, by drawing in a systematic way on the important work performed in the history and philosophy of science (HPS) relevant to science education (Matthews, 1994; Millar & Osborne 1998; Duschl & Osborne, 2002). This so-called HPS education addresses the relationships of school science to the history and philosophy of science, to common sense, and to current research (cp. relationships d, e, f, and a in Figure 3.2).

Both STS education and HPS education strive after fundamental curriculum changes, which require, in terms used in this thesis, new coherent coordinated combinations of a pedagogical, philosophical, and substantive substructure that replaces the traditional combination which led to the teaching of science as dogma and to the reproduction of facts and methods. It requires a vision and a method to realize this vision, the second and third conditions for escape.

3.3 Vision, method and the concept of curriculum emphasis

In this section I will discuss the concept of *curriculum emphasis* as developed by Roberts in order to give a further characterization of the second condition of escape: the development of a vision, and the third condition of escape: the method of development. The "conceptual lens of curriculum emphasis" (Roberts (1982, p. 254), functions as a "view affording lens", as it has aptly been described, and has proved to be an important:

- Theoretical instrument to describe, analyze and explain the *vision* and structure of past and current science curricula, documents, and textbooks;

- Practical instrument to deliberate, choose, develop, sustain, and evaluate in a structured way a *vision* on new science curricula.

Thus, the concept of curriculum emphasis is an important instrument with two functions: to analyze the vision of realized science curricula, a theoretical function, and to design or develop ('synthesize') the vision of new science curricula, a practical function. A discussion of Roberts' framework will lead to important insights with regard to the second condition of escape, the development of a vision, and to the third condition of escape, the method of development. These conditions need to be fulfilled if and when trying to escape from Normal Science Education.

In the following subsections, I will therefore describe in some detail the origin, elaboration, and functions of the concept of curriculum emphasis as it has been developed by Roberts (1982; 1988; 1995; 1998).

3.3.1 The problem of curriculum diversity

Roberts, at the time a bystander in the post-Sputnik curriculum movement, reflected in later days on how much he was intrigued by the difference between the Physical Sciences Study Committee course (PSSC) and the Harvard Project Physics course. As he put it:

> The intent and overall orientation of the Harvard Project Physics course were quite different from the intent and overall orientation of the PSSC course (Roberts 1998, p. 7).

Whereas the PSSC course focused mainly on "understanding how science functions as an intellectual enterprise", the Harvard Project Physics course "presented science essentially as one of the humanities" (Roberts, 1998, p. 9). Science is taken in the latter course as one of the possible explanatory modes (Roberts, 1982, p. 248). The *Self as Explainer* curriculum emphasis, as he later called it, provides "students with grounds for understanding the process of explanation itself" (Roberts, 1988, p. 37), more than any other curriculum emphasis including the one he called *Structure of Science* of which the PSSC course was a manifestation.

Another 'different' product of this curriculum movement was the "Science – A Process Approach", developed initially for primary science education, the emphasis being on *Scientific Skill Development*. As a science student Roberts had experienced, and later as a science teacher also taught, two other types of courses prevalent in the first half of the 20th century in North-America, one with an emphasis on *Everyday Coping* and another one with an emphasis on *Correct Explanations* (ibid., pp. 8, 10).

Roberts (1988, p. 27) later defined these different curriculum products in terms of the concept of curriculum emphasis. Since his initial problem was a problem of curriculum diversity, Roberts hoped, by developing this concept of curriculum emphasis, to create some order in the emerging pluriform curriculum landscape in science education.

3.3.2 Characterizing science courses by seven curriculum emphases

In his later, more systematic studies Roberts (1982, 1988) came to distinguish, identify, and define the seven curriculum emphases in science education as depicted in Figure 3.5. These were, as he put it, developed "inductively", that is, they are based on historical research of North American science textbooks and policy statements from 1900-1980.[1]

The seven curriculum emphases "do not necessarily constitute a set of mutually exclusive categories. Rather, they capture the essence of very broadly different overall orientations which science education can assume" (Roberts, 1982, p. 246). In several places Roberts gives elaborate descriptions, as well as examples of textbooks and other teaching materials that exhibit these seven emphases (Roberts, 1982; 1983; 1988; 1998). He arrived at the insight that "[it] is impossible to teach <u>content</u> without simultaneously expressing curricular <u>intent</u>, or purpose" (Roberts 1983, p. 8; underlining his). The new curriculum emphases which emerged in the 1960s were quite "deliberately, intentionally interwoven with science subject matter" (1988, p. 10). It is important to note that this was not the case for the traditional curriculum emphases: *Solid Foundation* and *Correct Explanations*.

> However, the curriculum emphases that tend to be silent about the purpose of learning science – Solid Foundation and Correct Explanations – may not have been *deliberately* selected, but their message and socializing influence are no less powerful for that (1998, p. 10).

Roberts, therefore, briefly characterizes these curriculum emphases as *default* emphases. The number of seven curriculum emphases is not a historically, let alone theoretically, fixed number. On the contrary, new curriculum emphases can be and have been developed in the last two decades. Thus, according to Fensham (1997, 1998) curriculum emphases such as *Science for Nurturing*, *Science in Applications*, and *Science in the Making* have been emerging.

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[1] Roberts refers to a number of other researchers who have "made sense of curriculum diversity in science education" (1982, p. 245). For school chemistry curricula, he refers to the work of Ogden (1975), for school biology curricula he refers to the work of Hurd (1969), and for school physics curricula he uses mainly his own studies.

Figure 3.5 Seven curriculum emphases and some examples

Curriculum emphasis	**Quotes and curriculum examples given by Roberts**	**References, Roberts**
SOLID FOUNDATION: Stresses science as cumulative knowledge	"in vogue from 1910-1950" in pre-Sputnik North-America	1998, p.7 1988, p. 38
STRUCTURE OF SCIENCE: How science functions as a discipline	PSSC, ChemStudy, BSCS late 1950s and 1960s)	1998, p.7 1988, p. 35 (1982, p. 253
SCIENCE/TECHNOLOGY DECISIONS: The role scientific knowledge plays in decisions which are socially relevant	Science in Society, ed. Lewis (1981) (largely post 1980s)	1998, p.7 1988, p. 52
SCIENTIFIC SKILL DEVELOPMENT: The 'science as process' approach	Science – A Process Approach (AAAS)	1978, p.5 1988, p. 37
CORRECT EXPLANATIONS: Science as reliable, valid knowledge	"very noticeable" in pre-Sputnik North America	1998, p.10
PERSONAL EXPLANATION: Understanding one's own way of explaining events in terms of personal and cultural (including scientific) influences	Harvard Project Physics (Watson, Holton) Harvard Case Histories (Conant et al., 1948) Patterns of Discovery (Connelly et al., 1972)	1998, p. 9 1988, p. 52 1982, p. 248
EVERYDAY APPLICATIONS: Using science to understand both technology and everyday occurrences	prevalent in North-America (1910-1950) "learn how to apply"	1998, p. 8 1988, p.34 1982, p. 244

3.3.3 Theoretical functions of the concept of curriculum emphasis

The framework around the concept of curriculum emphasis should be seen as:

> ...an analytical framework for understanding what is involved for policy makers, and for science teachers, when they shape answers to the question: What counts as science education? (Roberts, 1988, p. 27).

It is an analytical framework to make sense of past or present curriculum diversity and of the development of future curricula. The concept of a curriculum emphasis is defined as:

> ...a coherent set of messages to the student about science (rather than within science). Such messages constitute objectives which go beyond learning the facts, principles, laws and theories of the subject matter itself – objectives which provide an answer to the student question: "Why am I learning this?" Roberts (1982, p. 245).

The meaning of a curriculum emphasis, taken as a "coherent set of messages", can be 'unpacked' by using the idea of the 'common places' of the curriculum (Roberts, 1988, p. 45). There are four common places (Figure 3.6) which constitute the elements of meaning of any curriculum proposal: (i) the subject matter; (ii) the learner; (iii) the teacher; and (iv) the society in which the teaching occurs. Furthermore, these four common places have to form, as Schwab (1962, pp. 31 – 41) repeatedly stressed, a coherent and *co-ordinate* set of messages.[2]

Each curriculum emphasis, taken as an inevitable combination of subject matter and an objective going beyond content, can be realized in the span of one teaching unit, taking "five to six weeks of instruction" (Roberts, 1982, p. 250), that is, about 12 lessons. In this period the teacher can communicate the new emphasis, perform his or her new role, and the student can learn the new emphasis of the unit. Roberts gives examples of units conceived, developed, and taught in accordance with the particular emphasis in his discussion on the Ontario and Alberta curricula. Furthermore, he stresses the importance of:

> A research summary/analysis about a single emphasis, in terms of who can master it, how well, at what ages, what the unintended consequences are, etc. (ibid., p. 255).

Thus, Roberts also requires *evidence* for the realization of a new emphasis. The chosen vision or innovation should be shown to work, should be feasible.

The realization of a new emphasis in the span of one unit has an important corollary, namely, that it is possible to deal in a science course of one or more years with *more than one* emphasis. Therefore, one curriculum emphasis does not have to dominate a whole science course in order to come across for students. This is a powerful argument, according to Roberts, for those curriculum proposals which consist of a balance of different emphases. Since science has several facets, students of different age and ability should meet more than one of these facets as a preparation for their future lives. Each emphasis is in principle "a legitimate candidate for choice" (Roberts, 1988, p. 38).

In sum, a curriculum emphasis in science education consists of a coordinate set of messages about science, the learner, the teacher, and society. It can be empirically shown to be feasible, that is, teachable and learnable, in the span of one unit. One curriculum emphasis is neither more correct nor truer than another, and shouldn't therefore dominate a science curriculum for secondary education. Its legitimacy should be defended with regard to specific students and circumstances.

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[2] Similarly, Orpwood and Roberts (1978, p. 5) state that "an emphasis contains a selected set of messages (to the student) about science, about himself, about society, or about the relations among them".

Figure 3.6: Seven curriculum emphases for science education in terms of four commonplaces (From: Roberts, 1988, p. 45)

Curriculum emphasis	**View of Science**	**View of the learner**	**View of the teacher**	**View of Society**
Everyday Coping	A meaning system necessary for understanding and therefore controlling everyday objects and events.	Needs to master the best explanations available for comfortable, competent explanation of natural events, and control of mechanical objects and personal affairs.	Someone who regularly explains natural and man made objects and events by appropriate scientific principles.	Autonomous, knowledgeable individuals who can do mechanical things well, who are entrepreneurial, and who look after themselves, are highly valued members of the social order.
Structure of Science	A conceptual system for explaining naturally occurring objects and events, which is cumulative and self-correcting.	One who needs an accurate understanding of how this powerful conceptual system works.	Comfortably analyzes the subject matter as a conceptual system, understands it as such, and sees the viewpoint as important.	Society needs elite, philosophically informed scientists who really understand how that conceptual system works.
Science/ Technology/ Decisions	An expression of the wish to control the environment and ourselves, intimately related to technology and increasingly related to very significant societal issues.	Needs to become an intelligent, willing decision maker, who understands the scientific basis for technology, and the practical basis for defensible decisions.	One who develops both knowledge of and commitment to the complex interrelationships among science, technology, and decisions.	Society needs to keep from destroying itself by developing in the general public (and the scientists as well) a sophisticated, operational view of the way decisions are made about science-based societal problems.
Scientific Skill Development	Consists of the outcome of correct usage of certain physical end conceptual processes.	An increasingly competent performer with the processes.	One who encourages learners to practice at the processes in many different contexts of science subject matter.	Society needs people who approach problems with a successful arsenal of scientific tool skills.
Correct Explanations	The best meaning system ever developed for getting at the truth about natural objects and events.	Someone whose preconceptions need to be replaced and corrected.	One responsible for identifying and correcting the errors in student thinking.	Society needs true believers in the meaning system most appropriate for natural objects and events.
Self as Explaner	A conceptual system whose development is influenced by the ideas of the times, the conceptual principles used, and the personal intent to explain.	One who needs the intellectual freedom gained by knowing as many of the influences on scientific thought as possible.	Someone deeply committed to the concept of liberal education exposing the grounds of what we know.	Society needs members who have a liberal education ñ that is, who know where knowledge comes from.
Solid Foundation	A vast and complex meaning system which takes many years to master.	An individual who wants and needs the whole of a science, eventually.	One who is responsible to winnow out the most capable potential scientists.	Society needs scientists.

3.3.4 Practical functions of the concept of curriculum emphasis

In the late1970s Orpwood and Roberts (1978; 1979; 1980), applied for the first time the science curriculum framework centered around the concept of curriculum emphases. From the beginning they stressed the practical functions of the concept of curriculum emphasis and illustrated the heuristic potential of their view-affording lens "for the practical science education activities of curriculum policy formulation, materials development, and curriculum implementation in the classroom" (Roberts 1982, p. 249).

Using the 'lens' to analyze a vision

Orpwood and Roberts (1978) began to use the concept of curriculum emphasis for an analysis, clarification, and discussion of proposed curriculum guidelines for science education in the state of Ontario, Canada, for the Intermediate Division (grades 7-10; ages 12-16). The first thing they did was to group "the varied, though clearly not exhaustive list of Aims statements" (ibid., p. 5) in three distinct clusters:

- A *subject-centered* emphasis, characterized as: "science as a means for students to reflect on the nature of the discipline" (ibid., p. 5).
- A *learner-centered* emphasis, characterized as "the development of scientific skills in the learner" (p. 5).
- A *society-centered* emphasis, characterized as: "aims having their focus beyond school and the discipline toward the role of science and the science student in societal contexts" (p. 5).

Categorizing a multitude of aims in terms of three clusters or emphases, makes it possible for the policy and development committee:

> ...to discuss some of what is otherwise *implicit* in a curriculum, and thus to plan for one set of messages (a desired set) rather than another set to be incorporated into a science program (p. 6).

To put it in the terms of this thesis: making things explicit with regard to the envisioned curriculum is a necessary condition for escape.

Roberts and Orpwood participated in various forms of both research and development work, as "principal investigators", in which the analytical use of the conceptual lens of curriculum emphasis occupied a central place. At the policy level, or visionary curriculum level, they contributed an article to the provincial guidelines called "Relating Science Topics to Alternative Sets of Objectives" (Orpwood & Roberts, 1978, p. 5). They participated in the regular meetings of the planning committee for curriculum development and when clarification was needed, in a large representative group meeting twice a year. Finally, they recorded all policy deliberations, for subsequent transcription and analysis (Roberts, 1982, p. 250), a rare example of collecting research data on the policy or visionary curriculum level.

The following use of the concept of curriculum emphasis concerns the designed curriculum level. Orpwood and Roberts developed, in cooperation with science teachers, a grade 7/8 unit which focused on the topic *Properties of Matter* (1979, p. 4). They did this "in three alternative versions together with a commentary about alternative versions" (Orpwood & Roberts, 1979).

> When produced in trial form for teachers to implement in the classroom, the materials were even color coded: blue for Structure of Science, red for Scientific Skill Development, and green for Science and Society (Roberts 1982, p. 252).

The popularity of this "multiple-version manual" as well as the number of requests for professional development sessions in which different curriculum emphases are explained, articulated, and applied, indicates "that the use of the concept as an active, systematic approach to materials development has been very successful indeed" (Roberts 1982, p. 252).

Using the 'lens' to articulate a vision

Another function of the conceptual 'lens' of curriculum emphases in the area of policy, is discussed in Roberts (1995) where he describes how, in the period from 1986-1992, a curriculum committee devised a threefold strategy *based on* the concept of curriculum emphasis. The policy formulation concerned a revision of a science curriculum policy for junior high school (grades 7-9; ages 12-15) in the province of Alberta, Canada.

First of all, looking through the conceptual lens of curriculum emphasis, the committee saw "science subject matter as present throughout the program" (ibid, p. 499). The use of the conceptual lens led the committee to the insight that the required subject matter could be incorporated in the program while using *any* of the seven curriculum emphases, whether they were more traditional ones or more alternative ones. As a result, the two most traditional or 'default' emphases, *Correct Explanations* and *Solid Foundations* (both of which implicitly communicate to students a study of subject matter for its own sake) were discarded. We could say that, by performing the analysis afforded by the conceptual 'lens' of curriculum emphases, the committee broke away from, and did not import, the two most traditional emphases on school science. In other words, they were making an attempt to escape from Normal Science Education.

Secondly, the remaining five curriculum emphasis were amalgamated to form three program emphases, called "Learning Contexts" by the committee (Figure 3.7).

Figure 3.7 Amalgamation of curriculum emphases into three learning contexts

Curriculum emphases	Learning Contexts
Structure of Science, Scientific Skills Development, and Personal Explanation	Nature of Science
Everyday Applications	Science and Technology
Science/Technology/Decisions	Science, Technology and Society

Thirdly, these three *Learning Contexts* "were to be blended with different sections of content to achieve the desired balance of objectives" (ibid. p. 499). In other words, appropriate topics from the mandatory list consisting of concepts, attitudes, and skills were blended with one of the three selected learning contexts. This, according to Roberts

(p. 499), was the boldest move of all, that is, “to attach a learning context to each subject matter unit, to insist that the units would be taught that way” (p. 499).[3] Thus, the use of the conceptual ‘lens’ of curriculum emphases enabled the curriculum committee to formulate a coherent vision.

Using the ‘lens’ to safeguard consistency of vision in the development process

After the selection of a particular set of curriculum emphases follows the process of development of materials in which the selected curriculum emphases are articulated and operationalized. Two other curriculum elements should be addressed in this process, namely, science content and teaching strategy (Figure 3.8). Orpwood and Roberts point out that:

> It is reasonable to expect these *differing* emphases to be represented in the classroom in the form of *differing* teaching strategies (Roberts & Orpwood, 1978, p. 6; my italics).

Figure 3.8 Relationship between science content, curriculum emphasis, and teaching approach (Orpwood & Roberts, 1978, p. 4)

Science content	+	Curriculum emphasis	→	Teaching strategy
(fixed)		(selected)		(selected)

Although Figure 3.8 reads, in particular for teachers, ‘logically’ from left to right, as Orpwood and Roberts put it, they do stress at the same time that “the order used in planning a curriculum and designing units, is a matter for individual choice” (1978, p. 7). Whatever order is chosen, it is especially important to monitor, during the development of materials, the “*logical consistency* among science content, objectives, and teaching approach at every stage of the unit” (1979, p. 6, my italics). And they elaborate on this point, saying:

> It means, in practice, that one has to “revisit” each of the three columns frequently to make additional “fine tuning” until the required consistency is there” (ibid., 1979, p. 6).

This was the case in the materials development of the Alberta project:

> The textbooks, and the curriculum guides, take the concept of curriculum emphases seriously, so that each of the subject matter units *clearly and consistently* deploys the necessary blend of science topics and the Learning Context (Roberts, 1995, p. 503; my italics).

Thus, at the visionary or policy level, the concept of curriculum emphasis is a good starting point in order to make sense of, and then cluster or reduce, the multitude of objectives in a *given* policy document (top-down approach). On the other hand, the actors involved in a bottom-up developmental project should be able to deliberate on a desired

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[3] This raises the question, to what extent developers and teachers were able *to adhere consistently* to the design criteria following from the specific choice of curriculum emphases by the curriculum committee. In Chapters 4 & 5, I will try to answer in some detail a similar question for the Salters’ Chemistry curriculum. It would be very interesting to perform a ‘consistency’ analysis on the materials produced by the group of authors (Durward et al., 1989) for which Roberts acted as program consultant.

set of curriculum emphases and decide accordingly, which set to develop further.[4] Subsequently, either approach goes on to model or match, in a tentative and empirical way, the selected emphases with appropriate subject matter and with a suitable teaching strategy by 'fine tuning' in a process of 'dialectic recursive interaction'.

Roberts and Orpwood further point out that designing units for students also requires developers to address a fourth curriculum element, namely, the "evaluation of student achievement" (1979, p. 5), or the assessment of student achievement (Figure 3.9).

Figure 3.9: Four curriculum elements (adapted from Orpwood & Roberts, 1979, p. 5)

Science Content	Objectives	Teaching Approach	Evaluation (Assessment)

For the relationship between these four curriculum elements they stress that:

> These four elements are like the pieces of a jigsaw puzzle that require careful fitting together. As with the jigsaw, the selection of each piece has consequences for the selection of subsequent places (ibid., p. 5).[5]

As Roberts (1995, p. 497) puts it, such a "planning procedure also facilitates writing legitimate test items to assess students understanding". The developmental strategy should result in students exhibiting a behavior that can constitute reasonable evidence for the achievement of the objectives. The coherence and flow of the selected emphasis are matters of concern just "as much as the coherence and flow of the subject matter itself" (Roberts 1982, p. 251).

Upholding the 'logical consistency' between the four curriculum elements, by way of 'fine tuning' in a process of 'revisiting' these curriculum elements, can be seen as a general mechanism, part of new model of curriculum development which Roberts (1999, p. 125), following Schwab (1974, 1978), has described as follows:

> It has to do with the *dialectic, recursive interaction* between Purpose and Policy (ends) and Programs and Practice (means). That is, seeing the former as settled, without considering the implications of the latter, is simply not going to work, in Schwab's view.

As we will discuss in section 3.4, "dialectic, recursive interaction" can be seen as an important part of the process of 'developmental research', as practiced to varying degrees by the developers and researchers at the Center for Science and Mathematics Education, Utrecht University, The Netherlands (see further in Chapter 6).

Thus, it is very important to have a systematic method for safeguarding the consistency of an adopted vision while developing teaching materials and testing them in the classroom. The gathering of evaluation data at the different curriculum levels is essential for making appropriate curriculum decisions about clarity and consistency of

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[4] For example, in Westbroek et al. (2000) a choice is made to elaborate the three curriculum orientations as discussed by Van Berkel (2000).

[5] The metaphor of the jigsaw is also applied by Westbroek et al. (2001) to describe the process of fitting together the substantive, philosophical, and pedagogical substructures of a curriculum, in a coordinated way, *within* a particular chosen curriculum emphasis, as well as across diverse curriculum levels, thus elaborating a point made by Van Berkel (2000).

vision, on the one hand, and feasibility of the teaching, learning, and assessment process, on the other. Data should be collected at the policy or visionary curriculum level, at the designed, taught, and learned levels. Another way to put it is that developmental research on science curricula should be not only classroom based, but also design-room based and vision-room based.

In Chapter 1 we saw that the researchers of the Dutch MAVO chemistry project concluded, on the basis of a consistency analysis, that the developers of the project did not achieve the "Chemistry for the Citizen" aim which they set out to achieve. In Chapters 4 and 5, I perform a consistency analysis on the Salters' Chemistry curriculum in order to see to what extent the developers in England were able to realize their vision of a societal chemistry course.

Using the 'lens' for purposes of curriculum implementation

Roberts and his colleagues in several publications (e.g. Orpwood & Roberts, 1978, 1979; Roberts & Chastko, 1990; Roberts, 1988) examine different orderings of the curriculum elements discussed above, in line with their point about the ordering being a matter of individual choice. The ordering chosen is determined by the curriculum level addressed e.g. the visionary, designed, written, or taught curriculum (see par. 1.3.1, Goodlad). In other words the purpose of the curriculum work performed, e.g. content analysis of existing textbooks (written curriculum) or the design of new curriculum units (designed curriculum), determines the chosen order.

Content analysis of textbooks for in-service teachers

When performing content analysis of textbooks at the written or formal curriculum level, it is helpful for teachers to look at the teaching strategy as exemplified by the organization of the textbook, and then perform an analysis by following Figure 3.8 in reverse order (or backwards).

Such a 'reversed' analysis will reveal the selected curriculum emphasis which is often presented, at least with default emphases, in an implicit way and the science content selected to match these curriculum emphases (Orpwood & Roberts, 1980, p.38). The latter application of the concept of curriculum emphasis has led to "a rather popular scheme for practitioner use in analyzing textbooks to determine curriculum emphasis" (Roberts, 1982, p. 258). Teachers familiar with the conceptual lens of curriculum emphasis can also use it to guide their efforts to develop additional materials they want to use with their students in order to teach a selected curriculum emphasis (more) adequately.

Content analysis of textbooks for pre-service teachers

It is interesting to mention in this regard the "Science Teacher Thinking Framework" (STTF) as explored in Roberts and Chastko (1990, p. 200). The STTF depicted in Figure 3.10 contains similar curriculum elements to those mentioned before. That is, the heading *Objectives* of the third column of Figure 3.10 can be equated with the heading *Curriculum emphasis* of the second column in Figure 3.8, and the heading *Student Responses* of the fourth column in Figure 3.10 can be equated with the heading *Assessment* of the fourth column in Figure 3.9).

Figure 3.10: A Science Teacher Thinking Framework

Subject matter: +	**Teaching strategy:** ➛	**Objectives:** ⟷	**Student responses:**
What science is being taught?	What do I do in the classroom?	What is supposed to happen to students?	How do I know what is happening to students?

The authors discuss this framework in the context of a teacher training course they have developed, with the aim to make teachers aware of different emphases in curriculum materials or science textbooks. Teachers participating in this course should acquire, what they call following Schwab, a "view-affording lens" in the form of the concept of curriculum emphasis.[6] Thus, here is put into practice what is proposed by Roberts (1988, p. 51), namely:

> At the very least, teachers deserve to be taught that different curriculum emphases are possible, and that a particular view of what counts as science education (whoever holds or presents it) has been selected (by the person, albeit a professor of science education) from an array of alternatives.

3.4 Discussion

In this last section we will discuss some of the problems with the implementation of new curriculum emphases (3.4.1), the relationship between the concept *curriculum emphasis* and the concept *Normal Science Education* (3.4.2), and come back to the three conditions of escape in relation to the concept *'developmental research'* (3.4.3).

3.4.1 Problems with implementation of new curriculum emphases

For teachers not directly involved as co-developers in the development of the new curriculum built around a new set of emphases, a certain "resistance" (Roberts, 1995, p. 501) to the new emphases can be expected – at least, more than from trial teachers involved in some way in the process. For science curricula, introducing such non-academic emphases, such as *Personal Explanation*, *Science/Technology/Decisions*, and *Everyday Applications*, the typical comment of teachers and/or administrators is, "This stuff isn't science, it's social studies!". Depending on the emphasis, it is seen as philosophy, technology, or applied science (1982, p. 252; 1995, p. 502), not a proper science. Thus, teachers show an "intense, almost fierce affiliation to an academic direction which school science teaching tends to show" (Roberts, 1988, p. 49).

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[6] This could be seen an example of applying Goodlad's curriculum levels (see Ch.1), usually applied to student (training) courses, to teacher training courses. Thus the concept of curriculum emphasis, as developed by Roberts, is taught to teachers, and the research performed aims to find out what is learned by teachers about this concept.

In the broadest sense this academic tradition is composed of four curriculum emphases: Solid Foundation, Correct Explanations, Structure of Science, and Scientific Skill Development. The first two of these traditional emphases seem to have the strongest hold on teachers and other practitioners, and are aptly characterized by Roberts as "default emphases". That is, teachers do not explicitly state their goal, but implicitly seem to say, in the case of Solid Foundation: "Learn this stuff ... to get ready for the stuff you are going to learn next year" (Roberts, 1988, p. 38) or "Master now, question later" (Roberts, 1982, p. 248). Or, in the case of the curriculum emphasis Correct Explanations, the message is simply "Learn it because it is correct" (ibid., p. 37). The other two academically oriented emphases became more prominent in the post-Sputnik period and can be seen as modernized versions of the first two. In this they can be presented in revolutionary or radical forms, approaching Personal Explanation, or in more traditional forms, approaching the default emphases Solid Foundation and Correct Explanations, for example in the hands of academically oriented teachers.

As long as teachers cannot see the legitimacy of teaching science units with curriculum emphases which depart from the academic emphases they have been used to in their own schooling and teaching, they will feel that the new materials take "time away from the 'real science'" (Roberts, 1995, p. 502). Many of these teachers, Roberts explains, grew up on structure-of-the-discipline courses (BSCS, ChemStudy, PSSC). They studied these and now teach them (Roberts, 1982, p. 252), so the possible legitimacy of other curriculum emphases is difficult for them to comprehend. These teachers say, for example, that the structure of science emphasis is the proper one, or even the 'correct' one. One of the most important points the conceptual lens of curriculum emphases ought to bring home to practitioners is that the notion of correct or true does not really apply to curricular arguments. As Roberts and Orpwood have argued from the beginning:

> An emphasis is judged in terms of it defensibility for particular students under particular circumstances. One emphasis is not more correct than another (1988, p. 38).

Effectiveness is part of that defensibility, as is legitimacy, but correctness is not. Looking at science curriculum reform from the standpoint of the theory of curriculum emphasis, resistance from teachers to radical reform can almost be predicted. It is therefore likely that by providing "specifically designed" (Roberts 1995, p. 502) textbooks and other support materials, and (in-service) teacher training, the degree of resistance can be substantially reduced, as Roberts argues and showed for the case of the teachers in Alberta (ibid., p. 502).

The point about the defensibility of the new materials is, that its new curriculum emphasis can be defended as meaningful and worthwhile for a particular group of students, say of lower secondary mixed ability, to learn these materials.

3.4.2 Normal Science Education and the concept of curriculum emphasis

Roberts distinguishes seven curriculum emphases which he initially subsumes under three main curriculum orientations: subject-centered, learner-centered, and society-centered (Roberts, 1978). In another practical case of curriculum development, these seven emphases were clustered in three learning contexts: one combining a learner- and subject-centered orientation and two other society-centered orientations on science (Roberts, 1995, p. 499)

From my analysis of the IF responses there emerged three main curriculum orientations, which I called Normal Science Education; Science, Technology and Society; and History and Philosophy of Science. These curriculum orientations seem to be similar to those used by Roberts and similar also to other tripartite divisions made by several other authors such as Goodson (1987), De Boer (1991), and Matthews (1994).

Two of Roberts' curriculum emphases, *Solid Foundations* and *Correct Explanations*, are characterized by him as default emphases, because they are used as a means to communicate the message of science curricula in a silent and implicit way. The curriculum orientation labeled Normal Science Education can, I think, be taken as an amalgam of these two default emphases. Apart from its implicit function, I have characterized Normal Science Education with regard to the dominant school chemistry curriculum as having a rigid and isolated structure (section 2.3.).

Because of these properties, the replacement or even the reduction of this dominant curriculum orientation is bound to raise resistance or difficulties. This point is probably brought out more by the analysis in terms of the concept of Normal Science Education, since it stresses dominance, rigidity, and isolation of the curriculum, while Roberts concept of curriculum emphasis focuses on curriculum diversity and change.

The specific unpacking of the structure of the dominant school chemistry curriculum (based on the research reported in Chapter 2) has led to a detailed characterization in terms of a substantive structure, labeled corpuscular theory, a philosophical structure, labeled educational positivism, and a pedagogical structure, involving initiatory and preparatory training of future chemists. My characterization is specific for the dominant school chemistry curriculum, and because of its rigidity and isolation, foresees the resistance which will manifest itself in case of reform, and to a varying extent at all curriculum levels involved. In brief, my analysis in terms of the concept of Normal Chemistry Education, gives a specific edge to Roberts' valuable general analysis in terms of default emphases. Any fundamental reform can, of course, expect resistance from those actors, or stakeholders (Fensham, 1998), who support the traditional view of science education. In terms of the concept of Normal Chemistry Education, we can expect more specifically, for any attempt to escape from Dominant School Chemistry, a rigid adherence to the current combination of the pedagogical, philosophical, and substantive substructures of school chemistry.

As for the substantive structure, it can be expected that only marginal revisions will be allowed, that is, that some topics or concepts will be deleted (or added!) without changing the core of the traditional, corpuscular oriented content. A more radical change of content would be required, if and when a new curriculum emphasis would be taken up seriously. It would mean that a new substantive structure would have to be coordinated with a new pedagogical structure and new philosophical structure.

The recent reform of school chemistry in lower secondary education in the Netherlands ("Basisvorming") though fundamental in intent, turned out to be rather superficial in practice. with regard to content and teaching approach still largely of a traditional nature. As such, it is a good example of the mechanism of resisting fundamental change (Van Aalsvoort, 2000).

A radical reform of the current philosophical structure (educational positivism) would have to replace the ruling textbook image of science, which is still deeply ingrained in current textbooks, in the practice of teaching, and to a large extent also in the practice of teacher training, with a more philosophically valid position (Hodson, 1988). Many aspects of scientific research receive a simplified treatment in science textbooks. For example, the scientific method is reduced to a number of steps (Schwab, 1964), and the process of measurement is not dealt with explicitly but by implicit definitions, hidden from students (Kuhn, 1963).

It is likely that teachers, who are not familiar with a more valid philosophy of the science underlying scientific research, will fall back on some version of the textbook image of science, especially when the ‘new’ textbooks are not coherent in the philosophical message communicated.

Some of the latest curriculum reforms of school science address in their pedagogical structures a number of often fundamentally new aims or attainment targets, without as a rule being very specific about the teaching strategies which are needed to realize these new aims. This calls for developmental research projects in which teaching approaches need to be developed and adapted to any new aim or curriculum emphasis. Teachers, as well as students, need at least some heuristic which will lead them to the newly set aims (Janssen, 2004). Failing such an heuristic, whether for a *Science Technology and Society* oriented curriculum or for a *History and Philosophy of Science* oriented curriculum, teachers and students will, as before, fall back on traditional strategies such as transmission and reproduction.

3.4.3 Conditions of escape and the concept of developmental research

In attempts to develop a fundamentally new curriculum emphasis – matching in a coordinated and coherent way a new curriculum structure to a new curriculum aim – it seems be necessary to accompany the fundamental curriculum reform with systematic *developmental research*, succinctly described by Lijnse (1995, p. 192) as follows:

> The design of such teaching is therefore necessarily an empirical process of closely interconnected research and development, that we call “developmental research”. It concerns a cyclical process of theoretical reflection, conceptual analysis, small-scale curriculum development, and classroom research of the interaction of teaching-learning processes.

Given the tentative nature of such a project, it is mandatory that, at each level of the curriculum project, sufficient data are collected in order to test the validity of the new hypothetical curriculum vision and to arrange for the necessary revision or feedback. This is like “the dialectic, recursive interaction between Purpose and Policy (ends) and Programs and Practice (means)”, the process discussed by Schwab and Roberts earlier.

This labor-intensive and time-consuming developmental research has been used, up to now with reasonable success, mostly in the development and operationalization of individual units or topics (Vollebregt, 1998; Janssen, 1999, Kortland, 2001; Van Rens, 2005; Westbroek, 2005). The need to apply developmental research (Lijnse, 1995) to large-scale curriculum projects, though, is being gradually realized (for example, see Aikenhead, 1997).

Thus, the difficulty to escape consists, after knowing where to escape from, in the need to develop a coherent, new vision. This is a complex task requiring an innovative strategy preferably combined with painstaking developmental research at a number of curriculum levels addressing the coordination of the three substructures. Feedback of this developmental research is needed both to articulate and revise the tentative new vision and to identify and hopefully overcome the pitfalls and resistance met during the fundamental reform of the traditional curriculum structure of school chemistry (See Figure 3.11).

Figure 3.11 Three conditions of escape

CONDITION ONE: *In order to escape, we have to know what to escape from.*

- Perform a domain-specific analysis of the structure of the currently dominant school chemistry curriculum, using the curriculum framework developed here.

CONDITION TWO: *In order to escape, we have to know what to escape to.*

- Aim towards a coordinated replacement of the currently rigid combination of a substantive, philosophical, and pedagogical structure of school chemistry.
- Develop and legitimize a new coherent vision on the structure of a school chemistry curriculum, that is, a new curriculum emphasis for school chemistry, taken here as a new combination of a substantive, philosophical, and pedagogical structure.

CONDITION THREE: *In order to escape, we have to know how to escape.*

- Use a systematic method to articulate, operationalize, and implement the new, conjectural vision, which should operate in the following ways:
- Collect evaluation data at all curriculum levels to safeguard the adopted vision.
- Be aware of, anticipate, and avoid, or at least deal in time, with any difficulties related to the dominant school chemistry curriculum at all curriculum levels.
- Check the newly chosen curriculum emphasis for consistency at all curriculum levels: from the visionary, designed curriculum up to the taught and experienced curriculum level.

In the next two Chapters we will see how the Salters' Chemistry Project fares in the complex curriculum areas of development, research, and implementation. The detailed evaluative research reported will enlighten us in important ways about how the three conditions of escape can be fulfilled, that is, how to articulate a new vision while preventing the importation of the old one, and to plan, realize, and test the new vision by developmental research.

4 Salters' Chemistry: A curriculum analysis of its development process

> *" ... a window of opportunity ..."*
> *Francesca Garforth*

I start this chapter by describing the aims, rationale and method chosen for the evaluative research into the Salters' Chemistry curriculum, a Science, Technology and Society (STS) curriculum which made a serious attempt, by trying to develop a relevant 'Chemistry for All' course, *to escape from* Normal Chemistry Education (NCE) as embodied in England in a core chemistry syllabus (section 4.1).

The developmental process of the Salters' Chemistry project is analyzed in terms of the curriculum theoretical framework presented in section 1.3, that is, in terms of Schwab's substructures pertaining to each curriculum level (Goodlad) of school chemistry, Roberts' concept of curriculum emphasis, and the Kuhnian concept of normal chemistry education.

In order to determine whether, and to what extent, the developers succeeded in their endeavors, I first describe the problem situation in secondary chemical education in England in the 1970s as perceived and diagnosed by the developers, in particular by the project manager Francesca Garforth (4.2). Out of this evolved their vision of an alternative provision of chemistry for the secondary school level, to be called here the *visionary* curriculum (section 4.3). The promising results of designing relevant chemistry units in a first workshop, that is, of the *designed* curriculum, led to the decision of the developers to embark on a *full-scale* trial: the subsequent design of a one-year transitional course in chemistry for 13-14 year olds (section 4.4), followed by the development of a two year exam course in chemistry for 14-16 year olds (section 4.5).

The final revision of the *written* curriculum led to the formal acceptance of the GCSE Salters' Chemistry course for 13-16 year olds by an examination board, that is, the *formal* curriculum (section 4.6).

In sections 4.3-4.6, I compare, in terms of my theoretical curriculum framework, the successive curriculum phases of the Salters' Chemistry project: "Vision", "First articulation", "Year Three", "GCSE draft", and "GCSE revised" with the traditional 'academic' provision of school chemistry for 13-16 year olds as it existed in England at the time. Finally, I will discuss the results of these comparisons, the process of transformation of one curriculum level to another, and the *degree of escape* of the realized Salters' Chemistry course from NCE (section 4.7).

In the next, complementary chapter *Analysis of "Metals", a Chemical Unit of the Salters' Science Curriculum*, I perform a similar curriculum analysis on one of the chemical units of the Salters' Science curriculum, *Metals*, as designed by the developers. Here the analysis is extended to the curriculum unit as interpreted and taught by a teacher, and experienced and learned by students in the classroom.

4.1 Aims, rationale, and methods of research

First described here are the aims of my evaluative research on the Salters' Chemistry curriculum (4.1.1), followed by the rationale for choosing Salters' Chemistry as an object of study (4.2.2), and a discussion of the evaluative method I have used in this chapter and the next (4.3.3).

4.1.1 Aims of research

The aims of my evaluative research into the Salters' Chemistry[1] curriculum are to:

- analyze the Salters' Chemistry curriculum in terms of my curriculum theoretical framework in order to determine in what respects its curriculum structure *differs* from the traditional structure of dominant school chemistry;
- analyze the process of transformation of one curriculum level to another, and ascertain the degree of escape of the Salters' Chemistry course from dominant school chemistry, taken as a form of Normal Chemistry Education;
- explain these differences, mechanisms of transformation, and the degree of escape in terms of the concept of Normal Chemistry Education;
- assess the usefulness of my curriculum theoretical framework for analyzing both traditional and innovative school chemistry curricula.

4.1.2 Rationale for choosing Salters' Chemistry as an object of study

In Chapter 2 I have described the rigid structure of the currently dominant school chemistry curriculum, and given a functional explanation of this international curriculum phenomenon in terms of the concept of Normal Chemistry Education (NCE). This leads us to the question: to what extent it is possible, if so desired, to *escape* from dominant school chemistry or NCE?

The Salters' Chemistry course, an STS school chemistry curriculum for 13-16 year olds, seemed to observers, and was claimed as such by the developers, to be a *radical* departure from traditional school chemistry as it existed in England in the 1980s. Thus, a number of well known researchers and developers of chemical education present at the 11th International Conference on Chemical Education (ICCE), having heard several presentations on the rationale, characteristics, and effectiveness of the Salters' Science approach, seemed to think that the Salters' Chemistry course was a revolutionary alternative to traditional school chemistry (Kempa & Waddington, 1992). Put in terms used in this thesis, Salters' Chemistry seemed to these observers to be a bold attempt to

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[1] The Salters' Institute of Industrial Chemistry offered, from 1982 on "considerable financial help and encouragement" (The Salters' Chemistry Course, An Overall Guide for Teachers, 1988, p. 81), while large industrial organizations provided the rest of the funding. The projects developed and managed by the University of York Science Education Group (UYSEG) have been called "Salters' Projects", e.g. Salters' Chemistry, Salters' Advanced Chemistry, and Salters' Science.

escape from dominant school chemistry, both from traditional school chemistry *teaching* and from traditional school chemistry *content*. These perceptions were shared, as we saw in Chapter 2, by about half the members of the International Forum (which included some of these observers) and by a number of members of the Dutch Forum.

A first, global characterization of the Salters' Chemistry course can be given in terms of Roberts' curriculum emphases, namely, as a relevant school chemistry course which combines an emphasis on *Everyday Applications* by using science to understand both technology and everyday occurrences, and a curriculum emphasis on *Science, Technology, Decisions* by adducing the role scientific knowledge plays in decisions that are socially relevant (see section 3.3, Figure 3.6). The Salters' Chemistry course can be given a further categorization as a "Science through STS" curriculum (Aikenhead, 1994, p. 55), a categorization which taken over by the Salters' development team, albeit with some reservations (Campbell et al.,1994). In line with this, one could categorize the Salters' Chemistry course as a C*hemistry through CTS* curriculum (CTS), that is, as a school chemistry curriculum which attempts to make school chemistry relevant for all students by connecting chemistry as a science to the technological and societal contexts of chemistry present in students' daily lives (see further section 5.1.4).

Aikenhead (1994) has formulated his categorization of STS courses in terms of STS content and "Pure Science" content. In the Salters' Chemistry course then, STS, or rather CTS content set in a CTS context, is meant to serve as an organizer both for the Pure Chemistry *content* used or needed to make sense of the CTS context and for the *sequence* of chemical concepts deployed in teaching. That is, the CTS content set in a CTS context is seen as a *central* component of the school chemistry course and is not merely added on to a traditional theory-driven, pure chemistry course (Holman, 1987; Fensham, 1992).

CTS curricula such as Salters' Chemistry are to be seen as largely different from the curriculum products of the 1960s and 1970s which attempted to modernize science curricula in terms of general theoretical concepts and by emphasizing scientific inquiry and reasoning processes while, predominantly, aiming at recruiting future scientists (section 3.2). Such science-oriented curricula as part of their pedagogical structure largely retained the traditional aim of preparing students for the future study of science, by offering an upgraded version of the traditional substantive and philosophical structures of science curricula. In reaction to the sobering analysis and critical evaluation of this 'wave' of science-oriented curriculum projects, STS curricula of the 1980s generally attempted to effect different and more radical changes in traditional school science. Formulated in terms of Schwab's curriculum categories, an STS or CTS curriculum, here Salters' Chemistry, attempts to change in a coordinated way the:

- Pedagogical structure: both through its aim, *Science for All*, and through its context-led teaching approach from which (the sequence of) concepts emerge;
- Philosophical structure: by emphasizing everyday life and the societal and technological contexts of chemistry;
- Substantive structure: by adding CTS content, or CTS concepts as entailed in the selected contexts, and by discarding Pure Chemistry concepts not needed to make sense of the selected context used in teaching (Smith, 1988).

To sum up, Salters' Chemistry is taken here as a school chemistry course for which the CTS content is a *central* component. It constitutes, therefore, a bold attempt to escape from NCE.

The Salters' developers themselves (the pioneers, members of the development team, first teacher-users) made some explicit statements about the radical change they tried to achieve. First of all, Francesca Garforth, manager of the Salters' Chemistry project, stated that they wanted:

> To break away from the traditional mould and produce a *radical* rather than a piecemeal or *cosmetic* revision" (Garforth, 1983, p. 29).

Secondly, Holman (1987), who joined the Salters' Chemistry Project in 1984 as a developer of Year Three units, characterized the Salters' Chemistry course as "a *radical* approach, starting with everyday interests and experiences of students" (ibid., p. 436) which involved a "*radical* reappraisal of school chemistry" (p. 435). Holman described the central CTS approach of Salters' Chemistry as an "*applications first* course" (p. 434) contrasting it with the traditional, academic "*science first*" (p. 434) courses. The latter type of course might enrich its traditional content with add-on STS materials, such as SATIS units (1986), while retaining almost all the traditional *content* as well as the traditional linear *sequence*.

Thirdly, Smith (1988) analyzed the content and assessment procedures of various GCSE courses, including Salters' Chemistry. Two units of the latter course, *Metals* and *Warmth,* were trialled in his school which acted in 1984 as a Salters' Project school. He concluded that the "utilitarian aspects" (ibid., p. 109) of the Salters' Chemistry course made up a considerable part of the course, and that these aspects were also included in the assessment by specimen papers. The Salters' Chemistry course contained, in the terms used above, more CTS content than any other GSCE course he analyzed, and also more than was required by the draft National Criteria for Chemistry of 1985.

Finally, in the retrospective analysis of the Salters' Science approach by a number of its developers (Campbell et al., 1994, p. 423), it is maintained with regard to the *process* of development that:

> The design criteria approach thus encourages a *radical review of content,* and minimizes (though it does not remove) the influence of content selection decisions implicit in previous curricula.

The design criteria approach, an original attempt at curriculum development by the Salters' Project Team, will be discussed in section 4.3.4. The product of the developmental process, the Salters' Chemistry course, was claimed by those involved in the development, as well as perceived by a number of researchers and developers, as a *central CTS curriculum*, constituting a bold attempt to escape from dominant school chemistry or Normal Chemistry Education. For the theoretical reasons given above, the Salters' Chemistry curriculum was, therefore, considered by me as the most suitable candidate for the evaluative research undertaken here.

Practical reasons

Information about the Salters' Chemistry course prior to the conference was available in publications, and more information, such as syllabi and examples of teaching materials, was quite easy to collect at the Salters' presentations at the11th ICCE (held in York in 1991). At the conference I also arranged to have some meetings with John Lazonby who had been a member of the Salters' Chemistry Management Team (1984-1988). In those inspiring and extensive discussions, Lazonby also provided some striking examples of teaching activities, e.g., teaching chemical equilibrium by starting from a context of making a fertilizer, which illustrated that the Salters' Chemistry project made changes in traditional chemistry *teaching* and also, to a certain extent, in the chemical *content* of school chemistry.

Thereupon, I decided to try to perform a classroom-based case study of one or more Salters' Chemistry units. An in-depth qualitative case study could show to what extent *a change in chemistry teaching and content* had in fact been achieved by a classroom teacher while using units of the Salters' Chemistry course. (This classroom-based research is reported in Chapter 5.) Prior to that, an in-depth document and interview study could show to what extent *a change in chemistry teaching and content* had in fact been achieved by the developers in what I call the "design room", on which I will report in this chapter.

My research plan was discussed with David Waddington, Chairman of the University of York Science Education Group (UYSEG) which manages the Salters' Science Projects. This led to arrangements, made by his colleagues David Edwards and Peter Nicolson, for short visits to various schools that were using Salters' materials. The next year, a pilot study was performed by a teacher trainee from Utrecht, supervised by this researcher, which led to a report (De Gier, 1992) and which prepared the way for my own classroom-based research into two chemical units of Salters' Science, *Metals* and *Transporting Chemicals*. The results of the empirical research on the first unit, *Metals*, were subjected to further analysis in terms of my curriculum theoretical framework (see section 5.1.1 for the rationale). This led to a description and subsequent comparison of the visionary, designed, formal, interpreted, taught, and experienced curriculum levels of *Metals*, a unit of the Salters' Science course (reported on at length in Chapter 5).

To sum up, the Salters' Chemistry course provided not only an excellent *practical* opportunity for doing the research I wanted – it was accessible, suitable, and feasible, it also provided a good *theoretical* opportunity to test the effectiveness of a central CTS course to escape from Normal Chemistry Education. Or, in the words of the developers:

> The Salters' courses based upon an apparently *novel* structuring principle, provide a particular opportunity to explore the extent to which *structural variation* in chemistry syllabus design is possible in practice (Campbell, 1994, p. 443).

4.1.3 Method of curriculum evaluation

As Jackson (1992) notes in the *Handbook of Research on Curriculum*, curricula – science curricula not exempted – form a very complex field of study. This applies even more to the study of innovative science curricula, and to the study of their processes and products. Accordingly, "to provide a comprehensive understanding of the complex reality" (Parlett & Hamilton, 1977) constituted by an innovative chemistry curriculum such as Salters' Chemistry, I used the components of the curriculum theoretical framework as formulated in section 1.3.

The Salters' Chemistry course is characterized in terms of Roberts' concept of curriculum emphasis. The phases in the process and the intermittent products of the Salters' Chemistry development project are described in terms of Goodladian curriculum levels: visionary, designed, written, and formal curricula. To these curriculum levels is applied a further characterization in terms of Schwabian substructures: substantive, philosophical, and pedagogical. Finally, the concept of Normal Chemistry Education is used to explain the curriculum findings obtained.

Thus, in developing a framework and method of curriculum evaluation for the study of the development of the Salters' Chemistry curriculum (section 1.2.3), it is important to acknowledge the complex nature of science curricula:

> It becomes imperative to study an innovation through the medium of its performance and to adopt a research style and methodology that is appropriate" (Parlett & Hamilton, p. 21).

Thus, the researcher "concentrates on 'process' within the learning milieu, rather than on 'outcomes' derived from a specification of the instructional system" (ibid., p. 22). Parlett and Hamilton use the term *illuminative evaluation* for this kind of curriculum evaluation in order to distinguish it from comparative curriculum evaluation. Their reasoning implies a choice for a *qualitative* research design in which a substantial amount of time is spent in the classroom, for example, by performing a case study in order to investigate empirically the interpreted, taught, and experienced curricula. In this research this was done for the Salters' Science unit *Metals* (Chapter 5).

In considering the process of development of the Salters' Chemistry curriculum as a whole, we think it imperative to study also the important curriculum levels that were *prior* to those associated with teaching and learning that is, the formal, designed, and visionary levels. Thus, in this chapter another "medium of performance" of the Salters' Chemistry innovation is investigated by taking a look, as it were, into the *vision and design room* of the Salters' Chemistry project.

To what extent does the Salters' Chemistry course escape from Dominant School Chemistry? In order to answer this research question, I address the following curriculum levels later in Chapters 4 and 5. In so doing I focus on the process of transformation, from one curriculum level to the next, by asking to what extent these transformations proceed consistently, starting with the visionary curriculum.

- *Visionary* curriculum: the formulation by the developers of a vision of the new curriculum together with a number of design criteria;
- *Designed* curriculum: the first operationalization of the design criteria by designers or pioneer developers in a prototype;
- Written curriculum: the follow-up of the designed curriculum which is realized by elaborating or revising prototypical teaching materials after trials or testing in the classroom;
- *Formal* curriculum: the official codification of the written curriculum product in a syllabus by the developers in collaboration with the staff of an examination board;
- *Interpreted* curriculum: the curriculum (units) as perceived by teachers;
- *Taught* curriculum: teachers in the classroom executing the curriculum units;
- *Experienced* curriculum: students in the classroom experiencing the teaching of curriculum units.

Consistency analysis

Firstly, the curriculum vision of Salters' Chemistry is formulated in terms of a number of design criteria as given by the developers, criteria which must be articulated and operationalized during the process of designing concrete teaching units. In this chapter, I therefore analyze the Salters' Chemistry course in order to answer the question:

> *To what extent are the design criteria of the Salters' Chemistry course adhered to consistently by the developers?*

This question will be answered for the following transformations: from the visionary curriculum to the designed curriculum (section 4.4), from the designed curriculum to the written curriculum (section 4.5), and from the written curriculum to the formal curriculum (section 4.6).

Secondly, it is not only the designed, written, and formal curriculum levels as such, "but their translation and enactment by teachers and students that is of concern to the evaluator and other interested parties" (Parlett & Hamilton, 1977, p. 21). Therefore, I systematically analyze "Metals" (Chapter 5), one of the units of this course, in order to answer the question:

> *To what extent are the design criteria of the unit adhered to consistently by developers designing the lessons of the unit Metals and by a teacher teaching the unit Metals?*

This question is answered in Chapter 5 for the following transformations: from the formal curriculum to the interpreted curriculum, from the interpreted curriculum to the taught curriculum, and finally from the taught curriculum to the learned curriculum.

In both analyses I perform what I will call a *consistency analysis*, an analysis of a curriculum in terms of its own design criteria, which can be considered as a form of *illuminative* evaluation. This kind of analysis is reminiscent of the analysis performed by Joling et al. (1988) on the "Chemistry for the Citizen" course embodied in the "Chemie-mavo" project, discussed in section 1.1.1, and of the analysis performed by Herron (1970) on the structure-of-the-disciplines curricula such as PSSC, ChemStudy, and BSCS, discussed in section 3.2. In the case of the Salters' Chemistry curriculum, the consistency analysis is performed between the curriculum levels mentioned above, each time checking the consistency of the transformation of one curriculum level to another. This will lead to results to be used for the illuminative evaluation of the Salters' Chemistry curriculum.

Preview

The curriculum evaluation reported on in this chapter addresses, first, the background and genesis of the vision laid down in a number of *design criteria* by the pioneering developers (section 4.2); second, the further interpretation and articulation of this vision (4.3), its operationalization in a full year foundational course (4.4) and in a two year exam course (4.5), and finally its codification as the formal curriculum (4.6).

The curriculum evaluation of the aims and claims of a complex curriculum reality such as Salters' Chemistry, of its curriculum levels and structures, provide us with the qualitative information necessary to answer the question concerning the extent to which the Salters' Chemistry curriculum manages to escape from traditional school chemistry. In brief, this evaluation enables me to answer the question concerning the extent to which the Salters' Chemistry course escapes from Normal Chemistry Education.

4.2 Traditional school chemistry in England

Germane to the setting out of which Salters' Chemistry emerged was the *problem-situation* in secondary chemical education in England in the 1970s, as perceived and diagnosed by the developers, in particular by the Project Manager, Francesca Garforth (section 4.2.2). Regarding the analysis, the sources and the method of analysis which I have used to examine Salters' Chemistry are discussed in the first subsection (4.2.1). Using Schwab's terminology, I categorize (subsection 4.2.3) the critical remarks Garforth made with regard to the existing provision of school chemistry in England, in order to *compare* them with the visionary curriculum of the Salters' Chemistry curriculum (described in section 4.3).

4.2.1 Sources and method

My account of how the developmental process in the Salters' Chemistry project unfolded – from the visionary curriculum to the designed curriculum and its various trials in the classroom to the written, formal curriculum – is based largely on three extensive interviews held with Garforth.

Each interview took about one and a half hours, producing about 60 pages of transcript *in toto*. The three interviews, though different in emphasis, allowed the selection of a set of consistent quotes. For purposes of comparison, I also used quotes from interviews I held with three other members of the Salters' Management Team: David Waddington, John Lazonby, and Peter Nicolson. These four interviewees were given the opportunity to check the quotes (used in earlier drafts of this chapter) for accuracy, as well as to read the draft chapters and comment on my analysis. This was done in 1997 and later also in 2001.[2] In addition to the interviews, I refer to publications of Garforth and other researchers, developers, and teachers involved in the Salters' Chemistry project which were written either before, during, or after the development.

The first interview – a *double* interview with Francesca Garforth, Manager of the Salters' Chemistry project, and David Waddington, Professor in Chemistry at the University of York, and member of the Salters' Management Team – was held in September 1991 by Christie Borgford, an American chemical educator as part of her Ph.D. research.[3] This interview, referred to as (G/W91), was an open type of interview that Borgford started off with a leading question addressed to both Garforth and Waddington:[4]

> What are your perceptions of the conditions in chemical education in England in the late 70s and your response to that, which I think of as the *rationale* for the beginnings of Salters'? What is your recollection of the development *process*? (G/W91:1)

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[2] Garforth (retired) gave individual responses, referred to as G97 and G2001, while Waddington formulated a common response, on behalf of the last three interviewees, referred to here as W2001.

[3] See Borgford, C. (1992). *Change in science teaching and science content. Case study of an experiment with four traditional chemistry classes, using the Salters' approach* (Research Report). York, UK.

[4] Quotes taken from the double interview are Garforth's unless otherwise indicated; numbers after the semicolon refer to page numbers of the transcripts of interviews.

The second interview was a semi-structured one, held by the researcher (BvB) with Francesca Garforth in October 1992. Most of my questions focused on the role which the *conceptual structure* of school chemistry, as described in subsections 1.2.2 and 2.3.2, might have played in the Salters' Chemistry development. This interview is referred to as (G92a). The third interview, also a semi-structured one, was held by another American chemical educator, Mary Beth Key, working on her Ph.D. research in York in November 1992.[5] Her interview focused on the evolvement of Garforth's views with respect to the *teaching and learning* of school chemistry. Key's main question was: "I just wondered, when did you start listening to your students?" This interview is referred to as (G92b).[6] Although a simplification, one could say that whereas Borgford focused in her interview on the "rationale" [Ped/A] of the Salters' Chemistry's project, and Key focused on the teaching approach [Ped/TA]. In my interview with Garforth, I focused on the role of the *conceptual structure* of school chemistry [Sub] and the underlying views on science and chemistry [Phil].[7]

The three interviews with Garforth turned out to be rich sources, especially of her original intentions and developing vision as Project Manager. Garforth's inspiration and influence has been acknowledged by her co-developers (Hill et al.,1989a).

As for secondary sources, I refer to a few relevant publications from the science education research and development literature, mostly in the notes so as not to disturb the 'storyline' of the Salters' Chemistry development process too much.[8]

In order to answer my research questions on the development and teaching of Salters' Chemistry in terms of *consistency* of the design criteria (section 4.1.3), and in view of the complex nature of the process of development, I think it is justified to describe this process in some detail. Also, using many and occasionally lengthy quotes from the developers might allow the reader to participate in the process and to discover or "rediscover the excitement of those years" (G97), as Francesca Garforth put it in retrospect.

4.2.2 Perception and diagnosis

Three factors determined Garforth's perception of the problem situation in chemical education in England in the late 1970s and beginning 1980s, namely: (i) her experiences as a grammar school teacher of chemistry; (ii) her findings on learning difficulties of O-level students with precursors to ionic equations in her M.Ed. thesis research; (iii) her experiences with the education work she had done, on behalf of the Royal Society of Chemistry, on chemistry core syllabuses, first for 11-14 year olds and then for 14-16 year olds.

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[5] Key, M. E. (1998). *Student perceptions of chemical industry: Influences of course syllabi, teachers, firsthand experience*. D. Phil. University of York.

[6] Both Christie Borgford and Mary Beth Key have kindly given me permission to quote freely from the interviews mentioned above.

[7] For the meaning of these abbreviations used from here on, see subsection 2.1.3, Figure 2.2.

[8] For example, Ziman's *Teaching and learning about science and society* (1980) proved to be an important and particularly relevant source. The general analysis of *conventional* science education that Ziman gives supports my own analysis. His concept of the "validity of scientific education" (ibid., p. 14), similar to the concept of Normal Science Education discussed in Chapter 2, is illustrated by the workings of the English educational system for the same time period, the late 1970s, as Garforth's analysis dealt with in section 4.2.2 above.

After having taught mainly very able students at grammar schools for most of her career, Garforth experienced the problem of *how to teach less able and less motivated pupils* for the first time in 1974 when her school became comprehensive. As she puts it herself:

> I began to realize a great many things about my own teaching ... that I hadn't made the slightest effort to tailor the subject to the child I was teaching. I just assumed it was just a matter of *from me to them* and it would be taken in. I hadn't thought of sequence of teaching. I hadn't thought of strategies for the less able. I hadn't thought what it was that *the less able, or even the moderately able,* were getting hung up on in chemistry: why they were finding it difficult. (G92b:1)

Her first attempt to remedy this state of affairs failed. It consisted of doing, together with her O-level colleague, a small educational experiment in which they tried to execute, and then compare, the results of two different *sequences* of teaching ionic equations. One teacher followed the standard textbook route with formula equations first and then deriving ionic equations from them, while the other taught ionic equations first and then formula equations. As Garforth remarked afterwards:

> So that [the experiment] didn't work, but what it did do was to enthuse me to come on the first year of the M. Ed. course here [organized by David Waddington in 1974 in York, titled Chemistry and Chemical Education] to do research on chemical education with Alex Johnstone and John Lazonby, and as my project, I thought I'd try and sort out the teaching of ionic equations ... first of all the precursors to ionic equations ... do you understand what an ion is, an atom, a proton, an electron, the difference between covalent and ionic ...; try and work out if we could find *a better route through* so that we got some *basic* ideas firmly instilled before we moved onto something that *needed* those *basic* ideas (G92b:2).

In 1976 Garforth published her findings in her M. Ed. thesis on learning difficulties with precursors to ionic equations.[9] One of her most remarkable conclusions was:

> It was the pre-A-level people, who were highly selected, in the top 15% of the ability range, and had chosen chemistry and were good at chemistry, who were still were having difficulties (G92b:3).

This conclusion was based on strongly correlated peaks, found in the answers to the differently formatted multiple choice questions she had put to O-level students, which pointed to learning difficulties that "had obviously come way back in understanding what was ionic and what was covalent" (G92b:3). Although the very able students had no problem at all with "taking it in" or with "passing the exams", at the same time "they weren't making any kind of sense out of the [ionic] equations" (G92b:3). As for the *less and moderately able* students – after many English schools became comprehensive, the *majority* of the student population were finding the traditional academic grammar school chemistry very difficult indeed, whether to take it in, or to pass the exams, that is, if they were entered for exams at all.[10]

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[9] Garforth, F. M. (1976a). *Learning difficulties of O-Level students with precursors to ionic equations*. M.Ed., University of York. For a summary of her results, see Garforth (1976b) and (1976c).

[10] Nuffield chemistry (11-14), which Garforth trialled from 1964-1967, seemed to work better for this age group because it focused more on *exploration*, on "doing and recording...[on] observing, asking questions" (G92a:6). But Nuffield chemistry (14-16) with its focus on "deep or atomic explanation" (G92a:7) was again, she felt, much too difficult for many students, except perhaps for the most able.

In 1978 in her capacity as a member of a small working party of the Royal Society of Chemistry (RSC), Garforth had the opportunity to work on a *proposal* for a possible *core* content of chemistry for children aged 11-14. The motive was that, at the time, "every school was allowed to do *its own thing* for the lower half" (G92a:6), that is, there was no coherence. The RSC working party presented, in the same year, a discussion paper which was received most "*favorably*" (G92a:6) by many of the thousand teachers to whom it was sent. The proposal was subsequently revised in the light of this consultation and sent to advisors and examination boards as "the RSC's idea of chemistry that *should* be taught in the early part of secondary education" (G92a:7). This core "genuinely reflected the views of teachers ... *it wasn't Salterish, but it wasn't academic*" (G92a:7). It was a *new* chemistry core, in which we "wanted to make sure there was some *basic* chemistry taught ... [and] ... attempted to bring about some kind of coherence for the nation's children at a time when there was no coherence at all" (G92a:6).

In 1979, Garforth had a sabbatical term in Cambridge as a teacher-fellow, which made it possible, as she explained:

> ... to devote time on behalf of the RSC trying to think out where the learning difficulties arose during standard CSE [Certificate of Secondary Education] courses where before I had been devoting my attention to GCE [General Certificate of Education] candidates, more able ones. I thought if the more able ones were suffering, *the less able ones were probably suffering more* ... (G/W91:1).

Relevant details of courses and examinations in England and Wales for secondary education in the period 1974-2000 can be found in Figure 4.1, kindly provided to me by Garforth, in 1997, on the occasion of her comments on an earlier draft of this chapter.[11]

On the whole our higher ability pupils did O-level [GCE], our next ability pupils did Mode 1 CSE, that is the one set by the Board and marked by the Board, and *the least able did Mode 3 CSE*, which was the one set and marked by *teachers* and moderated by the Board. (G92a:4)[12]

Figure 4.1 Examinations in England and Wales at age 16

Percentile of age group	1 – 30	30 – 60	60 – 80	(approximate percentile)
Exams: 1947 - 1974	GCE O-level	CSE Mode 1	CSE Mode 3	3 separate syllabi and exams
Grades	A – F	1 – 6	1 – 6	Grade 1 CSE = Grade C GCE
Exams: 1974 - 1986		"Common 16+"		1 syllabus; 1 exam
Grades	O-level grades	CSE grades		offered by some exam boards
		This exam co-existed with separate O-level & CSE		
Exams: 1986 -		← GCSE →		all exam boards; all pupils
Grades A		B C D E F G		

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[11] Most terms in this table are explained in the text. As for the term "16+", Garforth explained in her letter (G97) that this was a "very confusing" term which could refer to: (a) the age group of the pupils or (b) the common exam syllabus or (c) any exam (GCE or various modes of GSE) taken at age 16.

[12] "Board" refers to the examination board.

Initially CSE syllabuses and courses had to be *different* from O-level/GCE syllabuses, and for a few years they probably were, according to Garforth. After all, they were *intended* for those children who did not go to grammar schools, but who went to so-called ‘secondary modern’ schools, introduced in the late 1940s. But then these teachers were told:

> In order to get *validation* from the examination boards they [the CSE syllabuses] had to be seen to be *comparable* to GCE. It’s awful, isn’t it (G92b:14).

This ruling meant that “the CSE people just slavishly followed the [GCE] O-level syllabus” (G92b:14), except perhaps for a minority of teachers who had already devised and taught *alternative* CSE syllabuses, and managed to keep teaching accordingly.[13]

Unlike the chemistry core for 11-14 year olds which was *designed* by the RSC working party, a proposal really of what *should* be taught in the early part of secondary education, the chemistry core for 14-16 year olds was *abstracted* by Garforth from existing syllabuses.

> And the only way I could really do this was to go through *every* exam syllabus there was, that is, *all* the O-level syllabuses and *all* the CSE syllabuses and *all* the common 16+ syllabuses that were then coming on the market ... and *extract* from them *a core*. So this was literally a core that *was* there, not a core I thought *ought* to be there. This was the core that was being taught to 14-16 year olds (G92a:6).

Garforth then circulated this core to teachers and others involved in chemistry teaching throughout the country “in the hope that it would provoke a riot ... this is what we are teaching, but couldn’t we do something else” (G92a:6). Contrary to teachers’ favorable response to the proposal of the 11-14 core syllabus, the response of teachers this time, as hoped for and to some extent anticipated by Garforth, was not favorable at all:

> Everybody who it was circulated to by the RSC shot it down in flames” (G/W91:1).

Thus, the first core (11-14) was seen by teachers as a real attempt to escape from tradition whereas the second core (14-16) was definitely not perceived as such:

> Obviously something needs to be done; but this isn’t the way to set about it. All you have done is to collate the least controversial aspects of a number of CSE syllabuses and put them together. What you need to do is to take a completely *fresh* sheet of paper and start all over again (G/W91:3).

What was needed was a new vision, and some method to elaborate and implement such a vision. As for now, there seemed to be, on the part of teachers:

> ... a feeling of utter dejection that things never changed: the picture of chemistry was just as difficult, just as *traditional*, and *they didn’t seem to be able to break out of the circle ... cycle* (G92b:13).

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[13] Garforth herself decided, in this period, first to enter her candidates for an adapted, that is, more user-friendly *O-level* exam. “*We* [Joint Matriculation Board] were taking out a lot of the hard arithmetic, and the more complicated equations, we took out permanganate and dichromate equations for the O-level. *It was still on CSE!*”. And later she devised “a very simple minded Mode 3 syllabus” with easy, though strictly marked questions, which was therefore awarded grade 1 by the examiner (G92b:14).

Or, to put it in terms I use in this thesis, many teachers and others involved in chemistry education in England in the late 1970s suddenly seemed to realize three things about the existing provision for school chemistry: (i) the rigidity of traditional syllabuses, that is, of Normal Chemistry Education (NCE); (ii) the necessity and willingness to break away or escape from NCE; with at the same time, (iii) the strongly felt improbability of being able to escape from NCE.

Let me summarize Garforth's perception of the situation in chemical education in England in the 1970s, and her diagnosis, as follows. Firstly, the provision for 11-14 year olds, *should* contain some basic and coherent chemistry, but not be academic. Secondly, the existing academic provision for chemistry for 14-16 year olds *can be taught to the exam*, but only to the more able, a minority of the students (about 20 % of the age group). Thirdly, research has shown that it *cannot* be taught successfully for *understanding*, neither to all of the more able students, nor a fortiori to most of the moderately and less able students, the majority in comprehensive schools. Therefore, it seemed unreasonable to continue the practice of teaching this majority a similar academic content as contained in traditional grammar school chemistry syllabuses.[14]

4.2.3 Discussion

At various places in the interviews Garforth gives a succinct description, as well as a critical analysis, of many aspects of the then existing provision for chemistry for 14-16 year olds in England from which many teachers wanted to get away. That provision is taken in this thesis as a representation of normal chemistry education (NCE) in England in the 1970s.

I categorize her characterizations and critical remarks with regard to the different curriculum levels of the Salters' Chemistry project in terms of Schwab's curriculum structures. (The structures were introduced in Chapter 1, and codes in Chapter 2, Figure 2.2.) This categorization is continued throughout this chapter, both for Garforth's perception of NCE in England and for the visionary curriculum and its realization which, if it had been successful, would have had to replace part of the NCE as it existed in England at the time.

I begin my discussion with components of the pedagogical structure [Ped]. The aim [Ped/A] of traditional or grammar school chemistry which Garforth perceived at the time for students was:

> Passing the exams [O-level] and going on to A-level, passing the exams and going on to university and becoming doctors or vets or whatever it was they wanted to become (G92b:1).

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[14] Ziman (1980, p. 16) explains the mechanism at work here as follows: "the '*validity*' of scientific education ... leads to debates which are often resolved by a compromise that ... transfers the *pressure* to the earlier stages of education" (ibid., p. 9). In this case the content of the new CSE syllabuses had to be *comparable* to the *validity* of O-level, which should prepare for A-level chemistry, the validity of which derives then, ultimately, from "*valid* science" (ibid., p. 22) as it is recognized by research scientists. See Garforth (1983, p. 29) for a similar statement. Chapter 2 of this thesis gives a functional explanation of this mechanism in terms of *normal science education*.

Garforth characterizes the traditional teaching approach [Ped/TA] as an activity in which teachers *transmit* what was required by the syllabus: “*from me to them* ... to people who had to be fed” (G92b:4). The information to be transmitted came from chemistry textbooks most of which were theory-based, and had a linear sequence. When she later trialled Nuffield chemistry, it led her to the realization that students were “people with a problem” (G92b:4). Her teaching then changed into “a communal activity in trying to get the class to devise solutions” (G92b:4), a problem solving approach [Ped/TA] within the bounds of academic school chemistry (NCE).

Garforth also makes a few remarks on aspects of the philosophical structure [Phil] of traditional school chemistry which, as she says, is introduced through “*a solid foundation of theory*” (G91b:3), that is, the idea “to work from theory up to experiment” (G92a:2). Traditional school chemistry, including Nuffield chemistry, was so “hung up on explanation at the atomic and sub-atomic level” (G92b:17), and as a consequence, “we plunge[d] them [the children] straight into the submicroscopic” (G92a:2); that is, “we were asking the fourteen year olds for a lot of *abstract* conceptual ideas which *they just couldn’t cope with*” (G92b:3). This led her to a second, maybe even more important realization: “What *justification* is there for it?” (G92b:3).

> Do we have *any justification* in making chemistry the sort of subject where we insist that they understand in terms of electrons and protons and movements of atoms and molecule [and] we say, well you’ve got to *accept* this for the moment. You can’t possibly understand it (G 92b:4).

The theoretical framework in terms of which Garforth formulated and interpreted some of her conclusions above owed much, she said, to the work of Alex Johnstone[15] “into the concrete/abstract accessibility content of school physics, chemistry, and biology” (G92a:2). For example, Johnstone’s research does not support the suitability of an abstract, theoretical approach to teaching chemistry for 14-16 year olds, let alone for 11-14 year olds.[16]

Waddington has aptly described the type of school chemistry with a strong emphasis on *solid foundation of theory* – one of the curriculum emphases identified by Roberts’ (1982) – as teaching or learning by “deferred gratification” (p.c.). That is, it is only at a later stage that some students will see the point of their O-level chemistry (see also section 3.4.1). This *can* only apply to the minority of students in an O-level classroom who will take A-level chemistry, and really only to those few students who then go on to study chemistry as a major or minor subject, that is, for those very few students for whom there *is* such a later stage in their studies.

In Garforth’s opinion, conventional school chemistry focuses on “chemicals in the laboratory as distinct from kitchen objects” (G92b:9). And it had to be “real chemistry” (G91:18) in the minds of “the great and the good – I mean the people who were really chemists” (G92b:9). The answers to the questions which textbooks provide are “either

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[15] In the interviews Garforth discusses, for example, the accessibility, for the teaching of school chemistry, of the macroscopic (concrete) and submicroscopic (abstract) levels in chemistry and the relation of both levels to a third, representational level as distinguished by Johnstone (1982; 1993).

[16] This is also not supported by the Piaget-based research of Shayer and Adey (1981).

right or wrong" (G92b:5); gray areas are not acceptable, either for students or for most teachers.[17]

Garforth's and Waddington's characterization of the existing provision for school chemistry for 14-16 year olds in England can be taken as a combination of two of Roberts' (1982) curriculum emphases: "S*olid Foundation*", stressing science as cumulative knowledge, and "Correct Explanations", science as reliable, valid knowledge (sections 1.3.3 and 3.3.3).

In the context of the interviews, Garforth characterizes the substantive structure [Sub] of traditional school chemistry, as it then existed in England, in rather general terms.[18] Conventional syllabi are dominated by theoretical chemical concepts on the whole, and by submicroscopic concepts in particular, and by "things you do in the lab, like heating, mixing with water, trying with indicator paper ... separating" (G92b:8). In brief, they are dominated by corpuscular chemical concepts and relationships [Sub/CR], and by standard chemical techniques [Sub/CT].

To sum up, traditional school chemistry, as perceived by Garforth, serves an academic purpose. It teaches in a transmissive and top-down way a kind of chemical knowledge which can be characterized as abstract in general, and submicroscopic in particular, with chemical techniques employed on chemicals in the laboratory.

4.2.4 Conclusion

It is now possible to formulate more precisely, and in terms used in this thesis, what the team of developers in York led by Garforth were planning to do.

First, they wanted "to break away from the *traditional* mould" (Garforth, 1983, p. 29), that is, from the *rigid* combination of the substantive, philosophical, and pedagogical structures which existed in dominant school chemistry. In other words, they wanted to escape from normal science education as it existed in England in the 1970s. Garforth's characterization of the O-level curriculum in England is summarized in Figure 4.2 below.

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[17] Nuffield developers attempted to make a change here too, in that it favored an open-ended approach with open-ended questions. In practice, however, the discovery approach proposed, with the pupil seen as a scientist, was difficult to realize even with bright pupils. One reason for this according to Garforth was: "you didn't want the children to ask questions that you hadn't the equipment for. Or even led to an argument that wasn't on the syllabus!" (G92b:7). Another problem turned out to be the lack of a regular textbook in Nuffield's trial phase. Hence, "in response to teacher demand, and pupil demand, and parent demand, the Nuffield team began to produce textbooks" (G92b:6). This, of course, came to detract even more from the open-ended character of the Nuffield courses. See also Schwab (1962, p. 55) for a lucid discussion of problems with regard to the real and "apparent openness" of much laboratory work, which is often "structured" and for which results are provided by the textbook. Ziman (1980, p. 27) makes the fundamental point: "*There is no real escape in this direction from the rigours of valid science;* what is to be 'discovered' thus must not be different from the scientific truth which the teacher is duty bound to transmit".

[18] At some points, though, Garforth does give details of the conceptual structure of traditional school chemistry, which coincide largely with the picture of dominant school chemistry as it came out of the fora (IF/DF) in this research (described in Chapter 2). Her response to one of our papers (De Vos et al., 1991) confirms this.

Her characterization *compared* with the currently dominant school chemistry curriculum (See Figures 2.3, 2.4. and 2.5) enables us to determine whether the O-level school chemistry curriculum can be considered as a form of Dominant School Chemistry (DSC) and thereby as a representation of NCE in England.

The *pedagogical* structures of both school curricula (the former O-level and the currently dominant school chemistry curricula) contain similar characterizations:

- of aims in terms of academic preparation of future chemists and exam-driven curricula;
- of the teaching approach using terms as *textbook-oriented*, *theory-led*, and to transmit;
- of the learning approach using terms such as reproduction or rote learning.

The *philosophical* structure of DSC is largely similar to that of the O-level curriculum: both emphasize a solid foundation of theory, corpuscular chemistry, and the certainty of answers to questions put to students. Though the *substantive* structure of DSC has been described in more detail with regard to the set of standard chemical ideas, it too will be considered as largely similar to the substantive structure of the O-level curriculum. Both curricula stress the application of laboratory techniques to simplified chemical systems. Therefore, the O-level curriculum as described by Garforth can be taken as a form of DSC, and as a representation of NCE in England at the lower secondary level.

Second, the developers would try to design, trial, and develop a *radical alternative* school chemistry "with *chemical awareness* for future *citizens* as a *principal* aim" (Garforth, 1983, p. 30), *a vision* addressing the need of the majority of students.

Third, the developers would proceed as follows. They would *try to discover, during the developmental process*, the exact components of an *alternative* combination of pedagogical, philosophical, and substantive structures, which would make up a justifiable, appropriate, and feasible school chemistry for the 13-16 year olds. The last point has been formulated, in retrospect, by the developers as follows:

> Only through the development of detailed teaching materials does it become clear what the broad aims mean – indeed whether or not they are *feasible* and, in that sense, have any *meaning*. Curriculum development is the process of *discovering* the detailed aims and objectives rather than starting with them (Campbell et al., 1994, p. 420).

The remarks of the developers made under these three points could be interpreted as touching on the three conditions for escape described in Chapter 3 (Figure 3.11), a topic to which I shall return in the next section.

Figure 4.2 The O-level chemistry curriculum

CURRICULUM CATEGORIES	O-LEVEL CHEMISTRY GCE / CSE CORE 14 – 16
Pedagogical structure	**Initiatory and preparatory for further study**
Aims	Academic preparation future scientists; Focus on needs of most able students, i.e. a minority of at most 20% taking exams.
Teaching approach	Top-down/transmit/from me to them; from theory up to experiment. Textbook and exam based.
Learning approach	Taking it in, textbook based. Syllabus/exam-driven.
Philosophical structure	**Educational Positivism**
Foundations of Science	Solid foundation of theory.
Methodology of Science	Problem solving: answers to questions either right or wrong.
Foundations of Chemistry	Submicroscopic level dominates. Atomic and subatomic explanation. Real, pure chemistry.
Methodology of Chemistry	Problem solving: answers to questions either right or wrong. Laboratory experiments.
Substantive structure	**Corpuscular Approach**
Chemical Concepts	Abstract conceptual ideas.
Chemical Relationships	Standard, e.g. corpuscular theory, periodic system, classification.
Chemical Techniques	Lab techniques applied to simple systems, i.e. to lab chemicals.

[a] Most keywords are drawn from interviews and publications of developers; some paraphrasing has been added.

4.3 The visionary and designed curriculum of Salters' Chemistry

Garforth's revealing experiences with the existing provision for school chemistry as a teacher, developer, and researcher had as a consequence that she became, on the one hand, "very disheartened about teaching" (G92b:11), but on the other, more determined and focused in her attempt to develop "a genuinely appropriate 16+ chemistry syllabus" (Garforth, 1983). It was in this spirit that she applied for a fellowship at the Leverhulme Trust, in order to create the circumstances for doing, what was for her, necessary chemical education work (G/W91:3).

This meant the articulation of a vision (section 4.3.2) and of an appropriate method of development of corresponding units (section 4.3.3). Together this led to the Salters' Chemistry project organized by the Science Education Group of the University of York. My description of the process of development, though, will begin with the developers' perception of three major obstacles on the road to the development of *any* alternative, relevant school chemistry course (section 4.3.1).

Where appropriate I will make a connection between the Salters' Chemistry management team's remarks on the process of development and the three conditions for escape discussed in section 3.4, and listed in Figure 3.11.

4.3.1 Three obstacles

In view of her diagnosis, Garforth had few doubts, either about the *necessity* or about the *desirability* of devising a new *relevant* chemistry syllabus which would depart *radically* from the content and teaching of traditional academic oriented school chemistry courses. But, would it be *possible* fully to "break away from the traditional mould", in other words, to escape from Dominant School Chemistry (DSC) as it existed in England at the time?

This led in the early eighties to a first workshop at the University of York, consisting of a small group of chemistry teachers, six from secondary schools and four from higher education, who set out to "produce a *radical* rather than a piecemeal or cosmetic revision" of existing 16+ chemistry syllabuses, characterized as "academic and abstract from too early a stage" (Garforth, 1983, p. 29).

Garforth's article, written April 1983 on behalf of the team of teachers-developers after their first workshop, has the significant title "*Chemistry to 16+ Examination: Work in Progress – Help Needed!*" Three obstacles are mentioned in it, of which the first is:

> First year University *content* [Sub] often appears to *determine* A-level *content* which in turn *determines* O-level *content*. Parity of Grade 1 CSE mode 1 with grades A – C at O-level *determines content* of CSE courses and both in turn *inevitably govern* the chemistry curriculum in the early years of secondary schooling. In view of the relatively small proportion of the age group continuing to A-level (about 7%) and an even smaller proportion using chemistry in higher education, it is *surely unreasonable that their needs* [Ped/A] should so overwhelmingly *prescribe content* [Sub] *and teaching methods* [Ped/TA] for chemistry 11 – 16 (ibid., 1983, p. 29, my italics; see also Figure 4.1).

Or, to put it in terms used in this thesis, is it possible to escape fully from the constraints which the pedagogical structure of DSC puts on the kind of content and teaching of chemistry at the secondary level?[19] The second obstacle is described as follows:

> It may well be that there is a *corpus of knowledge* [Sub] without which no syllabus could be called chemistry ... equally it may be that by our *own schooling, subsequent training and teaching we cannot see anything different* adequately filling the space called chemistry at this level (ibid., p. 29).

To put it in terms used in this thesis, is it possible for teachers, developers, and researchers in chemical education to escape fully from the substantive structure coordinated to the pedagogical structure of DSC (mentioned above)?

The third obstacle was, as Garforth and her co-developers found out, they were unable to agree beforehand what they meant by chemistry at this level of schooling. This raised the following questions:

> If it [Sub] really must be what we *recognize* now as an O-level syllabus, then should it be taught to any but *the most able* [Ped]? If the *academic nature* of chemistry [Phil] is *implicit* and *inevitable,* is it *worthwhile* attempting to rewrite chemistry syllabuses in terms of familiar, relevant, and socially and economically important materials and ideas? (ibid., p. 29)

We will see further below, that the developers did not make explicit in any detail what the structure was composed of, or what they called (above): "a corpus of knowledge without which no syllabus could be called chemistry". That is, they did not try to fulfill *condition one*: Perform a domain specific analysis of the nature and structure of the dominant school chemistry curriculum (see Figure 3.11).

What developers say here can be interpreted as follows: the constraints imposed by the pedagogical and substantive structures are *rigidly* coordinated with constraints imposed by the philosophical structure with regard to the proper nature of school chemistry. In Chapter 2 I gave an explanation of the rigidity of Dominant School Chemistry, in terms of the concept of Normal Science Education, more specific the concept of Normal Chemistry Education.

To sum up, it seemed difficult, if not improbable to the developers that they would be able to escape fully from the *rigid* combination of [Ped], [Sub], and [Phil] contained in Dominant School Chemistry.[20] But if this seemed so improbable, and since it was far more likely that it would only be possible to *graft* some relevant teaching material onto existing syllabuses, the question emerged, would "it be worth doing anything at all?" (ibid., p. 30). Such a conclusion, though, was regarded by the group at York as a "counsel of despair" (ibid., p. 30). They decided, as Waddington[21] has emphasized, "*to try a test*" (G/W91:3). This meant that the developers would accept the *challenge* to design a chemistry course which would "teach science for life ... life skills or whatever it is ... to *find out* what that meant ... what chemistry you taught" (G/W91:3). Addressing Garforth

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[19] Ziman (1980, p. 16) concludes that "the fundamental *vocational* purpose [Ped/A] of science education thus imposes upon it a certain degree of *uniformity* [Ped/TA] that seems to match the *universality* of science [Sub] itself ".

[20] As Ziman (1980, p. 29) puts it: "What I have tried to demonstrate ... is that the actual *form* of science education is *quite strictly determined by its content*, and is not susceptible to arbitrarily large variations."

[21] See, for example, Campbell et al. (1994, p. 419), where it is pointed out that the "implications ... had to be worked out *by trying to do it*" (italics theirs).

in the double interview, Waddington concludes: “I think that married up with what you wanted” (G/W91:3), that is, designing a school chemistry course aiming at *chemical awareness for future citizens*.

4.3.2 Tentative vision

Let me now describe more in detail the views Garforth, as Salters’ Chemistry project manager, arrived at with regard to both her vision and the way this vision could be realized. Where appropriate I will relate these views to the conditions of escape listed in Figure 3.11.

Background

At a general level Garforth’s vision had been nurtured by the study of publications and teaching materials produced by the science education community in England in that period. For example, the Association of Science Education (ASE) had been pleading for “Alternatives for Science Education” (1979), in terms of “Education through Science” (1981), the ideas of relevance and “Science for All” (1983). Furthermore, Garforth had done part of her chemical education work with Malcolm Frazer at the University of East Anglia, who, as she said, had influenced her with preliminary work on a teaching approach which started differently: “they’d had ideas about toothpaste” (G/W91:3). She also became acquainted with *existing alternative* resources: “a lot of very good science texts” (Garforth 1983, p. 30) for less able pupils which were rarely used. These included mixed science courses such as *Nuffield Secondary Science* (1971),[22] the *Less Academic Motivated Pupils* (LAMP) project (1976), and *Working with Science* (1978), all of which “provide courses based on materials and situations in the everyday world but which *deliberately do not attempt to explore explanations or understanding in terms of chemical concepts and principles*” (ibid., p. 30).

Finally, it was the exemplary local practice of chemistry teachers and the experience of comprehensive schools with CSE Mode 3 syllabuses for the less able pupils which prepared the way for what Garforth wanted to do. This eventually came to involve a lot of “hard work; writing materials, trials of these materials, evaluation, and rewriting” (ibid., p. 30); and further ahead, getting accepted by an exam board which was necessary for their later attempt at full-scale implementation at the national level.

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[22] Shayer and Adey (1981) claim, on the basis of their Piaget-based research, that Nuffield Secondary Science (13-16 range) – unlike Nuffield O-level Chemistry (11-16 range) and even Nuffield Combined Science (11-13 range) – is a course “initially well within reach of *concrete* operational thinking” (p. 122). Therefore, the *cognitive demand* or level of Nuffield Secondary Science “matched” rather well the abilities of “the great majority of children ... who might follow CSE or non-examination courses” (p. 121). Unlike the popular Nuffield Combined Science, though, this course was “relatively little used” (p. 149)!

Components of visionary curriculum

As for the aim of an alternative chemistry course, it was clear that in the first place it was meant to be a provision for the *majority* of pupils of *less and middle ability* which *might* also be suitable for the more able and thus in the end, for the full ability range [Ped/A]. Other components of the vision of the Salters Chemistry developers are nicely captured in the following quote:

> What we wanted to do was to tap peoples' views as to, first of all, whether *chemistry* [Sub] needed to be approached *differently*. And, secondly, whether it was possible *to do it any differently* [Ped/TA], I mean whether we could get away from starting with a *solid foundation of theory* [Phil] which a lot of children were *unable* to grasp at the age of fourteen and a lot never even *wanted* to grasp at the age of fourteen. And whether it would be a good idea, or a possible idea, to start them in on things which were the result of the *applications* of chemistry [Ped/TA] (G/W91:3).

Thus, the developers' view as to what *chemistry* should mean at this stage of schooling was changing – to put it succinctly: away from theoretical chemistry and towards *applied* chemistry.[23] Also, their views on teaching shifted from a 'top down' to a 'bottom up' approach, that is, from a theory-first approach to an approach which would put pupils' experiences first, either with *familiar materials* or with *applications of chemistry*. Thus, in my terms they were looking for a different combination of substantive, philosophical, and pedagogical structures that would cater for the majority of pupils.

Both vision and method of development were made more explicit in and *because of* the developmental process.[24] During a long weekend in September 1982, the developers reached a consensus which consisted of the five components given below (Garforth, 1983, p. 29). I will elaborate on each component by using comments that Garforth and other developers made in the interviews. The first component of their vision was:

> 1. That the activities which are carried out in a *chemistry laboratory* provide a *valuable* educative process for *all* pupils.

Garforth elaborates on this: "I'm sure there is a *motivation* in the actual *doing* of things and that we had to remember we are dealing with a chemistry syllabus, we are dealing with people [i.e. pupils] who are going to be working where there is chemical apparatus and they might just as well use it" (G92a:13). Therefore, the developers decided to use, optimally, the existing resources of the school laboratory, that is, "lab things, such as to filter, evaporate, distil, treat with acid, bash up with hammers ... " (G92a:12) should be in the course, and done by pupils. Activities in the laboratory should be approached differently, though, in order to turn these resources into "*worthwhile*" chemistry for *all* pupils. So, "*our problem* was looking for *familiar materials* with which we would do things that in the *lab* we had used to do with something quite *unfamiliar* like *sodium or zinc*" (G92a:15).

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[23] See also Harding et al.(1986), a researcher in chemical education who also contributed to the development of Salters' Chemistry. Harding argues that: "Chemistry is supremely a technological activity: we use, modify, purify and create materials and are concerned with the discipline of chemistry as a tool for enabling these activities" (p. 48). She feels strongly that "[a]n essential requisite for development is a change in view as to what chemistry *is*, the rest follows! (p. 51, italics hers).

[24] As the developers themselves state in retrospect: "the process of developing in detail a curriculum to promote scientific literacy is *an act of discovery* – finding out what such a curriculum might look like" (Campbell et al., 1994, p. 422; italics theirs).

This new starting point had an important consequence:

> And then we looked at these [things every child will have met in its everyday life] and thought, what can the children do with them, or what will happen if you do the ordinary kind of things that you do in the lab, like heating, mixing with water, trying with indicator paper, *so obviously at that point we'd got a set of ideas of experiments in our mind, but we were still holding out against concept sets* (G92b:8).

This led to the second component of their vision, namely:

2. For *some* pupils these activities may not develop beyond the *manipulative* and *observational* levels.

For these pupils, probably the majority of the less and moderately able, the emphasis should be on the "exploratory, yes ... and explanatory as long as you don't go too far" (G92a:20).

Activities at the manipulative and observational levels could concern things such as:

- the *making* of things, for example, "growing the biggest crystal in school" (G92a:13); or "raise scones" using baking powder which can give very young children, at home, in the kitchen, some idea about "*the principle* that an acid would react with the carbonate to give carbon dioxide to raise the scones with" (G92a:19).
- *doing* things such as "finding out what is in something ... in a great heap of shining, silvery metal", which a 15 year old pupil found and "her dad said it dropped off the back of a lorry". This turned out to be nickel, in the improvised "lovely lesson" following this up with "lovely green solutions". And by the next lesson this group of "moderate ability children ... had done *the reactivity series of metals*." (G92a:13)
- *observing* everyday life things, for example "something you can meet in your own kitchen", like seeing "plates with blackcurrant pie on it ... go green", while cleaning them with washing liquid. This then led , after a question of her granddaughter aged 7: "Does it do it with all the fruit?", to doing chromatograms with blotting paper and to the notion that not all fruits contain the same *indicator* (G92a:19).

Note that these are all examples of using existing resources optimally, either from the kitchen or the school lab, by exploiting the idea that "if you've got a resource there, see how you can use it" (G92a:13). Each activity leads to a simple and qualitative introduction of a basic chemical idea, respectively: the reaction of an acid with a base, the reactivity series of metals, and the idea of an indicator. These chemical ideas were set in a *daily life context* and appeared accessible to young pupils of average ability, a majority in secondary schooling. The principle behind these examples was later called *context and activity-based science* (Ramsden, 1994).

The third component of the developers' vision emphasized that:

3. *Other* pupils will *want* (and *need*) to explore the observations in terms of *chemical concepts and principles*.

This point would mostly concern some of the moderately able students and, especially, all of the *most able* students whose needs had always been taken care of by grammar schools in the past, that is, their perceived needs had “overwhelmingly prescribed teaching methods and content” (Garforth, 1983, p. 29). As the developers found out in that first workshop in York (1982), and much to their relief, it proved possible to *derive* chemical concepts and principles, including those needed for purposes of *explanation*, from “experiments with and reading about” materials and situations in the everyday world. For example, in activities related to what was called the *theme Crime*, “experiments on fingerprinting led to such *fundamental* scientific concepts as change of state ... and classification, those on casting methods for footprints to ... structure and synthesis, those on saliva and blood testing to catalysis and analysis” (ibid., p. 30).

This first design can be considered as an exemplar or prototype of what they wanted. It seemed that this *theme-led* approach (later called by them “context-led approach”) envisaged by the developers could work for pupils of *all* abilities, including the most able ones who wanted and needed fundamental chemical concepts and explanations.

The fourth component of their vision emphasized that:

4. *All* pupils will benefit from learning about the *sources and properties of familiar materials*.

As Garforth explains, “You see, in the old syllabuses, in the old teaching of chemistry you learnt about what to you and me are *simple systems*,[25] like sodium or chlorine, copper, and oxygen. Things children might never meet in their lives again, before or since, apart from oxygen” (G92a:14). The new “16+ chemistry syllabus genuinely appropriate for all future citizens” (ibid., p. 30) would be concerned with familiar materials: where they came from, which properties would be *useful* and for what *purpose*, and the effects of winning materials from the environment. For example, there could be lessons starting from themes such as “water, detergents, fuels” (p. 30). (See also the examples mentioned in the discussion of component 2.)

This led to the last component of their vision, namely:

5. It may be possible to develop concepts and principles through the work carried out on *everyday* materials and themes.

In the discussion following components two and three of their vision some examples were mentioned where the fifth component also appeared to be possible for the moderately able students working with the ideas: reaction of an acid with a base, reactivity series of metals, and indicator; and for the more able students working with such fundamental scientific concepts as change of state, structure, synthesis, and catalysis. In sum, this first workshop at the University of York had managed to produce at least a prototype of their vision.

By formulating their vision in terms of these five components of the visionary curriculum, and by producing a first prototype thereof, the developers fulfilled to a large extent condition two: Develop a new coherent vision on the structure of a school chemistry curriculum (see Figure 3.11).

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[25] See sections 1.2.2 and 2.3.2 for a similar point about what I called there, pure (school) chemistry.

Figure 4.3 Visionary curriculum of Salters' Chemistry[a]

CURRICULUM CATEGORIES	
Pedagogical structure	**Essential chemistry for living**
Aims	Chemical awareness for future citizens: learning about sources and properties of familiar materials. Focus more on needs of less able and moderately able students: a majority of ca. 80%.
Teaching approach	Bottom-up; Communal problem solving activity: theme, context, applications based.
Learning approach	Worksheets, no textbook; Accessible knowledge; Doing work, especially lab work.
Philosophical structure	**Relevance and Use**
Foundations of Science	Daily life phenomena/applications; Only most able need or want more theory, chemical concepts and principles, including those needed for purposes of deep explanation.
Methodology of Science	Communal problem solving activity, including social, economic oriented problems.
Foundations of Chemistry	Focus on exploration, on macroscopic level. Daily life chemistry e.g. home/kitchen. Explanation but not too far down the microscopic level.
Methodology of Chemistry	Making things; Analyzing of things made.
Substantive structure	**Familiar Materials Approach**
Chemical Concepts	Holding out against concepts sets; No preconceptions.
Chemical Relationships	Coherent basics; Recognizable sequential order.
Chemical Techniques	Lab techniques applied to familiar materials such as household materials and common phenomena.

[a] Most keywords are drawn from interviews and publications of developers; some paraphrasing has been added.

4.3.3 Method of curriculum development

Based on the five components of the visionary curriculum described above, the vision of the developers on the *process* of development was further articulated and characterized in terms of so-called *design criteria*, some of which were already implicitly present in Garforth (1983). I will first discuss what the developers have called the *design criteria approach* to curriculum development. This is followed by a brief account of the developers' organization of drafting and writing of teaching materials.

Design criteria approach

As the developers (Campbell et al., 1994, pp. 418, 420) stated in retrospect, the design criteria they choose were: "quite *general* criteria, providing direction but *not limiting the outcomes* at the level of detail". They thereby clearly distinguished their *design criteria approach* to curriculum development *from the more specific and constraining set of objectives* that a traditional curriculum development model uses. Initially, three general design criteria were formulated.

> ***Criterion one: No preconceptions***
> Start with "a completely fresh mind, a clean sheet of paper, and no preconceptions" (Garforth, 1983, p. 29). Getting rid of their own preconceptions was the most important criterion according to the developers, but they also thought it the most difficult to adhere to. It has been formulated in various ways, for instance, "We did try and rid ourselves of preconceptions as to what should be in a chemistry course" (G92b:8).
>
> ***Criterion two: Relevance***
> In view of the student-centered aim and the teaching approach adopted, "we were at great pains to *put familiar everyday experiences first*" (see components 1 and 4 of vision above).
>
> ***Criterion three: Context-led concept development***
> The developers wanted to find out whether "It may be possible to *develop concepts and principles through the work carried out on everyday materials and themes*"(see components 2, 3, and 5 of vision above).

By formulating their view on curriculum development in terms of these design criteria, the developers fulfilled, at least in a general way, condition three: Use a systematic method to articulate, operationalize, and implement the new, conjectural vision. In this and the following chapter on the Salters development process we will see more specifically, to what extent the developers were able to fulfill the conditions listed in Figure 3.11, in particular:

- Be aware of, anticipate, and avoid, or at least deal in time, with any difficulties related to the dominant school chemistry curriculum at all curriculum levels.
- Collect evaluation data at all curriculum levels to safeguard the adopted vision.

As noted above, the initial vision of the developers had much in common with what went on in curriculum reform in England in those years. There were also differences emerging, specific to the group at York, such as the *explicit* focus on the *full* ability range, on a relevant chemistry course for *all* students which includes the needs of the most able pupils. As Garforth put it:

> I used those teachers and their syllabuses shamelessly in trying to work out how we could use *the same approach* – an *experimental* approach to teaching chemistry [but] to the *full ability* range (G92a:4).

This implied that the "*essential chemistry of living*" (Garforth, 1983), the curriculum emphasis which the developers were trying to capture, should serve *both* the needs of a "scientifically aware electorate and [be] a basis for further study in chemistry" (p. 30).

As we will see below, this focus on the full ability range has consequences for the application of the third design criterion. It leads to an increased emphasis, not only for the most able but for *all* students, on *explanations* in terms of *abstract* chemical concepts and principles compared to exemplary CSE syllabuses or schemes for less academically minded pupils.

As has been evident from the interviews, the Salters' developers came to set great store by the first criterion, which can be seen as a kind of *a priori* conception or a so-called "tenet of faith" (G/W91), that developers and teachers participating in the developmental process should try to hold on to as much as possible.

Since the process of curriculum development is conceived as "the act of articulation of these broad aspirations" (Campbell, et al., 1994, p. 420), we will see that the design criteria stated above are reformulated in the process of development and adapted to the purpose at hand. The great advantages of the design criteria approach are that it is open to change, either to explication or evolvement of relevant design criteria, and that it invites the active participation of developers and teachers working on prototypes, trials, and revision of units. For example, in the process of development was also 'discovered' another design criteria, namely: *variety of teaching and learning activities.*

Organization

The actual writing of drafts of teaching material along these lines, that is, starting from general design criteria, was organized as follows. Teachers, six from secondary schools and four from higher education, were brought together at the University of York in September 1982 for the first Salters' workshop. Among the secondary teachers were "those who had responded most vituperatively to my mock [core] CSE syllabus sent out the previous year" (G/W91:3), that is "people who had written to me to say, here's my Mode 3 syllabus" (G92b:12).

> So, we got the ones who sounded as though they had the most to offer – school teachers on the one hand and an equal number of tertiary educators on the other hand. And with the money from the Salters' company we had them here for a long weekend. *So, that was officially the start* (G/W91:3).

These very *enthusiastic* teachers had a great "willingness to explore a completely *fresh* approach" (Garforth, 1983, p. 29) while trying to follow criterion one, *no preconceptions*. They were asked to submit in advance "a list of *familiar* chemical observations that could provide a foundation for starting chemistry in secondary school" (ibid., p. 29) in accordance with criterion two, *relevance*. A discussion on "their ideas as to what constitutes the essential chemistry for living" (p. 29) led to a consensus that it was too difficult to achieve this, as it were, *a priori*. Instead the developers chose to adopt criterion three, *theme-led development of concepts*, trying to work out the essential chemistry for the course empirically, that is, *a posteriori*.

Finally, four groups were formed, consisting of two or three teachers each, with at least one teacher from secondary and one from tertiary education. These groups then chose from a prepared list either familiar material or a *theme* from everyday life which they wanted to work on; subsequently, they "spent some time working on a teaching scheme suitable for the *full ability* range within the age range 13-15" (p. 29). In Waddington's summarizing statement:

> What we wanted was to *try a test*, we accept it [the emphasis on science for life] – and *find out* what chemistry you taught" (G/W91:4).

Evaluation and decision

The initial aim which they set out to achieve in this first workshop – to develop, starting from their general design criteria, drafts of relevant teaching materials – appeared to be feasible; a first prototype became visible. Although they "got left with bits of paper which weren't very sensible", as Waddington put it, they also felt that:

> We got left with the idea that it was *possible*, it would be terribly difficult, it might not be acceptable for the most able children – but it was a jolly good idea *for the least able* (G/W91:4).

Since it seemed possible to develop, starting from everyday materials and themes, *fundamental* explanatory chemical concepts and principles (see section 4.3.2) which the *most able* pupils would need or want to know, they agreed that further work in this direction was "both necessary and worthwhile" (Garforth, 1983). There were quite a few "reservations, though, about the practicality of achieving widespread acceptance" (p. 30) from an examination board. And they saw, as the greatest danger, that a theme- or applications-led approach might be so *incoherent* "that pupils following such a course might be even more confused at the end than they are already, after following existing O-level and CSE courses" (p. 30). At the end of the weekend four possible channels for future activities were distinguished (p. 30).

A. Identify the chemical concepts and principles which are necessary in order to appreciate and understand the content of any proposed *new* chemistry course.

B. Write and collate material for teaching chemistry through familiar substances and themes to fit in alongside or replace parts of existing syllabuses.

C. Collect and collate existing Mode 3 syllabuses and examination papers with a view to disseminating information about "relevant" syllabuses nationally.

D. Write a new 16+ chemistry syllabus based on everyday materials and the applications of chemistry, carry out trials in schools, and persuade an examination board to pilot it.

The group of developers at York decided not to do channel A since they had found out that it was not possible to agree, *a priori*, on a formulation of "*the essential chemistry of living*". Nor did they try to identify the structure of chemical concepts and principles, customarily present in traditional school chemistry courses and usually thought necessary for any new school chemistry course to be considered a proper course that is also acceptable to an examination board. In brief, the group of developers at York did not perform a domain specific analysis of the nature and structure of the dominant school chemistry curriculum (condition one), an analysis which I have performed and reported on in Chapter 2.

Channel B was also not chosen, though it was a channel which had been pursued by Garforth and other teacher-developers before and has been pursued by groups of developers in many countries. The most famous in the UK at the time was probably the ASE project *Science and Technology in Schools* (SATIS, 1986), which produced a resource of about a hundred units of one or two lessons (requiring about 75 minutes) that function as enrichment or "add-on" materials to existing "science first" courses (Holman, 1987).

The developers at York began by exploring the feasibility of Channel C. They pursued this for a short time, until they decided, for a combination of practical and fundamental reasons explained below in the section *Crucial Moments* (4.4.3), to abandon this route in favor of large-scale development of a new chemistry course, that is, Channel D. As Garforth (1983) remarks:

> After much discussion it has been decided to attempt the most ambitious project, i.e. [channel] D!

Thus, by electing to pursue channel D, the developers hoped to find out empirically what would constitute a specific, *concrete teaching scheme* out of which would evolve a general, alternative syllabus and the chemistry involved in this. According to Francesca Garforth, "We didn't make any decisions about 'should' ... at the outset we were looking about 'did', *what did come out of it that was recognizably* chemistry" (G92b:9).

4.3.4 Conclusion

The most radical changes in the visionary curriculum of the Salters' Chemistry course compared to the traditionally realized O-level curriculum in England are visible in the *pedagogical* structures of these curricula. While the former is oriented towards the needs of all students, including the more able, and emphasizes thereby the needs of the less and moderately able students as future citizens, the latter is mainly oriented towards the needs of the future chemists, emphasizing thereby the needs of more able students. The visionary curriculum of Salters' Chemistry also favors the use of a bottom-up, applications-led approach to teaching chemistry, a teaching approach in which it is attempted to use laboratory activities related to daily life contexts as well as other practical activities taught by way of worksheets, against the theory-led and textbook-based approach of the traditional O-level curriculum. It is important to note that although the latter's intended curriculum did originally aim at student's understanding of chemical concepts, what it as a rule actually *realized*, was a kind of teaching to the test or to the exam, and a type of rote-learning. (See, for this point, the IF analysis in Chapter 2, leading to the concepts of Dominant School Chemistry and Normal Chemistry Education; the analysis in section 4.2.2 based on interviews with Francesca Garforth; and the analysis of Ziman (1980), all concurring in this conclusion.)

The major changes in the *philosophical* structure of these curricula are a change from a curriculum emphasis on *solid foundation of theory* (O-level) to a curriculum emphasizing applications of chemistry in daily life (Salters' Chemistry) together with an intended change in focus from explanation to exploration.

In line with the changes in the pedagogical and philosophical structures of the visionary curriculum of Salters' Chemistry, the *substantive* structure puts less emphasis on the development of the full set of abstract chemical concepts that is traditionally present. Basic chemical concepts are introduced in the context of daily life phenomena, and laboratory techniques are used with familiar materials. Therefore, in sum, the visionary curriculum of Salters' Chemistry departs in a radical way from the O-level curriculum in England, which is the representation of Dominant School Chemistry in England.

In subsequent sections, I will keep track of how this tentative vision of school chemistry, its structural components and design criteria, evolved in the ensuing transformations that first led to two stages of the written curriculum (sections 4.4 and 4.5) and to the formal curriculum of the Salters' GCSE Chemistry course (section 4.6).

4.4 The written and experienced curriculum of Salters Chemistry: The Year Three course

In this section I analyze the transformation of the visionary curriculum into the first stage of the written curriculum of Salters' Chemistry, the Year Three course. In particular, I will examine whether this transformation proceeds consistently with regard to the design criteria used. Firstly, I describe how the design criteria were applied in the case of the development of the teaching units which came to make up the Year Three course (4.4.1). Secondly, I describe the preparation and organization (4.4.2), the crucial moments (4.4.3), and the evaluation phase (4.4.4) of the developmental process. In the concluding section I show that the method for developing a 'relevant' school chemistry course (as described in section 4.3) evolved during the process of development, by analyzing the changes in design criteria. Finally, I will discuss, using my curriculum theoretical framework, the product of the developmental process, that is, the Year Three course, and establish whether it escapes from Dominant School Chemistry (4.4.5).

4.4.1 Application of design criteria to the Year Three course

The first workshop had shown the feasibility of developing drafts of teaching materials which could possibly lead to a 'relevant' chemistry course for all. Waddington felt:

> That it was then an act of faith, we thought we ought to try it again, but on a *bigger scale* (G/W91:4).

This in turn led to the application and modification of the three design criteria (section 4.3.4) with regard to the *specific and concrete* development of teaching materials for 13-14 year olds in the so-called Year Three course. Specifications of the general design criteria were at this point referred to as *tenets of faith*. Besides the decision "that we would do Year 3" (G/W91:5), it came to be stipulated, as a tenet of faith, that all participants in the development should work on "separate chemistry" (G/W,91:5). As Waddington (G/W91:5) explained:

> Secondly, we wanted to do it in chemistry. People who loved integrated science, whatever it was, had to sign on the dotted line they weren't going to start that controversy.[26]

Year Three "seemed the obvious one to go for" (G/W 91:5), although it was considered by many teachers as a difficult year.[27] Relatively little material had been developed for it, since it was a *transitional* year between the first two years of *general* science education and the last two years of externally examined (O-level) *separate* science education.[28]

> Most schools, even in those days, taught – I can't remember what it was called now – they took *combined* sciences the first two years of secondary school. Some schools continued to teach *combined* science, but a lot of schools taught *separate physics, chemistry and biology* the third year of secondary school and then at the end of that year they chose their GCE subjects or CSE subjects, their *advanced* subjects [see Fig. 4.1]. And this third year wasn't at *risk* from the point of view of *examinations* because it didn't matter too much what they had done because it wouldn't be basically part of the syllabus as long as we *covered some agreed elementary ideas*. And the first two years were out because they would be taught in so many different kinds of groupings (G/W91:5).

Thus, the developers realized that Year Three was still at "the point at which teachers were able to take on and use material that they enjoyed rather than follow an exact syllabus" (G92b:11). Furthermore, the *most able* students would not take part in the first trial because:

> We realized that no teacher in their right mind would subject O-level candidates to a highly experimental and very dubiously constructed course, *even if we could construct it* (G/W92b:10).

Apart from these more practical reasons, the decision of the developers, to limit themselves initially to the developing of teaching units for just one year, can be considered as a consequence of their view on curriculum development, namely, of their idea of finding out *empirically*, in pilot projects in a piecemeal way, what the design criteria would entail in a concrete case.

The first design criterion, *No preconceptions*, applied to this situation was considered by the developers to be the most important *tenet of faith*. In Garforth's formulation it became:

> You must *not* be influenced by your thoughts of what we always do with *the third year* or your thoughts of *what we must have covered* before we arrive in the fourth year (G/W91:6).

The second design criterion, *Relevance*, meant that teacher-developers should "start where young people are" (L92), and applied to Year Three this meant:

> That in these thirteen-year-old units that we were writing ... we would introduce things that were normally introduced in unfamiliar materials, using *familiar* materials (G92a:15).

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[26] John Lazonby (L92) remarked that David Waddington was at that time particularly concerned about the small chemistry component in new or planned *balanced science* courses all over the world, courses which claimed to offer a balanced set of separate natural science courses. So, Waddington asked himself: "What, in all this, had chemistry to offer." See also Holman (1987, p. 435) who expresses a similar concern about school chemistry and "its future as a separate subject".

[27] Nuffield Secondary Science (13-15), unlike Nuffield Combined Science (11-13), made a similar choice, that is, it also started in Year Three. See note 21 and the text there.

[28] Campbell, et al. (1994, pp. 418, 423) mention the transitional nature of Year Three several times.

The third design criterion, *Theme-led development of concepts*, meant in this case that teacher-developers would start, in line with their experience with prototypical teaching materials gathered in the first workshop (see 4.3.2), from some selected areas: "Drinks", "Food", "Metals", "Clothing", or "Warmth", that is, to work on common areas which:

> "seemed to us to give the most comprehensive *coverage* of some agreed elementary chemical concepts and generalizations at this level" (G/W91:6).

For example, out of experiments on the theme of rusting would "gradually [come] the kind of generalized chemical concept of reaction" (G92a:15). For a detailed analysis of this theme or context of rusting, see Chapter 5.

4.4.2 Preparation and organization

The ambition of embarking on full-scale development along these lines led to a change, not only of the *scope* but also of the *nature* of the development process. As for the scope, producing teaching material for a one year course would require a lot of work. This also implied a greater amount of preparation by Francesca Garforth who was seconded therefore at this stage by John Lazonby, Malcolm Frazer, and David Waddington, who comprised the Salters' Chemistry Project Management.

Firstly, they tried to find out through consultations with teachers, what was the "lowest common denominator" (G/W91:5) of chemical concepts and experiments for pupils by the age of thirteen. This proved to be "almost nil" (G/W91:6). Secondly, they tried to find out what teachers could contribute, asking them to comment on "a list of about twenty global things" some of which had come out of the first workshop. They asked teachers: "Which [themes] do you think are the most fruitful" (G/W91:6), also requesting them to add one or two themes. Thirdly, they asked teachers which themes they thought they would like to work on. Fourthly, Waddington at this stage "took over organizing people at the workshops" (G92b:12), which included inviting "a representative of every level of education" (G/W91:13), and he took care of the urgent matter of finding necessary funds for the expanding project.

> We tried to have a mixture – teachers, industrialists, exam boards, inspectors. About thirty. We eventually got thirty. Writers – experienced writers, non-experienced writers ... young, old ... inner city, grammar, independent schools, comprehensive schools and so on. Most of whom stayed, the experienced writers, for example, we got John Holman and Graham Hill. So that group came. But in between I would think they probably had three or four bits of homework to do (G/W91:5).[29]

At this stage, Waddington felt that "we didn't want just *novices*, but we wanted people with a known track record of being able to write as well" (G92b:12). The next step was to ask invited participants of a Five-day Workshop to work in groups of three and, following the preparation and the homework, "to push them [the themes] around in terms

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[29] See also Campbell et al. (1994, p. 424): "The development process then centred around a series of intensive 4-day workshops which brought together a team of *experienced* school teachers from a wide range of types of schools (comprehensive, selective, maintained, independent, urban, rural), university-based science educators (with school teaching experience), school science advisors and industrialists."

of experience and so on” (G/W91:6). Finally, the Salters’ Chemistry Management Team also invited “people of other developments, so we weren’t seen in opposition” (L92).

In this way “we set up something that was counter to what the current fashion was” (G/W91:9). The current fashion in curriculum development in those days was: “The idea that “schools would be doing the curriculum development or [that] school things shouldn’t be sent up” (G/W91:9). Examples are Garforth’s initial efforts with developing materials for her CSE students, and her experiences with CSE teachers and their alternative CSE syllabuses (see 4.2.2).

In other words, there still was a widespread “anti-Nuffield feeling” as Waddington called it, which, the project management team in a way went against. At this point the *nature* of the Salters’ Chemistry development process changed, from a “peripheral” model to a more or less “center-periphery model”, a curriculum development model used in the 1960s and 1970s by, for example, the Nuffield programs in England and NSF programs in the USA.[30] But the Project Management Team did not use an extreme form of the center-periphery model. A great attempt was made to involve teachers not only in trialling the new units in the classroom, but also to involve many of them in the actual writing and developing process.

Thus, the Salters’ Chemistry Project Management Team, based at York, began to lead a systematic effort to produce relevant curriculum materials for a one year transitional course along the lines of the previously agreed-on tenets of faith, or design criteria, and in collaboration with a carefully selected team of teacher-developers working on previously generated and selected themes or contexts. The resulting draft materials would be trialled first by teachers directly involved in the project and later disseminated to the periphery for further use in classrooms. Feedback of the trials would lead to revision of materials, subsequent trials, and the final editing process.

All this started in September 1983 with a Five Day Workshop held in York, during which the invited teacher-developers and other invited participants worked in groups of three or four on themes such as Drinks, Fuels, Metals, and Food. Plenary sessions would reinforce the tenets of faith or “catechism” (G/W91:4), so that everybody would be firmly committed as well as clear in their mind about what they would set out to achieve.

4.4.3 Crucial moments

The first crucial moment came very soon with the realization “that our marvelous preconception that all this work was available somewhere, and all we needed to do was point the teachers to it was hopeless” (G/W91:7). Instead, there appeared to be several reasons, practical as well as principal, to abandon Channel C, that is, the idea “to write teacher notes accessing them [the teachers] to materials that had already been published” (G/W91:5).

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[30] Campbell et al. (1994, p. 433) describe this as “a model for educational change in which a development team (the *center*) produces materials which are then disseminated to teachers (on the *periphery*). The Research, Development and Dissemination (RD & D) model is perhaps the best known such model”.

> First of all, they wouldn't have the time to go and look things up; secondly, that they probably wouldn't have copies of these in the school library anyway, and thirdly, good as they were – and some of the experiments were very good indeed – *they didn't give us sufficient in the way of a teaching approach and that we would have to start writing from scratch* (G92a:5).

Furthermore, heads of department and beginning, as well as experienced teachers, all seemed to say to the development team that they would like to "actually have everything there to hand in the same booklet" (G92a). Under those circumstances it proved very hard for the teacher-developers *not* "to reinvent the wheel ... and we changed our plan of production at that point into full-scale workbooks" (G/W91:7), that is, they choose Channel D, as mentioned above in section 4.3.3.

The realization that they "were [now] doing something that was very different" (G92b:16) both with regard to scope (bigger scale) and nature of the development process (center-periphery) brought with it its own problems, the most important of which was:

> … the most worrying thought that everybody was worried about was that we were going to end up with a course which would be utterly and *totally confusing to both teacher and pupils* (G/W91:8).

More particularly, what had worried the developers since they first conceived of the possibility of an alternative, relevant chemistry course was how to achieve (Garforth, 1983, p. 30):

> A careful *integration* of the modules so that chemical concepts and principles evolved in *some recognisably sequential order* and that each was sufficiently *reinforced* in the course.

Whereas the starting point for the Year Three course could be chosen almost freely, since the baseline was for students about nil, the end point of Year Three was seen by the developers as being determined, at least partially, by the existing O-level content.

> We had to come out with *some kind of basis* for going on to do O-level, so when we got on to designing the course for Year 3, we had to bear in mind what pupils who had gone through a *standard* chemistry course would in fact have been exposed to, so at that point *external constraints* came in (G92b:10).

Thus, the problem for the teacher-developers now became: How to arrange a set of "appropriate chemical ideas" for 13-14 year olds, as introduced through selected contexts, into a *coherent* and what they called a "*recognisably sequential order*". Most of these "appropriate chemical ideas", they thought, were ideas such as "diffusion, solution, particle, molecule, atom or ... element and compound", chemical ideas which were considered "standard ... on any syllabus" (G92b:9).

Garforth realized that this procedure must sound "very anti-Salters" (G92a:5), in the sense that they were now obviously operating with a clear *preconception* of:

> Certain concepts which we all *recognized* we shouldn't leave out by the end of Year 3"(G92a:5).

In order to keep track of which concepts and experiments turned up in which lessons of the units organized around a theme, it was John Holman who proposed to have a "checklist" which evolved into lesson plans (blue sheets) and unit plans (green sheets). A lesson consisted of a double period of 70 – 80 minutes; a lesson plan would organize the set of activities which would lead pupils to understanding of a set of key points; a unit plan organized the 7-10 lessons of which a unit would consist; and the Year Three course would consist of four or five units. But, even more necessary, according to Garforth was to have the following device:

> But what was much more worrying was to have a *checklist* of what we had actually done [...] of the outcomes from everything in the *course* so that we could see that we weren't dealing with the same thing over and over again or that we weren't putting carts before horses […]. Or that we had actually got a logical basis, or a *fairly logical basis*, for something that turned up in another unit (G/W91:7).

It was Malcolm Frazer – "he was *Control*" (G/W91) – who took care of this, by starting to pin colored cards on boards on the wall. For instance, a green card for an "equation", or a white one for an "element" and other colored cards for concepts and for experiments. The functions of these course control or curriculum devices became to make sure that:

- nothing was done "more than once" (G92b:9);
- nothing was "missing" or "left out" (G92a:5);
- they had not done too much (G/W91:15);
- "people could see what was turning up in each unit so they could either work towards it or use the information that was turned up" (G/W91:8);
- reinforcement was taken care of as much as possible: that is, trying to develop chemical concepts in a progression of different levels of refinement, abstraction, and quantification after their initial simple and qualitative introduction.

Garforth remembered an interesting example, from the concomitant development process of the two Units, "Drinks" and "Clothing", of the first and, especially of the important fourth form of 'course control' (G92b:9).

> And then we tried *to match up* and make sure that we *didn't have it occurring more than once*, or if we got something like diffusion and we wanted the word 'particle' we had to make sure that 'particle' had occurred somewhere before. And when we got to "Clothing" we actually needed the word 'molecule', because we were dealing with large assemblages of atoms, so we had to go back and make sure that atom and molecule had occurred somewhere, so that was *put back* into "Drinks" as a sort of *refinement* of the word 'particle'.

In the process of working this way the developers came to the realization that they:

> Had to impose externally and by agreement a *sequence* of certain concepts (G92a:5).

Thus the developers made more and more explicit a design criterion which entails both a requirement for coverage and for a recognizably sequential order of elementary chemical ideas. This new design criterion did replace and goes, I think, directly against design criterion one, *No preconception*s, introduced in section 4.3.3. The latter admonishes developers to have no preconceptions about what should be in a chemistry course they are about to develop. So the design criterion now adopted sounds "very anti-Salters", as Garforth put it above.

Apparently, the developers felt they needed this design criterion for establishing some kind of *conceptual coherence* in order to avoid the feared confusion of both teachers and students. In this way they tried to solve their most worrying problem met during the development of a context-led chemistry course. After a few days of hard and intensive work – "several people were ... exhibiting battle fatigue" – came, in the eyes of the developers, the *most important crucial moment*. Waddington remembers the occasion as follows:

> And then about the third evening, or the fourth evening, there were dramatic moments when Malcolm [Frazer] spoke – he synthesized what was on his boards. He was a marvelous speaker. And this – it's remarkable, out of it suddenly *became sense* (G/W91:8).

At this point, the developers suddenly saw that a context-led development of chemical concepts could lead to a school chemistry course that was meaningful and worthwhile to the majority of students taking such a course as well as providing a coherent treatment of chemical concepts.

Besides the reinforcement of tenets of faith, and the ongoing process of checking the 'logical' basis of concepts, another function of the plenary meetings was "brainstorming" about ideas for themes or units: "each group was asked to explain itself at the plenary meeting in the evening" (G/W91:8). So, the units the teacher-developers worked on could be referred "back to the drawing board", and "there were several [units] that fell by the wayside" (G/W91:14,15), for instance at this stage a unit called "Shelter". By using the curriculum devices mentioned above, it could turn out that: the chemistry that came out of the units was not simple enough or just too much for that stage of learning (age and ability), or that the chemistry did not fit into the overall scheme of concepts used so far in the course units. Furthermore, the unit could not fit into the overall scheme of themes or contexts chosen so far. An example of an issue that came to be decided in a plenary session was the place and role of theory in the course. As Garforth recalls:

> ... and anything controversial like John Holman suddenly deciding that Drinks inevitably leading to kinetic theory, very simply. The Drinks people went rushing about the other groups and said, What do you think about kinetic theory? Do you think this is a good idea at this stage? And we had a plenary session to discuss kinetic theory (G/W91:8).

4.4.4 Experienced curriculum

In this section (and also in section 4.5.3), I will deal in a global way with the Salters Chemistry course as experienced by students in the classroom. In section 5.4, I will perform a detailed analysis of the experienced curriculum of the unit Metals, part of the Salters Science course.

Besides the 'internal' evaluation which took place during the ongoing development process including the plenary meetings, the first drafts of the Salters Chemistry units were also trialled in the classroom, that is, evaluated *externally* by feedback or comments from teachers and, initially, also through student responses.

Many teachers (about 1000!) reacted to Garforth's (1983) article in which the developers asked for help from teachers to trial newly developed relevant teaching materials, a confirmation of the readiness and willingness of teachers, alluded to in section 4.2.2. About 200 or 300 of these teachers – "those who were really interested in doing Year Three" (G/W91:11) – actually participated in the trials that started at the end of 1983 and went on the next year.

Their comments were on the whole favorable, although some were mixed with some concern about the level of understanding. As summarized by Garforth in one of the interviews:

> I've never known the children so motivated. It's amazing what stuck. Usually they go from one term to the next, without anything sticking from one term to the next, but this time it really seems to have sunk in what

> they did and they remember; and their practical skills have improved, and *they haven't reached the level of understanding that we would expect at the end of the third year*. But they've made up for that in what they have remembered: the *basics* that they've remembered and their *ability to think* and their *ability to physically manipulate* the material, so we think probably *it's worth it* (G92b:15).

On the other hand there were some teachers who remarked: "I can't think what the point of all this is, but the kids seem to like it" (G/W92b:15); and some teachers who felt that "it was pretty dull stuff and the fact that children were enjoying it really surprised them" (G92b:15).

Some children made "lovely comments", for example a pupil of a low ability group said:

> This is the best thing I have ever done since I came to school. We've been *using things I understood about* and not that stuff from the bottles on the shelf whose names I couldn't spell (G/W91:18).

Another pupil wrote: "I enjoyed this unit because it was dealing with *things I knew about* and not all those things with funny names we only see in the *chemistry laboratory*" (G92b:11). And one pupil simply said: "This is better than sulfur" (G/W91:18). These pupil responses seem to indicate that the developers were succeeding in one of their main aims, that is, "looking for *familiar materials* which would do things that in the *lab* we had used to do with something quite *unfamiliar* like *sodium or zinc*" (G92a:15). All units for Year Three were revised in the light of teacher comments and students responses. This kind of feedback along with the 'internal' evaluation led teacher-developers to the conviction that "we must continue ... knew we were off" (G/W91:8). Thus, the development of a one year course of relevant school chemistry, the desirability of which now was accepted by all parties concerned, seemed perfectly feasible. As pointed out above, *it made sense*.

Furthermore, there arose a quite unexpected, but favorable change in external circumstances which added considerably to the internal momentum gathered in the developmental process. This is summarized eloquently by Garforth:

> There was a lot of luck in the educational world at the time. So that the whole of the teaching of science had been thrown into the melting pot and the GCSE was on its way forward. Everybody had thought that it was going to die the death it had been dying since 1974 but quite suddenly it was on. And we knew that the *ground rules for the exam* were going to be totally different from the ground rules that had existed before. Students were going to be asked to show *what they could do*. *There was going to be a chance for a project and all kinds of things we wanted,* actually, to incorporate in our syllabus and we could see that our way, if we could get this third year over, we would have a clear run to Years Four and Five if we got it done in time. It was about the only time, I think, that there was *a window of opportunity* in secondary education where we could have got this through. We couldn't have done it at any other time (G/W91:9).

4.4.5 Conclusion and discussion

I will now try to answer the question, to what extent the transitional Year Three course captured "all kinds of things" the developers wanted, as formulated in their tentative vision and design criteria. In terms of my curriculum framework, this means whether the transformation of the visionary curriculum into the written curriculum of Salters' Chemistry was consistent with their proclaimed design criteria (see sections 4.1.3 and 4.3.3). I will do this in terms of changes in design criteria, focusing on the development process, and in terms of the curriculum structures introduced in Chapter 1 of this thesis:

the pedagogical, philosophical, and substantive structures, focusing thereby on the curriculum product (see Figure 4.5 below). This will also allow us to answer the question, to what extent the written curriculum of Salters' Chemistry, in the form of the Year Three course, did escape from Dominant School Chemistry as it existed in England at the time.

Design criteria

The most conspicuous change which occurred during the development process was the gradual replacement of design criterion one, *No preconception*s, by a conception referred to by the developers as a recognizably sequential order of elementary chemical ideas standard on any syllabus. At this point external constraints came in which would come to guide the development of teaching materials, the more so since a further development of the Year Three course would also have to address the needs of O-level candidates who were initially left out in the trial phase.

Design criterion two, *Relevance,* in the sense of starting from contexts taken from the daily life of students, could be applied in a largely consistent way. The choice of contexts at this stage was relatively free, as long as the contexts were fruitful with regard to the development of chemical concepts.

As noted above with regard to design criterion three, *Context-led development of concepts,* the design of the Year Three units were to some extent constrained by a standard list of chemical concepts and by a "recognizably sequential order" to be imposed on these concepts. Further, all but the first few units were further constrained by the extent to which previous concepts and the sequential order had already been introduced – only these first units could start as it were from scratch. The concepts introduced in later units had to fit in with whatever came earlier in terms of concepts and sequential order. This could lead to an imbalance with regard to the conceptual load the contexts of a unit had to carry.

Pedagogical structure

The developers had to bear in mind, as we saw, that the students they addressed had to make the transition from the first two years of general science education to the two years of an examination course in chemistry as a separate science subject. This meant that they had to comply with the, though not very strict, externally set constraints which had to be kept in mind in addition to their internally chosen design criteria that were part of the visionary curriculum of Salters' Chemistry. As became clear from their own evaluation of the trials, the Year Three units communicated to the less and moderately able students [Ped/A] some "worthwhile" learning experiences. These students not only enjoyed the course but also seemed to learn some basic concepts, and showed ability and confidence in thinking about and performing practical work [Ped/A]. Thus, the context-led teaching approach [Ped/TA], starting "bottom up" with familiar materials and applications, really seemed to further these students' appreciation of relevant chemistry, thereby also raising their chemical awareness as future citizens.

The pedagogical structure of the written curriculum of Salters' Chemistry, the first trial of the Year Three course, focused on the needs of the majority of students, on the less and moderately able students, aiming towards "chemical awareness for the future citizen" rather than on the academic preparation of future O-level candidates as potential future chemists. The development of a context-led teaching approach began to take shape, which together with the more customary lab experiments was used for the introduction and development of chemical concepts. At this stage the developers managed to escape to some extent from the pedagogical structure of Normal Chemistry Education (NCE), in other words, from the traditional O-level school chemistry in England.

Philosophical structure

The chosen curriculum emphasis on personal and societal relevance, using either familiar materials from the average home and kitchen or social, technical, and industrial applications, implies a different view or philosophy of chemistry. The central focus is not on theoretical or pure chemistry, but much more on practical or applied chemistry [Phil]. For instance, the focus is on “stuff that you could find around an average home” such as “pure cotton, pure wool, pure silk” (G92b:16), as against pure chemical substances such as potassium or pure water which you can find only in the laboratory.[31] The focus on familiar materials and chemical products, especially on the *purposes* for which these materials and products were used, and their properties in this regard, brought with it a greater emphasis on macroscopic properties [Phil]. The purpose or the use of things related to gross properties became more important for a relevant chemistry course than the relation of structure to atoms and molecules.

> We’re more concerned with relating properties to use. In other words, we are moving up the macro level all the time, instead of down the micro level (G92a:15).

The Year Three course had to have, though, “a recognizable sequential order” (Garforth, 1983) and should introduce some agreed on chemical elementary ideas as a basis for the O-level examination course following the transitional Year Three course. This external constraint did not deter the developers from devising an applications-led chemistry course. After all, the Year Three course differed in important respects from the traditional provision for that year. By having to accommodate some agreed on basic chemical content, the resulting Year Three course probably deviated more from the visionary curriculum than originally envisioned by the developers.

The philosophical structure moved away from theoretical, microscopic chemistry and towards applied and macroscopic chemistry emphasizing relevance, purpose, and use. The developers did not escape fully from the philosophical structure of NCE, but they did try to look seriously for applications of chemical knowledge to familiar phenomena and materials, thus not using only ‘academic’ or laboratory applications as had been customary. They tried to use applications as starting points of units or lessons, not as afterthoughts or add-on materials.

Substantive structure

Although making *sense of familiar contexts*, by using only chemical concepts needed to make sense of these contexts (need-to-know), was the overriding aim, the developers came to feel that in order to achieve this aim it would be wrong “to throw away the baby with the bath water” (G92a:12). Hence, at least standard chemical techniques and experiments [Sub/CT] remained largely in the course, albeit applied to familiar materials

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[31] See Chapter 1 for a discussion on the concepts of pure water (scientific context) versus tap water (technological context). *Pure* is used in pure cotton in a technological context; “pure cotton” is not a pure chemical substance here.

much more than to the usual laboratory chemicals. At first, the developers were still, as they said, "holding out against concept sets" (G92b:8). While developing the transitional Year Three course, though, they realized that a set of elementary chemical concepts [Sub/CC] had to be in the course, a set which should further have a fairly logical basis [Sub/CR].

Operating as they were within the common 16+ system (Figure 4.1), the objectives of the Year Three course had to be, they felt, on the one hand to enhance "chemical awareness for future citizens", and on the other hand, to lay a foundation for students who "were about to take O-level" chemistry (G92b:2). For the latter reason the Year Three units were called Foundation Units. While trying to establish a context-led teaching order by trial and error the developers had to, as they found out, impose externally and by agreement a *sequence* of certain concepts. The second design criterion, *relevance*, led them to emphasize as well as to *add* some chemical-societal or chemical-technological content about the making of familiar products and the *use* and *purpose* of these products as related to the *gross* properties.

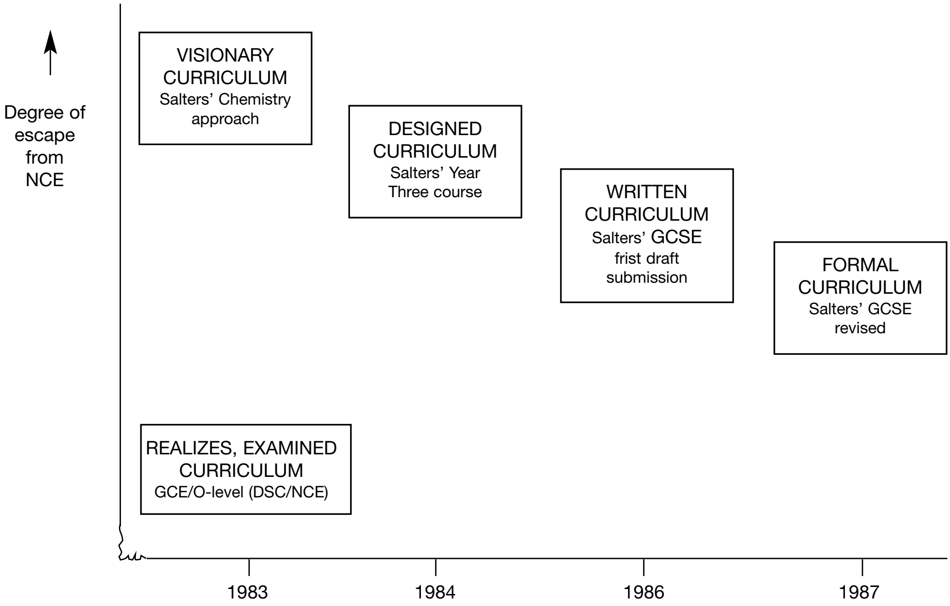
The substantive structure of the Year Three course shows, compared to a *traditional* Year Three course, some *reduced* chemical concept loading [Sub/CC]. For example, it avoids systematic chemical names for substances and reactions; on the other hand, it retains the same set of standard chemical techniques [Sub/CT]. The concepts were put in a "recognizable sequential order" (Garforth, 1983, p. 29) informed by "a fairly logical basis", although not in a top-down hierarchy, but bottom-up, that is, starting at the observational and manipulative level via low-level generalizations to more abstract relationships.

Thus, the developers did not fully escape from the substantive structure of NCE, nor from the philosophical and pedagogical structures of NCE. This partial escape has to do, I think, with both externally imposed and internally felt constraints, a point to be discussed further in section 4.7. There, the consistent use of all three design criteria, and the degree of escape of the written curriculum of Salters' Chemistry from NCE, will also be addressed in relation to the three conditions of escape listed in Figure 3.11. The discussion of the GCSE development of Salters' Chemistry, of the decisions taken and of the direction the development took, will make it possible to see the extent to which the chosen CTS curriculum emphasis of the Salters' Chemistry course, taken as a combination of a specific substantive, philosophical, and pedagogical structures, remained the same.

A schematic overview of the process of development over time is given in Figure 4.4 below. The box just above the baseline of the figure at the left marks the O-level curriculum, the representation of NCE in England in the 1980s. The boxes higher up the figure represent respectively: the visionary, designed, written, and formal curricula of the Salters' Chemistry course. The picture as a whole brings across the decreasing *degree of escape* in the process of development of an innovative course such as Salters' Chemistry, that is, in the process of matching the adopted vision and design criteria to the internal and external constraints met by the developers in designing a relevant, suitable, and feasible school chemistry course.

This is an illustration of an important curriculum phenomenon also described as "the *slippage* from any ideal formulation to what reaches the student" (Goodlad (1979, p. 64).

Figure 4.4 Process of development of the Salters' Chemistry course



The first box at the top left side of the Figure 4.4 represents the *visionary* curriculum of Salters' Chemistry as described and discussed in section 4.3. The distance between this box and the box put just above the baseline left, representing Dominant School Chemistry in England at the time, gives the maximum degree of escape.

The second box represents the *designed* curriculum, the first operationalization of the design criteria by the developers in a prototype, discussed in section 4.3. This phase was immediately followed by the development of teaching units for a *transitional* course in chemistry for 13-14 year olds, the Year Three course, as discussed in section 4.4.

The third box represents the next phase of the development, that is, the *written* curriculum, the extension of the designed curriculum realized by devising, elaborating, and revising prototypical teaching materials after trials or testing in the classroom by a group of developers. This phase consisted of the systematic development of a two year examination course in chemistry for 14-16 year olds, as discussed in section 4.5.

The last box represents the *formal* curriculum, that is, the formal acceptance of the GCSE Salters' Chemistry course for 13-16 year olds by an examination board.

In sections 4.3-4.6, I compare, in terms of my curriculum theoretical framework, the successive curriculum levels of the Salters' Chemistry project with the traditional 'academic' provision of school chemistry for 13-16 year olds as it existed in England at the time. Finally, I discuss the results of these comparisons, in particular, the *degree of escape* of the *visionary* Salters' Chemistry curriculum from Normal Chemistry Education (section 4.7).

4.5 The written and experienced curriculum of Salters Chemistry: The GCSE Course

In this section I will analyze the transformation of the visionary curriculum into the second stage of the written curriculum of Salters' Chemistry, the GCSE course, in particular whether this transformation proceeds consistently with regard to the design criteria used.

The decision of "extending to do Year Four and Five" (G/W91:10), that is, to provide relevant school chemistry for the 14-16 age group in the form and at the scale of a *national* examination course, had major consequences for the way the design criteria could be applied and the degree of professionalization and specialization of the management and development team.

Firstly, I will describe how the design criteria were applied in the case of the development of the first draft of the GCSE course (4.5.1). Secondly, I will describe those aspects of the preparation and organization process relevant for my analysis (4.5.2). Thirdly, I will analyze and discuss, in terms of my curriculum theoretical framework, the changes in design criteria and in curriculum structures during the development of the written curriculum, that is, the GCSE course, compared to the visionary curriculum.

4.5.1 Application of design criteria

In applying the first design criterion, *no preconceptions*, to the situation of developing an examination course and syllabus with national validation, the developers in York were to meet with further internal and external constraints. First of all, they now had: "a *baseline* ... the outcome of Year Three Salters'" (G/W91:14). Secondly, as the developers remarked,

> Then when GCSE became certain ... we had some very broad guidelines in the National Criteria for Chemistry as to what we would have to have in, if we were to be accepted as an exam course" (G/W91:15).

Thirdly, there was a danger, especially with an examination course: "by leaving something out that it would prejudice the child's opportunity to getting a grade at the other end" (G/W91:14). Thus, in this situation the developers were quite *explicitly* and *consciously* influenced by their *preconceptions* about what should be the beginning, the end, and the purpose of the course.

As for the second criterion, *relevance*, applied to this situation, this would entail that the themes for Years Four and Five had to be linked, at least to the ones already used in Year Three. Initially, these global themes "were a bit disparate and it was John Lazonby who came up with *links* ... a sort of *web*" (G/W91:14). This amounted to an ordering of the themes in terms of (i) survival, e.g., the units Food, Drinks, Warmth, Clothing; (ii) work and play, e.g., the units Metals, Buildings, Transporting Chemicals, and (iii) social relationships.[32] [33]

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[32] The 'web' had already proven its use for the five day workshop and had been based in part on the answers teachers had given to one of the questionnaires they had to fill in as homework.

[33] The latter theme was to be explored later in the Salters' Science materials for 11-13 year olds, in a unit called the "Salters Square" (L92). See also Lida de Gier (1992, p. 11).

The third criterion, *Context-led development of concept*s, when applied to this situation entailed that the set of themes or contexts for the examination course had to be matched to the particular "balance of theory, practicals, and relevance to social and economical problems" (G92a:8) as specified by the recent National Criteria for Chemistry. As a consequence, the generation and coupling of themes and topics was done by Garforth "the other way around this time; I asked for the topics; then myself tried to slot these into themes" (G/W91:14). Therefore,

> ... we had to be fairly *selective* about which topics we were going to use and how our topics were going to fit into themes. So, in a sense, I suppose, *we were going against our own philosophy* in that we had to have in our mind some idea of outcome even though it wasn't very specific. (G/W91:14)

Regarding the third design criterion, *context-led development of concepts*, the developers were, as they put it were also "going against our own philosophy". It was clear that the development of chemical concepts could, at this stage, no longer evolve from freely chosen themes or contexts, but had to take into account as an external constraint, the content requirements as specified by the National Criteria for Chemistry. Thus, on the one hand, the required chemical concepts were fairly fixed; on the other, the 'web of themes' grew tighter, too. Any newly suggested topic had to be fitted under two constraints: externally a set of a concepts, and internally a set of contexts, matched to each other in a coherent way. As Roberts (1982, p. 251) remarked:

> That is, the subject matter topics in a unit have to flow logically of course, *but so does the emphasis*.

Operating under these constraints, the application of the third criterion, *context-led development of concepts*, to the situation of the 14-16 age group, also meant that with these older pupils and with twice as much lesson time, "there might be more opportunities to put more *theory* into [the course]" (G/W91:14), a desideratum also required by the National Criteria of Chemistry. The latter criteria required the development of a relevant chemical course for the full-ability range, which again had consequences for the application of the third Salters' criterion, leading to an increased emphasis for *all* students on *explanations* in terms of *abstract* chemical concepts and principles compared to the visionary curriculum of Salters' Chemistry.

During the workshops for the GCSE development there evolved and was articulated *a new, fourth criterion*.[34] In addition to the teaching strategy which tried to use optimally the standard set of chemical experiments and techniques but with familiar materials and contexts, the developers now consciously "were trying to introduce as *many different [teaching] strategies* as possible" (G92b:15). This then led to learning activities which came to include, for example, "making a poster, or doing a survey ... tabulating data, role play" (G92b:15) and other forms of *practical* learning activities, including group discussion, which were all sandwiched, as it were, with the conventional laboratory

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[34] In Campbell et al. (1994, p. 419), the developers describe, *in retrospect*, this criterion as: "The course should include a *wide range of activities* in which students can actively engage". It is seen there as one of two design criteria of the Salters' approach while the first one (p. 418) mentioned there consists of a combination of what I call criterion three, *context-led development of concepts*, and criterion two, *relevance*. Criterion one, *no preconceptions*, is only mentioned in passing (p. 423) there, but see Lazonby, et al. (1992, p. 899) for a more explicit reference, saying: "Many curricula are devised by defining what is expected of students at the end of the course. We deliberately closed our minds to this ..."

experiments between the set of leading themes or contexts and the set of chemical concepts to be developed. Teacher-developers could thus devise an array of learning activities which would link in the best possible way required concepts to set contexts.

4.5.2 Preparation and organization

Teacher-developers were asked first to come up with topics but within a previously, more or less, agreed-on set of themes, and subsequently to think about "*suitable* topics within these themes", trying to answer the question "which of these [topics] do you think is going to produce some *worthwhile* chemistry?" (G92a:12). Worthwhile chemistry was conceived as the product of teaching and learning chemistry in accordance with the Salters' design criteria emphasizing for students "that you can *do* things and *understand* " (G92a:11).[35]

Writing and developing twice as much material, for the years Four and Five, for an examination course brought with it some further specialization of tasks. About the same management and writers team which had devised the Year Three course, started to develop another ten units needed for the GCSE course on the basis of the design criteria and within the external constraints mentioned above.

But a number of other tasks had to be attended to as well. Thus, Waddington went looking for an examination board which would accept the Salters' Chemistry course, while Garforth took care of writing the required GCSE syllabus. Peter Nicolson, initially one of the teacher-developers, joined the management as a full-time liaison officer between the development center in York (UYSEG) and the teachers in the field. Graham Hill and Susan Adamson, initially also teacher-developers, became full time editors for the project, and were in charge of editing the final version of the course; Susan Adamson also was to write the *"The Salters Chemistry Course: An Overall Guide to Teachers"* (UYSEG 1988). Finally, David Waddington together with Graham Hill, John Holman, John Lazonby, and John Raffan wrote a so-called *student* book supporting the Salters' Chemistry course. I will now discuss a few points concerning these tasks which are relevant for my analysis of the Salters' Chemistry curriculum.

Examination board

The first examination board they approached, David Waddington recalls, "criticized us for trying to do what we were doing" (G/W91:10), in particular for their choice of a center-periphery curriculum model. John Raffan then suggested to approach the Oxford and Cambridge Schools and Examination Board, part of the Midland Examining Group (MEG). The officer of that examination board eventually did accept the Salters' proposal quite easily and also offered, even more to their surprise, a substantial amount of money for development costs. Because, as explained later: "John (Raffan) said it is a good thing, and I trust John (G/W91:10)." Waddington and Garforth remarked on episodes like this (G/W91:9):

> A lot of *lucky* things happened at that moment that allowed us to continue; you use your luck.

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[35] This intriguing notion of worthwhile chemistry is also mentioned in the Overall Guide for Teachers where it says: "Of course, only those topics which turned out to provide a natural introduction to some "worthwhile chemistry" were developed" (OGT, p. 9, emphasis theirs).

Writing, trialling, editing and teacher guide

The actual writing process of GCSE units was organized in roughly the same way as that of the Year Three units. On the full course trials, starting September 1985, they received "progress reports and comments" (OGT, p. 79) from teachers. About twenty teachers were involved in 1985 and up to a hundred in 1986. Direct feedback from students in the form of written comments was not sought as it was in the design of the Year Three course (see section 4.4.4).

The GCSE course, to a much greater extent than the Year Three course, had to have as they put it a "recognisably sequential order", since it had to be developed under more constricting external constraints with regard to both content and coherence of concepts, over and above the internally led selection, sequence, and coherence of contexts. The curriculum devices mentioned earlier, the lesson plans, the overall plan of the unit, and the 'web' of contexts, were used to that effect, as was a "checklist of the outcomes from everything in a course" (G/W91.7), that is, the overall plan of the course.

The Salters' Chemistry course (OGT, 1988) further explained in some detail the teaching objectives, the philosophy, and structure of the course, including the development of chemical concepts in relation to the selected contexts and practical activities used to introduce them.

At the end of the development process Susan Adamson had "a more detailed look, an overall look at the development of concepts" (G/W91:15), the result of which was included in the Overall Teacher Guide (pp. 22-30). As a consequence, the editing of the final version came to involve not only leaving some things out but also "quite a lot of rewriting and new lessons and links" in order to increase the coherence of the course (G/W91:16). They "polished it up enormously while adding headings such as SIS and SAG" (G/W91:16), which stood for "Student Information Sheets" and "Student Activity Guides" and were pages of the units to be handed out to students.

They also reorganized and actually changed parts of the course, "sometimes a whole unit" (L92). Thus, in the editing process of the final version, more complete and explicit than during the developmental process, the editors "were analysing what there was, using what we perceive, what we *all* perceive to be *the structure of chemistry*" (L 92). In retrospect the developers stated:

> "Clearly though, there is implicit in this approach *a need*, at the editorial stage, to review the progression and "spiralling" of ideas within the course *to ensure coherence* in the treatment of the *major scientific concepts and ideas*" (Campbell et al., 1994, p. 423).

Syllabus

Garforth said, "our syllabus was going to be, in true Salters' fashion, to be derived from our units" (G/W91:14). The central principle that came to structure the units of the course, context- and activities-based teaching of chemical concepts, a sort of amalgam of the four design criteria, implied that chemical concepts would have to be introduced as it was called, on a *need-to-know* basis, that is, as they arose 'naturally' from the selected contexts. By the same token, it implied that chemical concepts which would *not* be needed to make sense of contexts and activities would not have to be dealt with in the units, and as a consequence also not in the syllabus.

The *draft* syllabus written with this idea in mind was presented in June 1986 to the School Examinations and Assessment Council (SEAC), which was "very sympathetic towards the syllabus" (G92a:9). Because the Salters' syllabus showed some *reduced* concept loading (Smith, 1988) it had to be revised if the developers wanted it to be accepted "as an examination with the full range of grades on the Mode 1" (G92a:9).[36] The syllabus did not deal substantially with a number of chemical concepts: some families of elements (halogens, alkali metals, and alkaline earths), the periodic system, atomic structure and bonding, some equations, and some quantitative chemistry, e.g. the mole concept.[37] This was, as noted above, an important consequence of the educational philosophy and method of development of Salters' Chemistry, that is, these chemical concepts did turn out *not to be needed* to make sense of the selected contexts. At the second presentation, after having accommodated their syllabus to SEAC's requirements – "we did insert a bit more" (G92a:9) – they were again criticized for not having some (other) chemical concepts in their syllabus (heterogeneous catalysis, equilibrium, and some equations) but this time they were "saved by an industrialist" (G/W91:12) on the SEAC committee.[38] It is worth recounting this "lucky" episode in full.

> When it came to the Salters' one [i.e., the syllabus], the chairman who is an *academic chemist* was terribly dubious, the HMI [inspector] was mildly enthusiastic; the *teachers* were very suspicious. And it was touch and go. The *industrialist* got to his feet and said, "You've given me I don't know how many syllabuses and exam papers to read. They have all looked utterly boring. *They all look just like what I did when I was a boy at school.* This is the only one that appears to pay more than lip service to the government's request that you should be more *oriented to the chemical industry and its products*. And I recommend that this go through ... if it doesn't I shall leave this committee." (G/W91:13).

And the chairman, quite taken aback, had to draw the conclusion that, "I suppose, yes, well, perhaps it's a good idea" (G/W91:13). And so it happened, that the Salters' Chemistry syllabus became but for "some minor alterations" (G/W91:12), in June 1987, the first nationally validated "relevant" GCSE syllabus, aiming at chemical awareness for the future citizen.

Examination papers

John Lazonby and David Edwards were writing the examination papers which "really were new" (G/W91:13), in the sense that the questions asked reflected the education philosophy of the Salters' approach as much as possible by stretching the "slim-line" constraints set by the National Criteria of Chemistry. The Midland Examination Group also "supplied welcome assistance in developing the assessment model for the GCSE syllabus" (OGT, p. 6). Furthermore, the developers were able to make full use of the marks (min. 15%) "for our examination for the industrial and social applications of chemistry" (G92a:14). As they said, "we could go up to 20%" (G92b:17) which was more

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[36] This *empirical* outcome was consistent with their thinking at the time, as can be gauged from the contribution to the Royal Society report of Garforth, Lazonby, and Waddington, titled, "A reduced-content 16+ syllabus in chemistry".

[37] See Smith (1988) where these concepts are identified in the context of a critical appraisal of the content of GCSE science courses and their assessment schemes at the time, including traditional O-level and Nuffield as well as Salters' Chemistry courses. See Lazonby et al. (1985) for a discussion of difficulties the introduction of the mole concept met in traditional and Nuffield courses. Campbell et al. (1994, p. 427) give as a reason for not including the mole concept in the Salters' Chemistry course: "The mole concept does not emerge, from the design criteria, as essential for understanding at this level".

[38] It was "government ruling", in agreement with the greater demand for social, economical, and industrial relevance as expressed by the National Criteria (*ca.* 15% of the exam), that every SEAC committee had to have an industrialist on it.

than any other course had at that time.[39] Peter Nicolson looked after the scheme for teacher assessed marks.

Teacher training

As a liaison officer, Peter Nicolson was also in charge of the teacher training, which initially comprised sessions with small groups, but which later in 1986 and 1987 evolved into “massive training sessions of teachers” (G92b:14). The latter, called Salters’ Users Workshops or Conferences, organized by UYSEG, took as much as four days and involved up to 150 teachers.

Teachers received an introduction to the Salters’ approach and examples of the teaching materials developed on the basis of the main Salters’ design criteria, relevance and context-led development. Subsequently, teachers working in small groups gained practical experience with the development of a prototype, starting from a relevant chemical context. In plenary sessions the drafts of the teaching materials were discussed. Thus, teachers had a chance to experience and reflect on the Salters’ approach in action. These activities were intended to reinforce their understanding of the Salters’ approach, and to contribute thereby to a proper use of the Salters’ Science course in the classroom.

The conferences were funded by the Salters’ Company, which had been persuaded by David Waddington who argued that a theme-based or context-led approach such as that taken by Salters’ Chemistry would have “a bigger impact on chemical education” (G/W91:11) than the customary public school-oriented funding. Garforth said that “they didn’t skimp” (G92b:14) on teacher training, as they had done on collecting feedback from pupils, due to time pressure.

> I think that was one of the best things about the course ... that teachers who were thinking of taking it up or who had said they wanted to take it up were invited to these courses at York. (G92a:11).

Thus, over the years many teachers were invited to York and became acquainted with the context- and activity-led materials developed, that is, with the Salters’ approach. At teacher workshops they also acquired “the experience of a lot of practical work they hadn’t done before” (G92b:11), including non-traditional practical activities such as role-play and group work. As a result of the Salters’ Users Workshops many teachers decided to adopt the course for their schools.

Student Book

The course was initially conceived, designed, trialled, revised, and edited in the form of sixteen teacher units. Each unit consisted of a unit plan, lesson plans and teacher notes, and of easy, removable, worksheets for students, that is, student information sheets (SIS) and student activity guides (SAG). Waddington explained:

> Then came this awful thing. We hadn’t got a textbook. We didn’t *want* a textbook. I suppose in the end it was, in part, a commercial decision. That if we didn’t write a textbook for it, somebody else would, and they wouldn’t write it as well, and anyway why not get some money back into the project by writing a textbook (G/W91:16).

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[39] See Smith (1988, p. 112) for data which support this conclusion.

This led in 1987 to the organization of the writing of a so-called *Student Book* which would fulfill a number of functions of a regular textbook: "To excite children, and to do homework, and to tell stories, and to revise" (G/W91:16). It was not a traditional textbook, since it had only a supplementary function for students who followed the course. In effect, the course was essentially carried by the sixteen teacher units, that is, for the students, by its worksheets. The student book was "very carefully written with the Salters' ideals in mind" (G92a:12) by the four most experienced authors who had actually written textbooks before, namely Graham Hill, John Holman, John Lazonby and John Raffan, with David Waddington acting as editor. It was this student book, *Chemistry, The Salters' Approach* (1989), that the authors dedicated to Francesca Garforth for her inspiration.

4.5.3 Experienced curriculum

The Salters' GCSE syllabus was officially and nationally validated by SEAC for the "full range of grades on Mode 1" (G92a:9), which made the course in principle suitable for the full ability range. The teaching units, which had given rise to the syllabus, had been revised and edited on the basis of teachers' comments that also signaled the need for an *overall* teaching guide.[40]

Just from the numbers (about 100) of schools or teachers who trialled the course, and from the much greater number (250 – 400) who took it up after the trial phase as an exam course for their GCSE students, it became evident that the Salters' Chemistry course solved the problems of these teachers. As the developers put it, the Salters' Chemistry course, and later the Salters' Science courses, were "a *solution* to the user's *problem*" (Campbell et al., 1994, p. 429):

> The extent of uptake will, therefore, depend on how well the developers have identified the current "problems" facing potential users, and whether their "solutions" are perceived as such by enough potential users.

Apparently many teachers felt they needed to do something different for their wider range of students, partly for principled reasons as had been the case with the pioneering CSE teachers (section 4.3.2) and partly for practical reasons with the national GCSE coming up. Thus, teachers felt a need to provide a course which would work also for their less able pupils, since many of them did not have any experience with less able students in the former O/CSE system (Figure 4.1).

In the GCSE system the course had to be appropriate for the full ability range, for both the less able and the more able students. So, the slogan 'Science for All' meant here *one science course for all students*. The Salters' Chemistry course seemed to fulfill this dual need to the satisfaction of teachers, and also indirectly, one could say, to the satisfaction of pupils. Although initially the developers had expected "about 500

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[40] See (Campbell et al., 1994, pp. 440-444) for more details on other forms of course evaluation.

candidates the first year", they got "up to 8000" in 1988, and "it peaked about 12000 – 15000" (G/W91:13) in 1990.[41]

It also became clear that the Salters' Chemistry GCSE course was suitable for the *full* ability range, that is, not only for the less and moderately able, as they had thought initially, but also for the *most able* children.

> Then when we actually got children from independent schools, children of really *high ability* doing it, we were *amazed*. The exam board had been perfectly prepared not only to accept the low numbers but also they would, in the first instance, be children of *lower ability*. Schools would enter their brighter pupils for traditional syllabuses and they would enter their less able for the Salters' syllabus. But we got a lot of schools, particularly girls' schools, who entered *the whole lot* for Salters' (G/W91:19).

While they were amazed about this, Waddington probably also felt relieved. Not only did the ground rules of the GCSE system require them to produce a chemistry course, appropriate for the full ability range including the most able students, but as Waddington remarked later:

> It was paramount that the course should also be, and be seen to be, appropriate for those students who had traditionally excelled in chemistry" (W97).

4.5.4 Conclusion and Discussion

As with the Year Three course, I will now try to answer the question, to what extent the GCSE course captured "all kinds of things" the developers wanted as formulated in their tentative vision and design criteria (see sections 4.1.3 and 4.3.3). In terms of my curriculum framework, whether the transformation of the visionary curriculum into the written curriculum of Salters' Chemistry, now in the form of the GCSE course, was consistent with their proclaimed design criteria.

Again I will do this in terms of changes in the design criteria, focusing on the development process, and in terms of the curriculum structures introduced in Chapter 1 of this thesis: the pedagogical, philosophical and substantive structures, focusing thereby on the curriculum product (see Figure 4.5 below). This will also allow us to answer the question, to what degree did the written curriculum of Salters' Chemistry in the form of the GCSE course escape from Normal Chemistry Education, that is, from traditional O-level chemistry, in England.

Changes in design criteria

Following is a brief discussion of the changes in design criteria that resulted from their application to the situation of developing the GCSE exam course (see section 4.5.1).

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[41] According to the Salters' Chemistry Overall Teaching Guide (1988, p. 6), "10,563 candidates took the first GCSE examination in Chemistry (Salters') in June 1988". The arrival of the National Curriculum, from 1989 onwards, which made balanced science (a combination of physical sciences, including chemistry and biology) mandatory led to a steady decrease from 1990 onwards in students taking separate chemistry courses, including, with some delay, Salters' Chemistry.

First, design criterion one, *No preconceptions*, has now been replaced by "what we perceive, what we *all* perceive to be *the structure of chemistry*" (L 92) in order to arrive at what was called some worthwhile chemistry. It is to be noted that the developers did not make explicit in detail, what they meant by-"*the structure of chemistry"* – and which Garforth (1983, p. 30) referred to as "a corpus of knowledge without which no syllabus could be called chemistry" (section 4.3.1). That is, the developers did not try to fulfill condition one: *Perform a domain specific analysis of the nature and structure of the dominant school chemistry curriculum* (see also sections 1.2.2 & 2.3.2, and Figure 3.10).

The application of design criterion two, *Relevance,* initially leading to a free choice of contexts, now led to a choice of contexts constrained by two factors: taking into account what the developers viewed as a "web of contexts", and matching these contexts with the topics as required by the National Criteria for Chemistry.

The application of design criterion three, *Context-led development of chemical concepts,* changed more and more from a strictly context-led development to a *conceptually* led development of chemical concepts, guided by the joint constraints of "*the structure of chemistry*" and the National Criteria for Chemistry. At the second editorial stage at the end of the GCSE trial this led to a reordering of chemical concepts in order to increase the conceptual coherence of the course. For example, the last unit of the Salters' Chemistry course *had* to deal with a number of concepts about chemical bonding not yet addressed in previous units. This resulted in a unit with a somewhat uneven conceptual loading compared to previous units. The unit was subsequently provided with the theme or label, "Burning and Bonding".

Finally, during the development process of the GCSE course a fourth design criterion evolved: stressing the use of a variety of learning and teaching activities.

To sum up, the curriculum emphasis of the Salters' Chemistry GCSE course changed from an intended school chemistry course with the emphases *Everyday Applications* and *Science, Technology, Decision* to an course which tried to combine these two emphases with what Roberts (1988) called a Solid Foundation emphasis. As we will show in detail in Chapter 5, this shift in emphases had as a consequence, that the ratio between CTS content and PC content (Aikenhead, 1994) used in a unit must change accordingly.

Changes in curriculum structure

The most important components of the pedagogical, philosophical, and substantive structures of the written curriculum of the Salters' Chemistry GCSE course are categorized in the right-hand column of Figure 4.5. For purposes of comparison, the left-hand column gives the corresponding components of the written curriculum of Salters' Chemistry for the Year Three course. The most prominent changes have been italicized.

To sum up, there emerges here a trend towards a stronger emphasis on the needs of the more able students corresponding to a stronger emphasis on chemical theory and corpuscular explanation, largely set within a traditional structure of school chemistry as perceived by the developers.

Figure 4.5 Shifting curriculum emphasis in the Salters Chemistry development [a]

Curriculum categories	**Written curriculum: Year Three course**	**Written curriculum: GCSE exam course**
Pedagogical structure	**Essential chemistry for living**	**Chemical awareness and** **Basis for further study of chemistry**
Aims	Chemical awareness future citizens; Making sense: internally set aims; CSE/GCE transition (external constraint).	Chemical relevance, making sense; Internally and externally set aims; *Full ability range, including most able.*
Teaching approach	Bottom-up; Central role of relevant experiments; Familiar materials- and theme-based; *No textbook*, only teaching units.	Bottom-up; Wide range of activities; Context- and applications-led; Teaching units and student book (add-on).
Learning approach	Accessibility of level of knowledge; Interest and motivation (worksheets).	Interest and motivation (worksheets).
Philosophical structure	**Relevance and Use**	**Relevance and Use**
Foundations of Science	Daily life phenomena/applications; Theory on “need-to-know” basis; Most able need or want more theory.	*Theory on “need-to know” basis: most able need or want more theory and abstract explanation for next level (A-level).*
Methodology of Science	Communal problem solving activity, including social, economic oriented problems.	Communal problem solving activity, including social, economic oriented problems.
Foundations Chemistry	Applied chemistry: internally set emphasis; Purpose/use related to gross properties; More macrolevel than microlevel.	Applied chemistry; Internally and externally set emphasis: industrial/product oriented; *More central role of corpuscular theory.*
Methodology of chemistry	Making things; Analyzing things made.	Making things; Analyzing things made.
Substantive structure	**“a recognisable sequential order”**	***“Structure of chemistry as we perceive it”***
Chemical Concepts	Some agreed elementary ideas.	*Some reduced conceptual loading, e.g. not the mole/some equations.*
Chemical Relationships	Some kind of basis for O-level; Standard on any syllabus.	*As much as needed by familiar contexts, e.g. not periodic system, atomic structure.*
Chemical Techniques	Lab techniques applied to familiar materials.	Standard but applied to familiar materials.

[a] Most keywords are drawn from interviews and publication developers; some paraphrasing added.

4.6 The formal curriculum: the GCSE exam course

In this section I will analyze whether the transformation of the visionary curriculum into the formal curriculum of Salters' Chemistry proceeded in a consistent way. The Salters' Chemistry GCSE examination course, taken as the end product of the developmental process, was published as a set of curriculum materials in 1987, with its first examination in 1988. As we saw, the project was not originally conceived as it turned out, nor did it follow-a fully predetermined plan. The developers stated:

> Rather, the work *evolved* from more *humble* aspirations and more *circumscribed* ambitions. Step-by-step extensions led from an original 1 year course in chemistry, for 14 year olds, to a 3 year chemistry programme and a national examination, the General Certificate of Secondary Education (GCSE), taken by 16 year olds at the end of year 11 (grade 10) of their schooling (Campbell et al, 1994, p. 416).

The very first "humble aspirations" originated with Francesca Garforth in the early 1980s. In section 4.2.2, I have described the circumstances and experiences from which her vision of a new and relevant school chemistry course evolved. The curriculum emphasis arrived at was described as:

> A chemistry syllabus based on everyday materials with *chemical awareness for future citizens* as a principal aim (Garforth, 1983).

Up to now, I have described and discussed the development of the visionary and designed curriculum (section 4.3), which evolved into two stages of the written curriculum of Salters' Chemistry: Year Three in section 4.4 and the GCSE course in section 4.5.

In this section of Chapter 4, I describe, analyze, and discuss the formal curriculum. Again, I describe and analyze in terms of my curriculum theoretical framework the application of the design criteria and its changes (4.6.1) and the resulting curriculum structures during the development of the formal curriculum, that is, the GCSE exam course (4.6.2), followed by a discussion of these changes, and the degree of escape from NCE in section 4.6.3. For an overview of the developmental process, see Figure 4.4.

4.6.1 Application of design criteria

In June 1988, more than 10,000 candidates took the GCSE exam as specified by *Chemistry (Salters') Syllabus Code 1377* (hereafter referred to as SLB). About 75% of the students passed with grade A – D. This constituted the successful realization of a "remarkable curriculum development which has been driven by the ideas and enthusiasm of the teachers involved", as it said in the *Overall Guide for Teachers* (first edition 1988; hereafter referred to as OGT). This teacher's guide contained the "overall strategies for introducing and managing the course which supplemented the tactical support [given by] the sixteen unit guides [revised edition 1987] which make up the main body of the course" (OGT, p. 1). A second supplement, a Student Book introduced for student support, *Chemistry: The Salters' Approach*, was published in 1989. These curriculum products make up the formal curriculum of Salters' Chemistry course.

The writing of a national syllabus implied, of course, that the course content, as it had evolved during the developmental process had to be *matched* as a whole to the National Criteria of Chemistry, a set of broad guidelines in force from 1985 onwards. Garforth:

> You start with one set of ideas, like Nuffield did, but you've got an exam at the other end, so somewhere you've got to *match*" (G92b:8).

The National Criteria were taken by the developers at this stage, as something to which one had to adapt in the end, so the criteria were not perceived as being very prescriptive. Once the National Criteria for 16+ chemistry were officially accepted, the developers tried to match the criteria, but to do so as much as possible in line with their intentions.[42] This meant that, "the *core content* required by the National Criteria of Chemistry is *covered* in the syllabus" (SLB, p.1).

Although "the syllabus does not constitute a teaching sequence and should be read in conjunction with the course materials" (SLB, p. 8), the overall guide for teachers notes:

> In some cases the logical development of concepts does dictate a teaching sequence and this is noted in the recommendations (OGT, pp. 22-24).[43]

This implies that in other cases developers and/or teachers had complete freedom to follow a sequence of concepts, for instance as it emerged from chosen contexts and/or activities.

It is noteworthy that in neither the Salters' Syllabus nor in the Overall Guide for Teachers is there a reference to the first design criterion, *No preconceptions*, while the other three design criteria are explicitly mentioned.[44] As we saw above, design criterion one did receive primary and explicit emphasis during the development of the visionary and designed curriculum, but it received less attention during the stages of the written curriculum of the Salters' Chemistry project. During the developmental process it was gradually realized by the developers that they had to conform to some extent to what they called, "a recognizably sequential order" of elementary chemical ideas, thereby replacing, albeit with a rather bad conscience, design criterion one, *no preconceptions* (section 4.4.3). The first design criterion, one could argue, is most relevant for developers, but not for teachers executing the curriculum or for administrators, that is, the very audience addressed in these documents (SLB and OGT) here. On the other hand, as it says in the introduction of the unit Metals (1989), design criterion one could well be relevant for teachers.

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[42] Many chemistry teachers had tried to influence the contents of the Draft National Criteria for 16+ Chemistry, by taking part, either individually or collectively, in "an exercise in *teacher consultation* never before undertaken" (Garforth, 1982a). Some of their comments, for example, those of the Education Division of the RSC (with Garforth as a member) "were considered by the working party when formulating the draft National Criteria for 16+ chemistry" which was published in January 1982 (Garforth, 1982b). See also Harding (1986, p. 49).

[43] As quoted above (section 1.2.2), a strikingly similar recommendation comes from a Dutch chemistry syllabus. There it said that: " Although it is true that a syllabus presents the topics in an order which is as *logical* as possible, this does not mean that the topics of a course in a certain year have to be taught in that *order*. The teacher is free to choose an order, though often *the structure of the subject* makes it necessary to teach certain topics before others." (Min. O&W, 1984b). My analysis and research of the *structure of school chemistry*, as reported on in Chapter 2, resulted in a description of Dominant School Chemistry as a form of Normal Chemistry Education, exemplified by the 'core content required by the National Criteria of Chemistry' referred to by the Salters' developers above.

[44] Holman (1987, p. 435), looking back on the design of the course units, does refer to the first design criterion as follows: "True to the philosophy of 'applications first' they [the units] were created by reference to everyday themes, *not to preconceptions about what should be taught in a chemistry syllabus*".

> "who want to introduce replacements and modifications to parts of lessons, whole lessons or *even whole units* where they feel it is appropriate".

As for the second criterion, *relevance*, this is expressed in the syllabus as follows:

> Each part of the course starts with a *material or phenomenon* with which most students can be expected to be *familiar* [Sub] as a result of their own experience or through the media of books, papers and television. The behaviour of such materials, their *use related to their behaviour* [FC] and their importance in our lives are studied through student activities ... (SLB, p. 1)
>
> Each topic should have its origin in *everyday* experience and be developed through the use of *familiar substances* [Sub] (OGT, p. 9).

The syllabus gives an elaboration of the "*fundamental* emphasis" (SLB, p. 8) of the Salters' Chemistry course as, what I called in section 4.1.2, a C*hemistry through Technology* (CTS) course. The relevance of chemistry in the real world is addressed by presenting "the syllabus *content* under the headings of eight *unifying themes* which run throughout the course" (SLB, p. 8). These themes are: Natural Resources, Food and Water, Fuels and Energy, Useful Materials, Health, The Environment, Corrosion and Erosion, and Industrial Processes.

These unifying themes support, as it is put, the "amplification of content" (SLB, pp. 9-13) in terms of sub-themes, contexts, and applications which are to be matched to the "Chemical Content and Concepts Developed" in the course units (SLB, Section A: 9-14).

In Chapter 5, I will give a detailed analysis of the theme Corrosion as treated in the unit "Metals" in relation to the chemical concepts introduced and developed through relevant contexts and applications.

The third design criterion, *context-led development of concepts*, is expressed as follows:

> ... chemical generalisations, principles and explanations are only introduced *as and when* they arise *naturally* from or *when needed* in the work on these 'everyday' substances [Ped/TA] (SLB, p. 1).
>
> Chemical theories, principles and explanations were to be introduced only *as* they were seen to be *needed* for understanding of the work being done [Ped/TA]. Of course, only those topics which turned out to provide a natural introduction to some "worthwhile chemistry" were developed (OGT, p. 9).

In these quotes a tension seems to surface between chemical content and chemical context. On the one hand, a theme or context should "provide a *natural* introduction" to some "worthwhile" chemistry by which is meant, I take it, some worthwhile chemical content. On the other hand, in the last quote and, also in the introductions to the units, it is emphasized that "chemical concepts and explanations *arise naturall*y *from the study of these everyday situations*" (Metals 1989) as and when needed for making sense of the chemical contexts. This raises the important question as to what the developers thought was more fundamental: the new fundamental CTS emphasis (SLB, p. 8), embodied in the themes or contexts chosen, or the traditional emphasis on a solid foundation of fundamental concepts, a question to which I will return in Chapter 5.

The fourth criterion, *variety of learning activities*, mentioned above (4.5.1), emerged during the developmental process and also found explicit expression, albeit with slightly different accents:

> The teaching materials allow a wide *variety of teaching and learning activities* leading to a positive and mature *involvement* by students [Ped/TA] (SLB, p. 1).
>
> Particular attention was to be paid to encouraging an *interactive teaching* approach in which students would be *actively involved* [Ped/TA] and which would help encourage students' *study skills* and general *personal development* [Ped/A] (OGT, p. 9).

At least from the time of creating pilot materials, to be used by teachers in the Salters' Chemistry Project, another, fifth criterion was articulated: *flexible, teacher-mediated use*.[45]
This idea of flexible use also found expression at the stage of the formal curriculum:

> Further, we want the materials to be used *flexibly*, and it is possible for teachers to introduce replacements for or modifications to whole lessons, parts of lessons and student activities (SLB, p. 1).[46]

> The intention has been that the unit guides should provide *a basis* from which individual schools would develop their *own* teaching materials. ... They should be as *flexible* as possible in use, so encouraging *continual review and development* of the course within each school. (OGT, pp. 7, 9).

4.6.2 Pedagogical, philosophical, and substantive structures

In this subsection I will analyze, in terms of the Schwabian framework and codes introduced in Chapter 2, the two documents pertaining to the overall formal curriculum of Salters' Chemistry: the syllabus (SLB) and the Overall Guide for Teachers (OGT). The first document gives a detailed enumeration of the aims and the assessment objectives of the Salters' Chemistry course with cross-references to the aims and assessment objectives given by the National Criteria of Chemistry (SLB, pp. 2-4; 20-22). The overall teacher guide deals with the design criteria and discusses also in detail the variety of teaching and learning activities used to achieve the set aims (see also Figures 4.6 and 4.7).

Pedagogical structure

The teacher guide gives the following general statement of the aim [Ped/A] of the course:

> ... a complete course which would give a *sound foundation* of chemical knowledge and understanding [Sub] through an "applications led" [their emphasis] approach [Ped/TA] which would be accessible to a *wider* range of students [Ped/A] than those catered for by more traditional courses (OGT, p. 6).

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[45] Already in Metals (1984) this criterion of flexibility had emerged: "The materials should be organized in such a way that detailed guidance would be provided and yet they would be capable of being used *flexibly* in the sense that it should be possible for teachers to introduce replacements for, or modifications to, whole lessons, parts of lessons, experiments, etc." See also Campbell (1994, p. 430).

[46] Also, in the teaching units such as Metals (1989), it says in the introduction under the heading "Design of materials", "The materials must be *flexible* enough to allow [experienced] teachers to introduce replacements and modifications to parts of lessons, whole lessons or *even whole units* where they feel it is appropriate". On the other hand, and in particular for "those who are starting their career and those who are teaching outside their main specialism" (Metals, 1989), a substantial level of help would have to be given in the unit, also because the Salters' approach meant that many units would contain relatively unfamiliar material (See OGT, p. 9).

The syllabus defines the target group [Ped/A] as "the whole range of GCSE grade A – G" (SLB, p. 2; see also Figure 4.1). Thus, any uncertainty the developers had previously felt about the range of the target group (low, middle and high ability), during the development of the written curriculum (see section 4.5.2), disappeared at the level of the formal curriculum. The course explicitly addresses the full ability range, primarily students of middle ability but supplying additional strategies for the less able as well as the more able students (OGT, pp. 35 – 36).

The syllabus section titled "*Aims of the course*" [Ped/A] starts by giving the following general aims, that is to say, to provide a course in chemistry which will:

- be relevant and appropriate to students who will have no further contact with the subject;
- provide an appropriate body of knowledge and skills for those continuing to more advanced studies in chemistry and other related disciplines;
- stimulate students and create and sustain their interest in and enjoyment of the study of chemistry.

The description of the aims of the course continues (SLB, pp. 2-3) with three sets of aims [Ped/A]. These aims are largely similar to the curriculum orientations on science education introduced in Chapter 2 of this thesis and discussed in Chapter 3 using the labels: *result-oriented* (NSE), *process-oriented* (HPS), and *society-oriented* (STS) science education (see Figure 4.6).

These three sets of aims and the associated specific assessment objectives can be seen as the detailed elaboration of the balance of "theory, practicals and relevance" (G92a) sought by the Working Party of the National Criteria of Chemistry (Garforth, 1982a).

A set of aims and objectives stated in such detail guide but can also seriously constrain any attempted alternative teaching scheme such as Salters' Chemistry. The point is, that at the stage of the formal Salters' Chemistry curriculum the developers had to "match" fully and explicitly their written teaching units to the aims and objectives listed above, that is, to a much greater extent than in the earlier phases of the development. Thus, the developers could no longer focus primarily on the curriculum orientation or CTS emphasis they preferred, that is, on the development of a society-oriented and applications-led chemistry course.

As we saw in section 4.5, to obtain acceptance as an exam course, it was necessary to add some theoretical concepts to the first submitted GCSE Salters' syllabus in order to comply with the required *result-oriented* science demands of the National Criteria of Chemistry. This increases the *tension between context and content*, a tension which has manifested itself during the development of the Salters' Chemistry course, as we will discuss in detail in Chapter 5 on the development of the unit Metals.

Further, the set of aims and objectives with regard to students' abilities and skills leads to a greater emphasis on *process* objectives than originally envisaged by the developers. This introduced to some extent a second tension into the formal Salters' Chemistry curriculum, this time between *context and process*, as we will see in Chapter 5. Hence, the Salters' Chemistry curriculum, originally and primarily intended as a relevant and *context*-led chemistry course aiming at raising the chemical awareness of future citizens, now has to integrate in its course both detailed *process* objectives as well as demanding *result* objectives (Figure 4.7).

The OGT (pp. 38-68) contains a detailed description and analysis of the *variety* and frequency *of teaching/learning activities* used in the course [Ped/TA], as well as strategies for introducing and managing them. The developers feel confident, on the basis

Figure 4.6 Aims of the Salters' Chemistry Course

RESULT-ORIENTED SCIENCE EDUCATION (some terms put in italics refer to STS aspects)

To encourage students to relate their chemical knowledge and understanding to:

(a) *making* and *using* materials;
(b) chemical structure and the behavior of materials;
(c) the development of chemical patterns and principles;
(d) the *environment*.

PROCESS-ORIENTED SCIENCE EDUCATION

To develop students' abilities and skills in:

(a) formulating hypotheses and designing investigations;
(b) performing and interpreting experiments;
(c) evaluating data, making decisions and solving problems;
(d) communicating findings.

SOCIETY-ORIENTED SCIENCE EDUCATION (same terms put in italics refer to HPS aspects)

To provide the opportunity for students, through practical studies on the behavior of familiar substances and discussion of familiar experiences, to

(a) appreciate that the study of chemistry is relevant to everyday life;
(b) appreciate that the applications of chemistry may be both beneficial and detrimental to the individual, the community and the environment;
(c) become well informed and hence confident citizens in a technological world;
(d) realize the strengths and limitations of the ways scientists attempt to solve problems and the application of these methods to other disciplines;
(e) become aware that the study and practice of chemistry are human activities which are subject to social, economic, technological, ethical, and cultural influences and limitations.

of previous trials, that these varied activities will serve as the means to realize the aims and objectives sought.

According to the activity analysis performed (OGT pp. 38-45), the following activities are used most frequently in the units: teacher-led introduction/explanation/discussion, teacher-student discussion, data analysis/interpretation/translation, and class practicals. The latter activity, *practical* work, is seen by the developers as being "*central* to the Salters' Course" (OGT, p. 57). The discussion in the teacher guide deals to a great extent with non-traditional or "less familiar teaching strategies" (p. 37) such as small group discussion, the use of computers, and the managing of role play; traditional teaching activities receive less attention.

Both SLB (appendix D, pp. 23-39) and OGT (pp. 68-79) discuss at great length the *internal* assessment model with regard to practical skills and individual assignments which make up 40% of the total assessment against about 20 – 25 % in traditional courses.[47]

In brief, the pedagogical structure entails, besides a *relevant emphasis* on chemistry, quite a lot of *practical* chemistry, while its chemical content is appropriate for the full ability range of students. This gives rise to two curriculum tensions: (i) between context and content and (ii) between context and process. More will be said about these tensions at the end of Chapter 5 after the lesson and unit analysis of Metals (1989).

Philosophical structure

Both SLB and OGT also contain statements which express views of science [FS] and/or chemistry [FC]. The ambition to develop a course which would show the relevance of chemistry in the real world led developers (SLB, p. 1) to:

> ... rethink our ideas of what *theory* is *appropriate* to teach in such a course. In particular, we found that many of the substances familiar to students are structurally too complex to be amenable to *molecular* interpretation by GCSE students. We have, therefore, developed *explanations* of properties in terms of *macro* structures [FC].

Central importance was given to the *use* of familiar materials *in relation to* their *behavior* [FC] as can be judged from the theme-based summary of the unit content (OGT, pp. 10-12), the experiments which have been selected for assessment of practical skills (OGT, p. 69) and for individual assignments (OGT, p. 75), and also from the choice of role-play (OGT, pp. 53-57). Chemical-societal concepts such as *source*, *manufacture*, and *use* of materials (e.g. of fabrics, metals, fertilizers, cosmetics and plastics), as well as chemical-societal relationships between properties and use of familiar materials, are mentioned frequently. Furthermore, in the syllabus it is stipulated for individual assignments that students should have:

> a wide scope both in the *choice* of topics and in the *mode* in which the work is presented ... the only *constraint* is that the work should illustrate chemical knowledge and understanding within a *social, environmental, industrial and technological context* (SLB, p. 30).

So, design criterion two, *relevance*, receives primary importance here. Besides the consequences for teaching and assessment, the society-oriented emphasis of the course has, according to the developers, the following practical consequences:

- Since many of the everyday substances cannot be bought on requisition to a *laboratory supplier* teachers or technicians have to go to *local shops and markets* (OGT, p. 18).
- *Common* names of chemicals are used when these chemicals are met by students in everyday experience or activities; once the activity moves to a study of the chemistry of a substance, the *systematic* chemical name is used (OGT, p. 13).

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[47] See Smith (1988, p. 111). Neil Smith, whose school became from September 1986 onwards a Salters' Chemistry Project school, performed a detailed comparison of the assessment model of the Salters' Chemistry course, Nuffield courses, and a number of traditional courses.

- Since the course *overlaps* with other subject areas, in particular with “biology, physics, geography, home economics and craft, design and technology” (OGT, p. 19), liaison with other school departments should be established.
- Visits to local chemical industries or contacts with relevant organizations are encouraged e.g. Fire Brigade (OGT, p. 19).

In brief, this part of the philosophical structure is about relevant chemistry in real life, including technology and industry (see Figure 4.7). It is not primarily about pure substances, but rather deals with the sources, manufacture, and use of materials. These are mostly mixtures and as such go beyond the pure school chemistry conception referred to in Chapter 1 of this thesis.

The OGT also discusses some points concerning the methodology of science [MS], saying that “the balance of the [practical] work is more towards students *discovering* scientific principles for themselves and *solving problems* rather than completing experiments to *illustrate* theory taught earlier” (OGT, p. 57). For problem-solving the developers use the following definition (OGT, p. 62):

> Students planning, devising, carrying out and evaluating a method to solve a problem. The problem could be *technologically* orientated and could be open-ended and ideally would be set in a real life context.

Problems can be open or closed. An open problem may either “involve the possible use of many different routes to achieve a solution or may have a number of acceptable solutions” (OGT, p. 62). A closed problem has only one solution. Enough time has been made available in the course for students “to be given some open problems to solve” (OGT, p. 62). Problems should as far as possible arise *naturally* for the student during the course, although they might have to be set and clarified by the teacher (OGT, pp. 62-64). This type of activity makes it possible for the course or teacher to address, as much as needed, the required science process objectives, but they can thereby also lead to a tension between the time required to deal thoroughly with these process aspects and the time needed to deal with contextual or relevant aspects of the course.

Substantive structure

The substantive structure of the formal curriculum of Salters’ Chemistry had to coincide, after the necessary matching, with the National Criteria of Chemistry (Figure 4.7). Thus, SLB (section B, pp. 15-16) lists the “chemical principles” [Sub/CT] developed during the course, while section C (pp. 17-18) does so for the “principal substances and reactions” [Sub/CC], just as Section D (p. 19) does for the chemical “techniques and tests” [Sub/CT] (see Figure 4.7).

The OGT goes further by giving an elaborate analysis of the chemical concepts developed during each year of the course (OGT, Section 3, pp. 22-29). This leads to the interesting observation, already mentioned above, that:

> In *some* cases the *logical* development of concepts does dictate a *teaching sequence* and this is noted in the recommendations (OGT, p. 22).

It leads to a recommended teaching sequence of units for Years Four and Five, but interestingly not for Year Three. The teaching order recommended adheres to the following guidelines:

- Macroscopic chemistry first (predominantly in Year Three)
- Corpuscular chemistry as a later, central emphasis (Year Four and Year Five)
- Introduction of concepts on a need-to-know basis
- Spiral revisiting of qualitatively introduced concepts in different contexts
- Increasing sophistication of qualitative concepts
- Increasing mathematical demands

For practical skills developers do not assume a specific sequence except for purposes of assessment. Some practical skills are "assumed to be mastered prior to Year Three" (OGT, p. 58).

The National Criteria of Chemistry only specify a *core* chemical content, which makes it possible to teach and assess topics and issues "from areas of social, economic, environmental and technological applications of chemistry" (SLB, p.1) more than the recommended 25%. The opportunity to teach chemical-societal-technological (CTS) content can amount to about 40–50% of the total content as it did in the case of Salters Chemistry.[48]

In brief, the substantive structure of Salters' Chemistry is governed to a certain degree by the *logical* development of concepts. Corpuscularity is given a *central*, although not a primary focus, while macro-chemistry is emphasized, especially in Year Three.

Figure 4.7 Salters' GCSE Chemistry: Structure of the formal curriculum

Categories	**Specifications taken from OGT (1988) and SLB (1992)**
SUBSTANTIVE STRUCTURE	**LOGICAL DEVELOPMENT OF CHEMICAL CONCEPTS AND PRINCIPLES**
Chemical concepts	States of matter, solutions and solubility, dispersions; Elements, compounds; pure substance, mixture; the Periodic Table; Symbols, formulae and equations; quantitative chemistry; simple balanced equations; Atoms, molecules and ions; structure of atom – electrons, protons and neutrons Speed of reactions; affected by concentration, surface area, temperature, and catalysts; Reversible reactions; enzyme reactions; Energy changes in chemical reactions (exothermic, endothermic), conversion of energy; Acids, bases and salts; Oxidation and reduction (in terms of gain and loss of oxygen only); Electrolysis.

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[48] See Smith (1988, p. 112) who, after analyzing the assessment model and specimen papers, arrives at a percentage of *ca.* 50 % for what he calls the *utilitarian* aspects. See also Harding (1986).

Figure 4.7 Salters' GCSE Chemistry: Structure of the formal curriculum (continued)

Chemical relationships	Relationships (external) with real world e.g. common names; with physics, technology, society; Particulate and kinetic theory of matter explain reversible physical processes Structure and bonding (ionic, covalent), simple ideas in terms of microscopic models; Relation between properties and structure, e.g. hardness related to packing of particies: Macrostructure of materials.
Chemical techniques	Methods of separation e.g. filtration, paper chromatography, electrolysis, and flotation; Methods of purification e.g. simple and fractional distillation, evaporation, crystallization; Standard tests e.g. for hydrogen, oxygen, carbon dioxide, water, metal ions; Testing for soil nutrients, proteins, fats, sugars; titration.
PHILOSOPHICAL STRUCTURE	**RELEVANCE, CHEMISTRY FOR INDUSTRY AND EVERYDAY LIFE; SOURCES, MANUFACTURE AND USE**
Foundations of science	Strength and limitations/human activity.
Methodology of science	Processes of enquiry e.g. hypothesizing, experimenting, evaluating; Problem solving e.g. control variables/comparative testing; Discovering scientific principles; use of models.
Foundations of chemistry	Use of familiar materials in relation to their behavior; Social, economic, environmental, industrial, and technological contexts; Theory/explanations of properties as much as needed in terms of macro-structures.
Methodology of chemistry	Making and analyzing; Practical skills e.g. using a chemical balance, pipette.
PEDAGOGICAL STRUCTURE	**WORTHWHILE, PRACTICAL, AND RELEVANT CHEMISTRY**
Aims	Accessible to full ability range of students, providing whole range of GCSE grade A – G to: (i) students who will have no further formal contact with the subject; (ii) students continuing to more advanced studies of chemistry and other related disciplines; Sound foundation of chemical knowledge and understanding; Develop students' skills/understanding of science processes; Develop study skills/personal development; Practical studies of familiar substances and of relevant applications; The importance of chemistry in industry and in everyday life.
Teaching approach	Familiar contexts: materials/phenomena first; applications led; Variety of interactive classroom activities/central value of practical work; Chemical concepts as and when needed/drip-feed/spiral revisiting; Teacher mediated, teacher guidance and support.
Learning approach	Motivate students through relevant contexts and various activities; Enable students to develop their own interests and ideas.

4.6.3 Conclusion and discussion

I will now try to give an answer to the question regarding the extent to which the formal curriculum, the last phase in the Salters' Chemistry development process, has developed in a consistent way from the visionary curriculum, that is, from the initial vision and design criteria. As before, I will also look into the changes of the pedagogical, philosophical, and substantive structures of the formal curriculum compared to the visionary curriculum and NCE.

Changes in design criteria and resulting curriculum

First of all, design criterion one, *No preconception*s has now been replaced by guiding conceptions, internally by "what we *all* perceive to be *the structure of chemistry*" (L 92), and externally by the demands of the General Certificate of Secondary Education fulfilled for the Salters' Chemistry course in the *Chemistry (Salters') Syllabus Code 1377*. Design criterion one is not mentioned in the curriculum products of the Salters' Chemistry course, not in the teaching units or in either the syllabus or the teacher guide. The initial uncertainty about the suitability of the course for the *full* ability range has disappeared.

The application of design criterion two, *Relevance*, to the situation of the formal curriculum leads to a choice of contexts constrained more and more by GCSE requirements of content or process, giving rise to the tensions mentioned above between context and content and between context and process.

The application of design criterion three, *Context-led development of chemical concepts*, has led to an increased emphasis on chemical concepts and their sequential and/or logical development. Important too was a greater emphasis on scientific processes over and above the initial emphasis on chemical techniques and practical skills.

Finally, inspection and comparison of Figures 4.3 and 4.7 show that many components of the pedagogical, philosophical, and substantive structures of the written curriculum of Salters' Chemistry did change: they became much more explicit or more detailed, while some important components, as we saw above, were discarded or replaced.

Discussion

All these changes came about, in my analysis, as a result both of the *internal* dynamics of the development process and the *external* constraints acting upon the developers in the form of the National Criteria of Chemistry and later the demands of the GCSE . Furthermore, the changes in substantive, philosophical, and pedagogical structures are probably connected. The greater emphasis by way of the GCSE criteria on cognitive aspects, concepts [Sub] and processes [Phil] of science, seems to indicate a greater priority given, again, to the needs of the more able students [Ped] than was intended originally by the Salters' Chemistry developers.[49] As a result, the formal curriculum of Salters' Chemistry appears to give at least equal weight to the needs of students "continuing to more advanced studies in chemistry and other related disciplines" and

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[49] This was, of course, the curriculum orientation paramount in previous O-level courses, and also, with a renewed academic emphasis in the Nuffield courses. See Shayer and Adey (1981).

"those who will have no further contact with the subject" (SLB, p. 2). Salters' Chemistry now had to serve both aims and both target groups equally well which, as we will argue, must be considered as a tall order containing several inherent tensions.[50]

The decision to extend the Year Three course to a national exam course, and to be accepted as such "with the full range of grades on Mode 1" (G/W92a:9), resulted in a relevant chemistry course suitable for the full ability range [Ped/A], thus including the *most able* students. In line with this, Campbell et al. (1994, p. 421) claim for the Salters' Science courses in general that:

> They were in *no sense* developed as courses "for the less able" or for "less well-motivated" pupils but for a wider and more varied group of students which *might* include these categories.

This is claimed in retrospect, while reconstructing the process of development for the purpose of giving a systematic analysis of the "framework, approach, and development process" (ibid., p. 417) of the Salters' projects. As we have seen in sections 4.3 and 4.4, however, this does not apply to the first Salters' project, that is, to the Salters' *Chemistry* project, although it might apply to the later Salters' *Science* projects. Unlike the Salters' Chemistry Project:

> The Salters' Science Projects started off by being in two straight-jackets, one that they had to write a course that looked like the Salters' Chemistry. Two, that they had to write a course that conformed to the national curriculum. So we had our freedom and we had to *constrain* it with the national criteria, but they never had their freedom (G92b:12).

In my analysis of the process of developing teaching materials for the Salters' Chemistry course, based on interviews with the developers, I have been led to a different account for *this* project's focus on the needs of "the less able" and "less well-motivated students".

In order to achieve their aims, the same context- and applications-led teaching approach [Ped/TA] was used by the developers as in the Year Three development, but with a need to create more *coherence among themes* accompanying the evolving *conceptual coherence* already striven for by the developers in the Year Three course; that is, they tried to match a set of coherent themes *via* a set of activities to a set of chemical concepts, while using, as much as they thought necessary, the logical structure of chemistry [Sub] as they all perceived it. This led to a different context- and activity-led *teaching sequence* of concepts. More than in the development of the Year Three course, the developers decided to use or devise a *wide* range of activities [Ped/TA], over and above the standard experimental lab work.

The practical or applied view on chemistry [Phil], already adopted in the Year Three units, was reinforced by the emphasis, put by government and industry alike, on the chemical industry and its products. For example, quite a few Salters' Chemistry units dealt with the making of familiar products such as "mayonnaise or paint" (G/W91:15).

On the other hand, providing an examination course for *all* students, including the most able ones, brought back a greater *academic* emphasis on conceptual chemical

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[50] Garforth (1982, p. 130) made this point some years before the start of the Salters' projects as follows: "A daunting task for any syllabus designers!", in her reaction to the DES document *Science Education in Schools – a consultative document* in which it says: "removing material which has little relevance to the pupils needs ... [but] without reducing the intellectual demands made on pupils".

content [Sub] and on chemical theories and *explanations* using those concepts [Phil]. So, at this stage, to quote John Lazonby (L92) once more:

> [The developers] were analyzing what there was, *using* what we perceive, what we all perceive to be *the structure of chemistry*.

Thus, this was the structure of chemistry as the teacher-developers were accustomed to *use*, often in a *tacit* way, either in their own years-long teaching of school chemistry or in their writing of school chemistry textbooks. Since, as discussed above (4.3.3), the developers had decided *not* to pursue Channel A[51], after it turned out that it was not possible to arrive in their first workshop (1982) at a clear view of the "essential chemistry of living" (Garforth, p. 30), their ideas of what they all perceived to be the structure of chemistry were not made explicit by them a priori, but a posteriori, that is during the developmental process (checklist, 'Control'), and at the end of the developmental process (OGT, pp. 22-30). That is, the developers did not try to fulfill condition one: Perform a domain specific analysis of the nature and structure of the dominant school chemistry curriculum (see also sections 1.2.2 & 2.3.2, and Figure 3.10).

At this point it is worthwhile to remember one of the major obstacles, mentioned by Garforth (1983), on the road to development of a radical, alternative school chemistry curriculum:

> "It may well be that there is a *corpus of knowledge* [Sub] without which no syllabus could be called chemistry ... equally it may be that by our *own schooling, subsequent training and teaching we cannot see anything different* adequately filling the space called chemistry at this level" (p. 29).

Therefore, the developers, using a partly implicit notion of the structure of chemistry, went against criterion one, *no preconceptions* of the Salters' education philosophy, although this was attenuated as much as possible by their adherence to criterion two, *relevance*, and criterion three, *context-led development of concepts*, that is, using a need-to-know as well as a bottom-up approach to developing chemical concepts. So, I have argued that the Salters' Chemistry course was initially developed as a course focused primarily on the less able or less motivated pupils, without excluding the more able students whose needs were used to prescribe content and teaching methods for chemistry 11–16. In other words, the course managed to make the experimental approach of the CSE relevant syllabuses viable and productive for the full ability range, that is, one relevant chemistry course for *all* pupils.

Thus, the National Criteria for Chemistry brought to the fore – and imposed – additional, *external* constraints on the developers. These constraints were sometimes favorable in regard to the matter of using relevant contexts, but often were less so, namely, in regard to the required level of standard chemical concepts, theory and explanation. As their meetings with the SEAC committees have shown, the developers had to bend their educational principles here, and more than they wished. Some chemical concepts which they felt were *not* needed to make sense of the familiar contexts that they had chosen for the 13-16 year olds *had* to be fitted in, however superficially or awkwardly, in order to get the course accepted as an exam course.

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[51] Channel A entailed (6.2.3): "Identify the chemical concepts and principles which are necessary in order to appreciate and understand the content of any proposed *new* chemistry course".

4.7 Discussion and conclusion

First, I will reflect on the process of transformation of one curriculum level to another. As we have seen above, the design criteria adopted by the developers of the Salters' Chemistry course may lead to different formulations and interpretations of these design criteria when put into practice. Hence, I will now look more fully into the matter of the interpretation of the Salters' design criteria (4.7.1). Secondly, I will answer the question, to what extent has the formal curriculum of the GCSE course *escaped* from Normal Chemistry Education, as embodied in England in the abstracted core chemistry syllabus (see Figures 4.2, 4.4 and 4.7) in terms of the substantive, philosophical, and pedagogical structures of the formal curriculum.

4.7.1 Interpretation of design criteria of Salters' Chemistry

This section has been written partly to respond to the written comments made by the "central planning team" of the Salters' Chemistry Project (W97; W2001, in which were raised objections to the emphasis I laid on design criterion one, *No preconceptions*, on "the target audience of Salters' [being] less able students", and on describing (the "history" of) the developmental process in terms of individuals, not in terms of a team of developers.

First, *how* is design criterion one, *No preconceptions*, to be interpreted? Is it to be interpreted in a *strong* sense: are developers supposed to get rid of any preconceptions with regard not only to the *list* of chemical concepts, but also to the *structure of school chemistry*, that is, concepts as well as the relationships normally used in school chemistry for 13-16 year olds? Alternatively, is design criterion one to be interpreted in a *weak* sense? Are developers supposed to get rid of any preconceptions with regard to the *sequence* of chemical concepts used: how to start, proceed, or end a lesson / unit / course; while the list or structure of concepts is taken by the developers as largely given, that is, accepted by them as it has traditionally been passed on?

Second, *how* is design criterion two, *relevance*, to be interpreted? This design criterion, too, can be interpreted in both a strong and a weak sense. Are the selected contexts used only to *motivate* students to learn the *given* chemical content? Or, in a stronger interpretation, do (or should) the selected contexts give rise only to those chemical concepts really needed to make sense of the CTS contexts, and perhaps even introduce some relevant CTS content? Some related queries are: Do the selected contexts for the lessons all stem from a *coherent* theme of the unit? At the level of the curriculum as a whole, how are the themes of the units of the course related? Is the chemical content chosen "worthy of study" as it says, for example, in Metals (1984) and justified by the chosen CTS themes and contexts?

How is design criterion three, *context-led development of concepts*, to be interpreted, especially the phrase "concepts and explanations should only be introduced *when* they are *needed*", as it says for example in the introduction of the unit Metals (1989). Again, there can be a strong and a weak interpretation of what has been termed the *need-to-know principle* involved here (Ramsden, 1997). This is sometimes reflected in the words chosen to formulate design criterion three. For example, Campbell et al. (1994, p. 419) use the phrase "... introduce ideas and concepts *only as* they are needed". This formulation implies that it will *depend* on the context used, how frequent and in what depth concepts will be introduced and developed.[52] This is a stronger interpretation than the one reflected by the phrase, "only be introduced *when* they are needed", as used in Metals (1989), and the other units of the Salters Science course. The latter phrase implies that developers will only *choose* the *time* of introduction or development of a concept, yet the list and structure of chemical concepts is taken as that largely given by tradition. Related queries are: For what or whom do these chemical concepts constitute a need to know? Are they needed to make sense of only the CTS contexts or also, partly or wholly, to understand the conceptual structure of school chemistry as traditionally perceived?[53] Are these concepts needed for future citizens or for prospective chemistry or science students, or for both?

The meaning of design criteria four, *variety of teaching and learning activities*, seems to be relatively straightforward, but, as we will see in Chapter 5, it still allows various interpretations.

The meaning of the last criterion, *flexibility*, seems rather clear, but it allows, again, two kinds of interpretations. For example, what does it mean for teachers to be allowed and even encouraged "to introduce replacements and modifications to parts of lessons, whole lessons or even *whole units* when they feel it is appropriate" (Metals, 1989)? Should teachers be encouraged to make these changes at lesson and even unit level while retaining the essence of the Salters' approach to chemical education as embodied in the adopted design criteria? Having done so, should they, if and when possible, trial any changes they have made in the course for effectiveness in their classrooms? Would this imply that teachers are seen as co-developers, subjected to the same standards of empirical evaluation as the original developers? Or, taking a stronger interpretation, are teachers free to use "the course as a starting point from which they could develop their own teaching syllabus" (Metals, 1989), whether it is in line with the Salters' design criteria or not? Should these changes, at unit or course level, be trialled for effectiveness?

The problem of the interpretation of the design criteria is compounded by the fact that the design criteria, as the developers have repeatedly emphasized, are articulated and operationalized *during* the developmental process from 1982-1990. Therefore, during the design process the meaning of the initially adopted design criteria might change as a result of these processes. The trialling of the designed units might even lead to the addition or deletion of design criteria. For example, design criterion four, *variety of teaching and learning activities*, was largely articulated or discovered during the course. It evolved from an initial wish to offer students a greater and different variety of

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[52] *The New Fowler's Modern English Usage* (1996) gives the following explanation of the meaning of the locutions 'when', 'as and when', and, 'as and if': 'when' refers only to the time, 'as and when' refers to time and frequency, while 'as and if' refers to time, frequency, and condition.

[53] Ramsden (1997, p. 698) explains that it is "difficult to *cover* all aspects of these ideas in a single context", so for the purpose of understanding these chemical ideas *they need to be revisited* at other points of the course units and in more depth. This has also been termed the *'drip-feed'* approach to conceptual development. Chemical ideas are revisited in order to ensure that pupils learn and understand all the chemical ideas on which they are examined. The "context-and-activity-led" approach to science teaching does not necessarily mean that the contexts of a unit play a leading role over and above their role as starting points of lessons to motivate pupils. Thus, chemical concepts lead the way since *they* are systematically revisited, and not the contexts of the unifying CTS theme (see also 5.2.8).

laboratory experiments (Garforth, 1983), to offering students a greater variety of *all* kinds of practical activities.[54]

As we have seen, design criterion one, *No preconceptions*, has gradually been articulated. Developers have emphasized that they "encouraged those involved in the writing workshops not to think about what students *should* know at the end of the course" (W97). On the other hand, they "did not tell this group of experienced and outstanding teachers to forget all they knew about how an understanding of certain concepts require a *prior* understanding of other concepts" (W97). Thus, according to the developers, design criterion one, *no preconceptions*, refers only to *coverage* of content, and not to relationships between concepts, since they "*needed* people's views of how the understanding of these concepts developed" (W97). This distinction made by the developers and the role of design criterion one during the development process of the Salters' units are further discussed in section 5.2.8.

It is clear that the answer to the central question addressed in this, and also the next chapter, will depend on the *interpretation* we put on these design criteria.

> *To what extent are the design criteria of the units of the Salters' Science such as Metals (1989), taken as the articulation of the visionary curriculum of Salters' Chemistry, adhered to consistently by the developers designing, and by teachers executing, the lessons of the unit Metals?*

If we take a *strong* interpretation of the design criteria, the answer to this question is probably negative. Developers might have preconceptions with regard to the list of concepts and the set of relationships they use for school chemistry courses, both of which to a certain extent also constrain the choice of the sequence of concepts used. Relevant contexts might not be given first place in all lessons, either as starting points or as the dominant focus of a lesson. Chemical concepts may be introduced which are *not* needed in order to make sense of the contexts of the overarching theme. A reasonable variety of activities might be offered, and the unit allows some flexible use by teachers in line with their interpretation of the core criteria of the Salters' approach.

On the other hand, if we take a *weak* interpretation with regard to the Salters' design criteria, the answer is probably positive. In this case it is sufficient if it can be shown that the developers did *not* have a preconception with regard to the traditional *sequence* of concepts: units such as Metals (1989), as discussed in Chapter 5, show *prima facie* a sequence quite different from the traditional sequence. Contexts are used, mostly, to start units and motivate students, and, occasionally, at other places in the units for the purpose of applying acquired chemical knowledge to similar relevant contexts. Concepts are introduced *when* needed, and revisited *as and when* needed to ensure that students of all abilities and aptitudes, ranging from future citizens to future chemists, are properly prepared for their exams. A variety of activities is visible in units, which allows flexible use by teachers and active engagement by students.

The open and provisional character of the Salters' design criteria approach is a great asset to curriculum development. It can lead to a creative application of the adopted design criteria resulting in the development of motivating and cognitively challenging teaching units by teams of researchers, developers, and teachers. At the same time, though, it calls for a thorough *empirical* study to accompany the process of development.

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[54] Borgford (1992, p. 7) mentions the fact that it was during a Salters' users workshop that the different categories to classify the evolving variety of activities were first formulated or articulated.

Ideally, we would like to research the processes of deliberation, articulation, and operationalization as they go on in, what could be called, the vision room and the designer room. Such a study might be something analogous to the research of the teaching and learning processes in the classroom. Failing such an empirical study of the processes occurring in the vision room and designer room, it is only possible to resort to interviews and document analysis, as we did for the Salters' Chemistry course (Chapter 4). In the case of a concrete teaching unit, here Metals (1989), we can perform an *empirical* study of the teaching and learning processes in the classroom, followed by a consistency analysis of the content of the lessons of the unit Metals (1989).

Reflection

In 1997 I sent a first draft of (what is now) Chapter 4 of this thesis to the developers for comments. Their main criticism was "we found parts of the chapter misleading, both in terms of the history of the project or in terms of our strategic thinking" (W97). First, my aim was not historical (see also section 1.1.2), but to give in this chapter a *reconstruction* of the developmental process of the Salters' Chemistry course on the basis of interviews and relevant educational documents and publications. What I set out to do was to reconstruct the developmental process in light of the problems of structure and escape and of the framework I used to solve them (see further Chapter 6).

Secondly, the developers objected to my attempt to "measure" the Salters' Chemistry course "against a predetermined framework" (W2001). My answer to both objections is that the *reconstruction* I make should be assessed in terms of its usefulness or fruitfulness in describing and explaining curriculum phenomena (see further section 6.4.4). For example, as I have tried to show in this chapter, the steady decrease in the degree of escape from Normal Chemistry Education (Figure 4.4) in the process of *development* can be counted as such a phenomenon, which we will encounter again in Chapter 5. In this way I hope to show, as the developers put it, "how a study which sets out to evaluate against predetermined criteria can be an illuminative study" (W2001).

4.7.2 Changes in substantive, philosophical and pedagogical structures

The *substantive structure* of the Salters' Chemistry GCSE course, compared to a traditional O-level course, initially contained a somewhat *reduced* load of chemical concepts [Sub/CC] and relationships [Sub/CR], while retaining about the same set of standard chemical techniques [Sub/CT]. The concepts and relationships were put in a teaching sequence partly informed by, and consistent with, the structure of chemistry as the developers perceived it, not in a top-down hierarchy, but bottom-up led by contexts and activities, and starting at the observational and manipulative level via low-level generalizations moving to more abstract relationships and theories. The developers did not escape *fully* from substantive structure of NCE, but they did to a certain degree, since many of the usual concepts were retained. As we have seen above, the ruling of SEAC brought back in most of the concepts which had been excluded by the developers.

The *philosophical structure* of Salters' Chemistry, as mentioned above, moved away from theoretical chemistry and towards applied chemistry by emphasizing relevance and use. The developers did not escape *fully* from the philosophical structure of NCE, but nevertheless they did try to look seriously for applications of chemical knowledge to familiar phenomena and materials, instead of using ‘academic’ applications as had been customary in traditional O-level chemistry.

The *pedagogical structure* of the Salters’ Chemistry GCSE course initially focused on the needs of the majority of students, the less and moderately able, but at a later stage had to consider the needs of the most able students as well, in particular by incorporating explanation using abstract chemical concepts. At a later stage the original aim of chemical awareness for the future citizen had to compete with the traditional aim of preparing future A-level candidates in an exam course for the full range of grades. The context-led teaching approach evolved into a context- and activity-led teaching approach using a varied set of learning activities including customary lab experiments. The developers did escape from the pedagogical structure of NCE by devising a context-led teaching sequence which differed from the traditional theory-based sequence. There also increasingly surfaced in-built *tensions* both with regard to the target group, the less or more able students, and with regard to the aims set, chemical awareness and/or academic preparation. This raises the question, whether both of these aims can be realized.

Finally, as is clear from the analysis and discussion so far, the developers had – by working out the consequences of the *visionary* curriculum (4.2) into detailed teaching materials (First trial, Year Three, GCSE) – *to a certain extent* managed to “break away from the traditional mould” (Garforth, 1983). In other words, they had escaped from NCE as it existed in England in the 1970s, that is, from traditional O-level chemistry; but they did this in different degrees with respect to the substantive, philosophical, and pedagogical structures which make up NCE. In the next chapter, *Analysis of Metals, a unit of the Salters’ Science curriculum*, we will see how these in-built tensions of the pedagogical structure of the Salters’ Chemistry course came to influence the philosophical and substantive structures of the Salters’ Science curriculum, both in the designed curriculum and in the taught curriculum of a particular unit.

5 Analysis of Metals: A chemical unit of the Salters' Science curriculum

In Chapter 4, I described, analyzed, and compared the visionary, designed, written, and formal curriculum levels of the Salters' Chemistry course. My research there focused on the course *taken as a whole*, either on the Foundational course or on the GCSE exam course.

In this complementary chapter, I will perform a similar analysis but now focused on a course *unit*, namely on the chemical unit Metals of the Salters' Science course (1989), while extending the curriculum analysis to the interpreted, taught, and experienced curriculum levels of the unit. The process of developing the chemical unit Metals, and now also the process of teaching the unit in the classroom, will again be analyzed in terms of my curriculum theoretical framework, that is, in terms of the substructures pertaining to each curriculum level of school chemistry, the concept of curriculum emphasis and the concept of normal science education.

In section 5.1, I will give the rationale for performing a case study on the unit Metals, the method of analysis of the lessons of this unit, followed by a description of the design criteria and the pedagogical, philosophical, and substantive structures of Metals (1989).

Secondly, I will perform a consistency analysis on the unit Metals, taken as a C*hemistry through Technology* (CTS) curriculum unit, on the written curriculum as operationalized in the *lessons* of the unit Metals (5.2). This kind of analysis, performed at the level of specific lessons of a particular unit, makes it possible to see more precisely the extent to which the developers were able to fulfill in a *consistent* way the adopted design criteria.

Thirdly, I will describe and analyze how a teacher congenial to the Salters' approach *interpreted* the written curriculum as embodied in the lessons of Metals (1989), and *taught* the lessons of Metals thus interpreted in the classroom (5.3).

Fourthly, I will describe and analyze how the curriculum, as embodied in the lessons of the unit Metals (1992) and as taught by the teacher, is *experienced* by students (5.4).

Fifthly, I will compare the curriculum realized for Metals – at the written, interpreted, taught, and experienced levels – with, on the one hand the formal curriculum of Metals, and, on the other hand, with Normal Chemistry Education (NCE) as represented by O-level chemistry as it existed in the 1980s in England (Figure 5.1). Subsequently, I look back, both at the different articulations and operationalizations of the visionary curriculum of the Salters' Chemistry course, as discussed in Chapter 4, and at the analysis of the lessons of the written unit Metals (1989) and its different operationalization, as discussed in Chapter 5 (section 5.5).

5.1 Introduction

I will begin by giving my reasons for performing a case study on a unit of the Salters' Science course, Metals (1989), that is, for doing empirical classroom-based research on the teaching and learning processes, and for performing an in-depth consistency analysis of the intended and realized lessons of the unit Metals (5.1.1). Following that, I will describe and analyze the Salters' design criteria as formulated by the developers of Metals and the authors of the Teachers Guide (5.1.2). Subsequently, I discuss the problem of interpretation of the Salters' design criteria, and will give the interpretation I have chosen as a starting point for my consistency analysis of Metals (5.1.3). Next, I will describe the specific method I used for the consistency analysis of the content of the lessons of the unit Metals (5.1.4). Finally, I will give the content of Metals (1989) represented in terms of Schwab's categories (5.1.5).

5.1.1 Rationale of the case study of the Salters' Science unit Metals

As noted in section 4.1.2, I initially wanted to do curriculum research on two units of the Salters' *Chemistry* course (1987). This *central* chemistry-technology-society (CTS) course seemed at the time to be the best *theoretical* choice as well as to offer an excellent *practical* opportunity to test the effectiveness of a bold attempt to escape from Normal Chemistry Education in England. However, I was led to perform classroom-based research on two units of the Salters' *Science* course, modeled and developed after the Salters' *Chemistry* course (1987). For reasons explained below, one of these units, namely the unit Metals (1989), was subjected thereafter by me to the in-depth curriculum analysis reported on in sections 5.2, 5.3, and 5.4.

New developments in the educational system of England and Wales (Figure 5.1) interfered with my initial research plan. From 1990 on, it became mandatory for schools to follow the National Curriculum (DES, 1989) and, from 1992, the revised version thereof (DES, 1991).

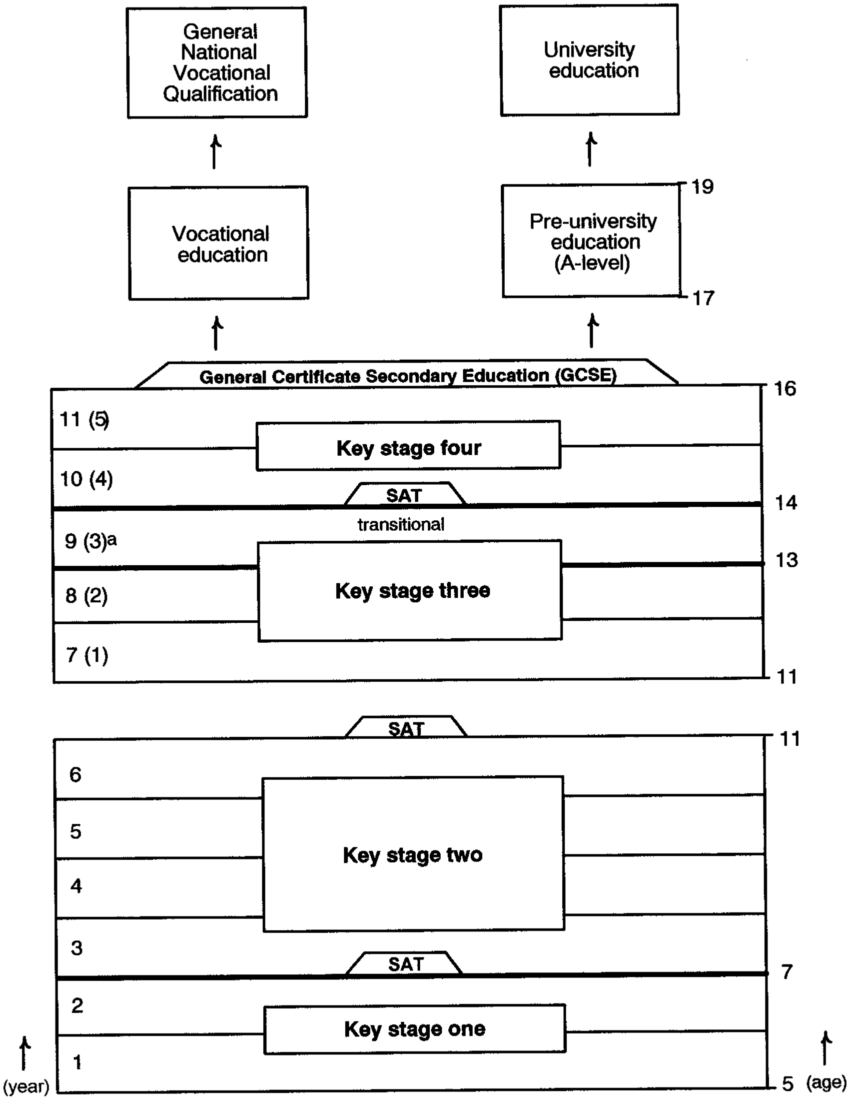
The National Curriculum required the provision of a so-called *balanced science* course, that is, a science course containing a balanced mix of biology, chemistry, and physics units. Many users (schools, departments, teachers) of the Salters' GCSE *Chemistry* course from 1990 on therefore transferred in increasing numbers to the Salters' GCSE *Science* course (Campbell, 1994). Many Salters' schools in the vicinity of the University of York also took up Salters' Science instead of Salters' Chemistry. I wanted to use York as a base to do classroom based research, to interview the developers and study the Salters' teaching materials. With the help of Peter Nicolson, Project Officer of the Salters' Science Project, I started looking around for a school with a chemistry teacher willing and interested to permit me into her/his classroom while s/he taught chemistry using *chemical* units of the Salters' *Science* course.

The structure and content of units of the Salters' Chemistry course (1987), Nicolson felt, were largely *retained* in the *chemical* units of the Salters' Science course, such as the Third Year unit Metals (1989). (For the differences between Metals, 1987, and Metals, 1989, see the analysis given in section 5.1.4, and also Figure 5.5.)

Furthermore, schools and science teachers had to comply with the requirements of the National Curriculum (DES1991) as to whether they would teach units of the Salters' Chemistry course (1987) or chemical units of the Salters' Science course (1989).

Although the external constraints for the development, trialling, and teaching of the Salters' Chemistry course differed (noted in Chapter 4) in some important aspects from

Figure 5.1 Educational System England and Wales within the National Curriculum



[a] Before the introduction of the National Curriculum (DES, 1989), Year Nine was referred to as Year Three.

those present for the development, trialling, and teaching of the Salters' Science courses, there was also some common ground. First, developers of both courses had to take into account *nationally* set criteria, the National Criteria for Chemistry in the former case, and the more constricting criteria laid down by the National Curriculum in the latter. Nonetheless, as the developers have stated:

> ... the *original* design criteria provided a viable means of making the major decisions about curriculum content *throughout* the development program (Campbell et al., 1994, p. 420).

Both courses, Salters' Science and Salters' Chemistry, set out to solve a similar problem, that is, to devise a science or chemistry course which would gain and retain the engagement and interest of children so as to provide the basis for scientific or chemical literacy for those who would finish their formal study at age16. Also, the respective courses aimed to increase the number of students choosing to carry on studying science beyond 16 (Campbell et al., 1994, pp. 418, 424). Further, year Three, or as it was later called year Nine, remained in a way a *transitional* year in which some kind of "foundation" had to be laid down for the last two years of science in the form of an *examination* course; in the first two years of their secondary schooling students received introductory or *general* science teaching.

There were also some differences. Before 1989 students could, as in the case of the Salters' Chemistry course, either choose chemistry for their GCSE examination or opt out at age 14. By the time the Salters' Science course had arrived, science had become a *compulsory* subject for *all* students till age 16.

Finally, a *balanced* science course, such as the Salters' Science course, often meant a course, which combined – but which did not necessarily integrate – physical, chemical, and biological units. As a rule teachers of a single science taught such a course within their own specialization (Hezeken, 1996). The National Curriculum also came to mean, in general, a greater emphasis on scientific content and processes, and a lesser emphasis on relevant contexts. So, a study of the development and teaching of Salters' Science units under constraints as set by the National Curriculum would also give me the opportunity to analyze the effects of these increasingly more constricting criteria on the content and structure of the course units and on their execution by the teacher. Such a study could shed some light on mechanisms of change under nationally imposed external criteria or constraints. Although from a strictly theoretical point of view, I would have preferred to do research on two units of the Salters' Chemistry course, perhaps one from Year 3 and one from Year 4, practical reasons led me to a compromise, namely, to perform *classroom-based* research on two *chemical units of Salters' Science*.

The analysis of the data collected by the classroom-based research (observation, interviews, questionnaires, and audio taping) turned out to be rather time consuming, as was the ensuing in-depth curriculum analysis. Therefore, I limited my research to a case study of Metals (1989), a Salters' Science Foundation unit from Year 3.This was the *first* unit usually taught to 13 – 14 olds, because, according to trial teachers:

> Teaching Metals first allows the introduction of a number of *basic* concepts at an early stage: elements, mixtures, compounds, reactions and reaction rates (OGT, p. 22).

Thus, this unit provided an educational situation furthest removed from examination constraints, probably the most favorable situation to investigate the question, to what extent a chemistry teacher congenial with the Salters' approach would execute a chemical unit in accordance with the Salters' criteria; that is, with fewer constraints present, whether external or internal, a teacher should have a greater chance of realizing the intentions of the developers. For example, there are probably more opportunities for a teacher to devote a substantial amount of lesson time to *relevant* contexts and topics in an early Foundational Year Three unit such as Metals, than in year Four or Year Five units, which are closer to the GCSE examination. Furthermore, the unit Metals (1984) was one of the prototype units of the Salters' Chemistry course, which makes possible a comparison with Metals (1987) and Metals (1989), given in section 5.2.8 (see Figure 5.14).

Since the unit Metals survived various trials, either as a Salters' Chemistry trial unit or as a Salters' Science trial unit, it must have been evaluated by the developers as a good example of the operationalization of the Salters' approach to school chemistry as defined by their design criteria. Compared to other Salters' Chemistry units, the unit Metals is considered by the developers as a typical unit with regard to the teaching activities deployed (see 5.1.2). As we will see below (5.4.4), students perceived the unit Metals as an average unit in terms of interest in science and understanding of everyday problems (Ramsden, 1992). For these reasons, the unit Metals is taken here as being a *representative* Salters' unit.[1]

5.1.2 Design criteria

Just as in the *Chemistry (Salters') Syllabus* (SLB) and the *Overall Guide for Teachers* (OGT), there is neither an explicit nor an implicit reference in course units such as Metals[2] to the first criterion, *no preconceptions*. The OGT (p. 16) advises teachers to become familiar with the course by considering, among others, the question: "What are the design criteria of the course?" Although the other four criteria are mentioned in the OGT, and in unit guides such as Metals, there is no reference to the first criterion. This is partly to be expected, since the developed units and the ensuing syllabus had to fit the constraints set by the National Criteria of Chemistry in order to get SEAC validation (see Chapter 4). Thus, in the end the developers had to conform, albeit reluctantly, to the preconception of school chemistry as contained in the National Criteria. Furthermore, the developers might have thought that this first design criterion was not of immediate concern for teachers *using* already trialled units in the classroom.

The second criterion, *relevance*, was formulated in the introduction to Metals (1989) as follows:

> It [the unit] should have its *origins*, and hence its *justification* for study, in *aspects of everyday life* with which students aged 13 – 16 years will be familiar either personally or through the media.

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[1] The second unit I considered for an elaborate case study was a Year Four unit, Transporting Chemicals (1987). My purpose would have been to see how a chemistry teacher executes a chemical unit at a conceptually later stage of the curriculum, in the first year of the Salters' Science GCSE exam course. It was recommended by the developers as a good unit to start the year because it "introduces atoms, molecules, formulas, and equations. If it is taught first in the fourth year, it allows the use of these concepts in later units." (OGT, p. 23). For reasons mentioned above, I limited the research to the unit Metals.

[2] "Metals" usually stands for Metals (1989), a *chemical* foundation unit of the Salters' Science Course, produced as a limited edition for a full course trial by the Salters' Science Project (1989). I analyzed this unit (section 5.2) and observed its execution in the classroom as Metals (1992), that is Metals (1989) as interpreted and taught by the teacher (5.3) and experienced by the pupils (5.4). For purposes of comparison, I will occasionally refer to Metals (1987), the revised edition of the third year unit of the Salters' GCSE Chemistry Course, and to Metals (1984), a third year unit of the Chemistry (Salters' Project), trial edition 9/84.

The third criterion is formulated in the introduction of the unit Metals (1989) as follows:

> Scientific concepts and explanations should *arise naturally* from the study of these everyday situations and should *only be introduced when they are needed*. Social, economic, environmental, industrial and technological aspects of science are, therefore, *fundamental* to the whole course.[3]

The fourth criterion, *variety of teaching and learning activities*, is not mentioned explicitly in the unit Metals but has found explicit formulation[4] in both the SLB (p. 1) and the OGT (p. 9). From the activity analysis it is clear that a variety of teaching activities has been *used* by the developers in writing the course units. The following set of teaching activities (OGT, p. 39) is deployed in the unit Metals, see Figure 5.2.

Although traditional, teacher-led activities receive less attention in the OGT (section 4.6.2), inspection of Figure 5.2 seems to suggest that they occur at least as frequently as student-centered activities and other less familiar teaching activities.[5] Of course, only on the basis of empirical, classroom-based research of the lesson activities of the unit Metals (section 5.2) is it possible to ascertain whether traditional teaching/learning activities still take up a substantial amount of the lesson time in a student-centered, context-led unit of an CTS course such as Metals (1989).

A fifth criterion, *flexible, teacher-mediated use,* has been formulated in the course units in a section of the introduction called “Design of materials”:

> The materials must be *flexible* enough to allow teachers to introduce *replacements and modifications* to parts of *lessons*, whole lessons or even *whole units* where they feel it is appropriate. A science department should be able to regard the course as a starting point from which they could develop their own teaching syllabus.

Consistent adherence to this criterion would put teachers squarely in the role of developers. This would call for an explicit statement and explanation by the developers of *all* design criteria, including the first criterion, *no preconceptions*, in the course units, the SLB, and the OGT.

In the next section (5.2), I will give a detailed content analysis of the *lessons* developed, focusing thereby on the second and third criteria, in order to determine to what extent the developers of Metals managed to *adhere consistently* to design criterion two, *relevance,* and to design criterion three, *context-led-development of concepts*.

The implicit role of the first design criterion is discussed in section 5.2.8, and the role of the fourth and fifth design criteria is exemplified in section 5.3.2, the Interpreted Curriculum. The analysis here is thus concentrated on design criteria two and three, with occasional reference to design criterion five. The latter criterion is discussed more fully

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[3] Metals (1987) gives, but for the word *chemical* replacing *scientific*, the same formulation of design criterion three. Design criterion two is worded exactly the same in Metals (1987) and Metals (1989).

[4] Borgford (1992) notes that the categorization of teaching activities emerged during an INSET course. This seems a good example of the process of articulating or discovering a design criterion during, and as a result of, the developmental process (Campbell, 1994, p. 422).

[5] Compared to other Salters’ Chemistry units, Metals might be considered as a typical unit in this respect. Thus, a few units contain fewer student-centered activities, such as Burning and Bonding (1987), whereas some other units contain more student-centered activities. For example, the unit Buildings (1987) contains five student-centered discussions, and other units such as Transporting Chemicals (1987) contain alternative teaching activities such as a role play for pupils.

Figure 5.2 Variety and frequency of teaching activities used in lessons Metals (1987)

Teaching activities*	**M1**	**M2**	**M3**	**M4**	**M5**	**M5X1**	**M5X2**	**M6**
Teacher introduction/ explanation-led discussion	+	+	+		+			+
Teacher-student discussion	+	+	+	+	+		+	
Student-student discussion				+				
Reporting to class (orally or in writing)					+			
Role play								
Teacher demonstration			+	+	+			+
Class practical	+	+	+	+	+	+	+	
Exp. design/problem solving/ directed discovery			+	+				
Questions (including text-related activities)					+			+
Data search/collection/selection	+							
Data analysis/interpretation/ translation	+	+		+	+			+
Surveys/displays	+							
Numerical work				+				
Making/using models								
Using computers				+				

* The symbol (+) indicates that a lesson of Metals contains a specific teaching activity.

in sections 5.3 and 5.4, while the former criteria (two and three) can be considered, as I argue, as the two *central* design criteria.

5.1.3 Interpretation of design criteria of Metals (1989)

In Chapter 4, I have described, analyzed, evaluated, and discussed the Salters' Chemistry curriculum as a whole while taking, initially in an implicit way, a *strong* interpretation of the design criteria. In section 4.7, I have given my reasons for taking a strong interpretation. In this chapter I will perform a consistency analysis of the lessons of the formal curriculum as operationalized in the chemical unit Metals (1989) of the Salters' Science course, while taking a strong interpretation of the Salters' design criteria right from the start.

Some of the teachers and developers involved at the early stages of the Salters' Chemistry project, including Francesca Garforth, took a strong interpretation of the design criteria, at least until the year 1989 when the National Curriculum began. The stronger or more radical interpretation of the Salters' design criteria is more interesting, certainly, from a research point of view. Thus, it is much more interesting to answer the question: *Does Salters' Chemistry escape from NCE?*, if the units of Salters' Chemistry are characterized by design criteria, interpreted in the strong sense. This way, the intended innovative school chemistry curriculum is considered as a *bold* attempt to escape from NCE, an attempt from which we can learn much about the external and internal constraints involved in the escape process, even if it fails to some extent.

If the developers take a *weak* interpretation of the design criteria, they will of course meet their design criteria more easily, either in the development of the units of the Salters' Chemistry course, or later in those of the Salters' Science courses (Campbell, 1994, p. 420), and the question of the escape from normal chemistry education will seem to lose its force.[6]

Thus design criterion one, *No preconceptions*, is to be interpreted in the sense that developers are supposed to get rid of any preconceptions, not only with regard to the *list* of chemical concepts, but also with regard to the *structure of school chemistry* as relating to chemical concepts and chemical relationships normally used in school chemistry for 13-16 year olds.

Design criterion two, *relevance*, is also interpreted in a stronger sense: the selected contexts should give rise only to those chemical concepts really needed to make sense of the CTS contexts (perhaps even introduce some relevant CTS content as well). Related queries are: Do the selected contexts for the lessons of the unit Metals (1989) or Metals (1992) all stem from a *coherent* theme of the unit, in this case the theme *corrosion*? Is the chemical content, deemed "worthy of study", as it says in Metals (1984), justified by the chosen CTS theme and contexts?

Again, design criterion three, *context-led development of concepts*, is interpreted in a strong sense, that is, "... introduce ideas and concepts *only as* they are needed" (Campbell et al. 1994, p. 419). This formulation implies that it will *depend* on the contexts used, and how frequent and in what depth concepts will be introduced and developed. This is a different, and stronger interpretation than the one reflected by the phrase, "only be introduced *when* they are needed", as used in Metals (1989), and the other units of the Salters' Science course. This latter phrase implies that developers will only *choose* the *time* of introduction or development of a concept, while the structure, sequence, and even the list of chemical concepts remains largely as given.

The interpretation of design criterion four, *variety of teaching and learning activities* varies, as we noted above (footnote 5). Based on information given by the developers (OGT, p. 39), the variety of activities of the unit Metals (1989) can be displayed as in Figure 5.2. Knowing that, it is possible to determine the extent to which a teacher executing the unit Metals in the classroom is interpreting, and/or able to use this level of variety to engage the pupils actively in class as intended by the developers. This will depend, of course, on how this variety is perceived or interpreted by those involved (sections 5.3 and 5.4).

The meaning of the last criterion, *flexibility*, is taken here in a strong interpretation. That is, it is taken to mean that teachers are allowed and encouraged "to introduce replacements and modifications to parts of lessons, whole lessons or even *whole units* when they feel it is appropriate" (Metals, 1989). Again there are queries. Should teachers be encouraged to make these changes at lesson and even unit level, while retaining the essence of the Salters' approach to chemical education as embodied in the adopted design criteria? Having done so, should they, if and when possible, trial any changes they have made in the course for effectiveness in their classrooms? In turn, would this imply that teachers are seen as co-developers, subjected to the same standards of empirical evaluation as the original developers? Are teachers free to use "the course as a starting

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[6] Some developers will take a middle position in that they see the Salters' Chemistry course, as "a unique hybrid" (Borgford 1992, p. 36) of a course for both academically and societally oriented pupils, preparing both groups adequately for their future science studies or societal roles.

point from which they could develop their own teaching syllabus" (Metals, 1989), whether or not their syllabus is in line with the Salters' design criteria? Should these changes, at unit or course level, be trialled for effectiveness?

The open and provisional character of the Salters' design criteria approach is a great asset to curriculum development. It can lead to a creative application of the adopted design criteria, resulting in the development of motivating and cognitively challenging teaching units by teams of researchers, developers, and teachers, and possibly of students. At the same time, though, it calls for a thorough *empirical* study to accompany the process of development. Ideally, we would like to research the processes of deliberation, articulation, and operationalization as they go on in, what could be called, the vision room and the designer room, (analogous to the research of the teaching and learning processes in the classroom). Failing such an empirical study of these processes taking place in the vision room and designer room, it is only possible to resort to interviews and document analysis, as we did in Chapter 4 for the Salters' Chemistry course. In the case of a concrete teaching unit, here Metals (1989), we can perform an *empirical* study of the teaching and learning processes in the classroom, followed by a consistency analysis of the content of the lessons of the unit Metals (1989).

5.1.4 Method of analysis of the lessons of the unit Metals (1989)

The analysis of the curriculum levels of the Salters' Chemistry *course* in Chapter 4 as well as the analysis of the design criteria (section 5.1.2) and of the formal curriculum of the *unit* Metals (section 5.1.5 below) was, and could only be, based on interviews with the developers and on formulations in publications, curriculum documents, and teaching materials. However, in the case of a particular course unit such as Metals (1989), it is also possible to analyze the content of concrete *lessons* in a unit, in order to see to what extent the design criteria of the course unit are adhered to *consistently* by the developers *designing the lessons* of a particular unit.

Each unit of the Salters' Science course (1989) gives a list of teaching materials (Figure 5.3). Most of these will be referred to throughout the analysis; for the lesson plans see Appendix 5.

Figure 5.3 Materials of unit Metals of Salters' Science (1989)

1. An overview (summary) of the unit.
2. An overall plan of the unit in the form of a flow diagram. Each box on the sheet represents one lesson (70 – 80 minutes).
3. A pre-planner indicating the less readily available materials and equipment that a science department may have to obtain in order to teach the unit.
4. A suggested plan for each lesson indicating the key ideas covered in the lesson. Key activities and techniques encountered during the lesson are also indicated.
5. Teachers' notes relating to teaching strategies, demonstrations, student activity guides, etc.
6. Student materials in the form of student activity guides (SAG) and student information sheets
   (SIS). Care and safety in the laboratory is drawn to the attention of students at appropriate points in the SAG.
7. Sample assessment items for the whole unit.

Research questions

I will perform, in section 5.2, a detailed consistency *analysis* (see section 4.1.3) of the content of the lessons of the unit Metals.[7] The focus here will be on the two central design criteria of *relevance* and *context-led development of concepts*.

In the analysis of the lessons of Metals (1989), I will try to answer two research questions. The first research question stems from design criterion two: *relevance*:

1. Does each *lesson* of the unit Metals have its *origin*, and hence its *justification* for study, *fundamentally* in aspects of *everyday life*?

I have inserted the word ‘fundamentally’. As the developers emphasized, these *everyday life* aspects or situations are related to “social, economic, environmental, industrial and technological aspects of science [which] are, therefore *fundamental* to the whole course”.[8]

The second research question stems from design criterion three: *context-led development of concepts*, which can be put in the form of two sub-questions. The first of these is:

(2a) Do all chemical concepts and explanations, treated in the lessons of the unit Metals, *arise naturall*y *from* the study of these everyday situations?

This sub-question addresses the same point as question one if we take the meaning of the locution “arise naturally” as being similar to the locution “have its origin”. The second sub-question addresses a different point, namely:

(2b) Are all chemical concepts and explanations, treated in the lessons of the unit Metals, *only* introduced *when they are needed*?[9]

The second research question addressed here is, therefore:

2. Are all chemical concepts and explanations, introduced in the lessons of the unit Metals *needed* for the study of these everyday situations?

In the previous chapter on the process of the development of the Salters’ Chemistry course, I have analyzed the relations between dominant school chemistry (O-level) as it existed in England in the eighties, a form of NCE, and the structure of the Salters’ Chemistry course. The latter, an alternative societally-oriented school chemistry

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[7] OGT (p. 9) refers to “each topic” and SLB (p. 1) to “each part” of the course in their formulation of design criterion two. It seems appropriate, therefore, to focus the analysis on the eight *lessons* of the unit Metals. Each lesson deals with a subset of topics or key points using a number of activities (see Appendix 5).

[8] For this point about the fundamental emphasis of the course, see also SLB (p. 8).

[9] The locution “only introduced when needed” seems to have an ambiguous meaning. Does it mean, that chemical concepts and explanations should be introduced only *as and when needed* for pupils on their way to citizenship, or, alternatively, that chemical concepts and explanations should be introduced as and when needed for pupils heading for a scientific/chemical career? Garforth (1982b) points to a similar ambiguity discussing the idea to teach pupils only the “essential chemistry” they need. She then asks herself: essential for whom, for future citizens or future chemists, for society or chemistry? Based on my description and analysis of the visionary curriculum (Chapter 4), I take it that, at least in the early stages of the Salters’

curriculum has been characterized by the fundamental emphasis that the developers wished to put on "social, economic, environmental, industrial and technological aspects of science" (Metals, 1989). In this chapter I will focus the analysis on the *lessons* of a particular unit of such a course, in order to compare the curriculum realized for the unit Metals – at the written, interpreted, taught, and experienced levels – with, on the one hand, the formal curriculum of Metals (1989), and, on the other, with NCE.

Pure chemistry versus chemistry-technology-society content

The lesson plans of all the units of Salters' Chemistry (1987) contain the following headings "Type of Activity, Activity, Requirements, Outcomes, Skills Practised". The developers have further identified two types of outcome (Metals, 1987):

1. Fundamental chemical ideas, concepts, principles, patterns, etc. are preceded by an asterisk." (emphasis developers).
2. Social, economic, environmental, industrial and technological aspects of the subject are italicized".

A categorization of the unit Metals (1987), based on this distinction and the accompanying notation (asterisks/italics) is given in Figure 5.4.[10]

Figure 5.4 Lesson plans of Metals (1987), written unit of the Salters' Chemistry Course

Lesson	Key teaching points / Outcomes[a]
M1: What are metals?	- *Metals are important materials in extensive use* * Characteristic physical properties of metals (2x) - Names of common metals (2x) * Each metal can be represented by a symbol - *Relationship between the use of a metal and its properties* - Using apparatus to test for electrical conductivity (P)
M2: Which metal is used to make a drawing pin?	* Metals have similar physical properties - Chemical tests better than physical tests in distinguishing between metals - *Relationship between the properties of metals and their uses* - Testing for metals in solution (P)
M3: What happens when metals corrode?	- *Metals are often corroded* - *Corrosion occurs at the surface of metals* - *Corrosion produces a new substance* - *Some metal is used up to produce this new substance* * An element is the simplest possible substance * A chemical reaction involves the formation of a new substance * A compound forms when two or more elements combine

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[10] The trial edition Metals (1984) contains a precursor of this distinction, namely, between "understanding of and ability to use concepts which are also met elsewhere in the course [and] understanding of the technological, social and economic implications of chemistry" (emphasis developers).

Figure 5.4 Lesson plans of Metals (1987), written unit of the Salters' Chemistry Course (continued)

Lesson	**Key teaching points / Outcomes**[a]
M3X: A closer look at corrosion and burning.	- *Air and water are both needed for rusting* - *Salt accelerates rusting* - *Iron is used up during rusting* - *A new substance is formed when iron rusts* * Elements can combine to form compounds, they cannot be made to weigh less
M4: Do all metals corrode?	- *Air and water are both needed for rusting* - *Salt accelerates rusting* * The Reactivity Series - *Corrosion involves reaction with oxygen* * Gain of oxygen is called oxidation * Metals (elements) form compounds when they react with oxygen - *Importance of preventing corrosion* - *Methods used to prevent corrosion* - Testing for hydrogen (P)
M4X: How can we prevent rusting	- *Rusting is prevented by excluding air and/or water* - Manipulating apparatus and materials (P) - Using chemicals safely (P)
M4X2: Do other metals stop iron from rusting?	- Using a control (O) - Controlling variable (O)
M5: What are metal alloys?	- *Methods used to prevent rusting* - *Importance of preventing corrosion* - *Metals above iron in the reactivity series slow down rusting; those below iron speed it up* - *An alloy is a mixture of one metal with one or more other elements* - *Forming an alloy changes the properties of a metal* - *The composition of an alloy determines its properties* - *Relationship between properties of alloys and their uses*

[a] Outcomes or key teaching points are stated on the lesson plans. Two types of outcomes have been further identified:
1. Fundamental chemical ideas, concepts, principles, patterns, etc. preceded by an asterisk.
2. Social, economic, environmental, industrial, technological aspects of the subject are italicized.
The skills practiced by students are coded on the lesson plan as follows: P – practical skills; O – other skills.

The first impression one gets from the distribution of these two types of outcomes is that the two kinds of "key teaching points", as they are also called (Metals, 1987), are addressed about *equally* in the unit. A number of key teaching points (9), though, are neither provided with an asterisk nor italicized. It will probably depend on the specific context of the lesson as to how these terms are to be interpreted, as fundamental or societal content, or whether they remain ambiguous. For example, the term *burning* can refer to a fundamental chemical context such as oxidation reactions or to a societal context such as the operations of a fire brigade (section 5.3). Assuming that these ambiguous key teaching points are divided about equally, the ratio between fundamental and societal content will remain about the same.

STS curriculum categorization by Aikenhead

A similar distinction to that made (above) by the developers for chemistry education has been made by Aikenhead (1994, pp. 47-59) for science education, namely, between traditional, or pure science (PS) content, and science-technological-society (STS) content. The distinction between PS content and STS content was made in order to devise a scheme describing eight categories of STS curricula. Category one of the curriculum spectrum contains hardly any STS content (*ca.* 5%), thus mostly PS content, while category eight of the spectrum contains mostly STS content (80% or more) and little PS content (ibid., pp. 55-56).

The Salters' Science Project is classified by Aikenhead in his curriculum spectrum as a category five curriculum, labeled "SCIENCE THROUGH STS CONTENT"; it contains about 30% STS content and about 70% pure science content. Campbell et al. (1994, p. 422) agree with a classification of the Salters' Science curricula, *including the* Salters' Chemistry curriculum, as a "Science through STS Content" type of curriculum. Aikenhead (1994, pp. 55-56), though, does not refer specifically to the Salters' Chemistry course. If we take (pace Campbell et al.) a strong interpretation of the design criteria characterizing the Salters' Chemistry course (5.1.3), the *chemical* units of the Salters' Science course such as Metals (1989), stemming from the former course, could be considered as examples of category six: "SCIENCE ALONG WITH STS CONTENT". This category is described as follows:

> STS content is the focus of instruction. Relevant science content enriches this learning. Students are *assessed about equally* on the STS content and the pure science content (Aikenhead, 1994, p. 56).

Following Aikenhead, I will draw a distinction between the pure *chemical* (PC) content of school chemistry consisting of chemical concepts, relationships, and techniques, and the chemical-technological-societal (CTS) content of school chemistry consisting of CTS concepts, relationships, and techniques. As we saw above (Figure 5.4) "fundamental chemical ideas, concepts, principles, patterns, etc. [and] social, economic, environmental, industrial and technological aspects of the subject" are addressed *at least equally* in the lessons of the unit.

As for the assessment, Smith (1988) arrived in his analysis of some trial units, e.g. Metals (1984), and of the draft syllabus and specimen papers of the Salters' Chemistry course (1986) at a degree of assessment of *ca.* 50% of *utilitarian* aspects (section 4.5.4). He concludes that the actual assessment of *utilitarian* aspects, in 1988, will probably be about the same level (ibid., p.112).

Although the trial unit Metals did undergo some minor revisions (section 4.5.3), the revised unit, Metals (1987), can, I think, still be largely considered as an example of a CHEMISTRY ALONG WITH CTS CONTENT unit (Figure 5.5).

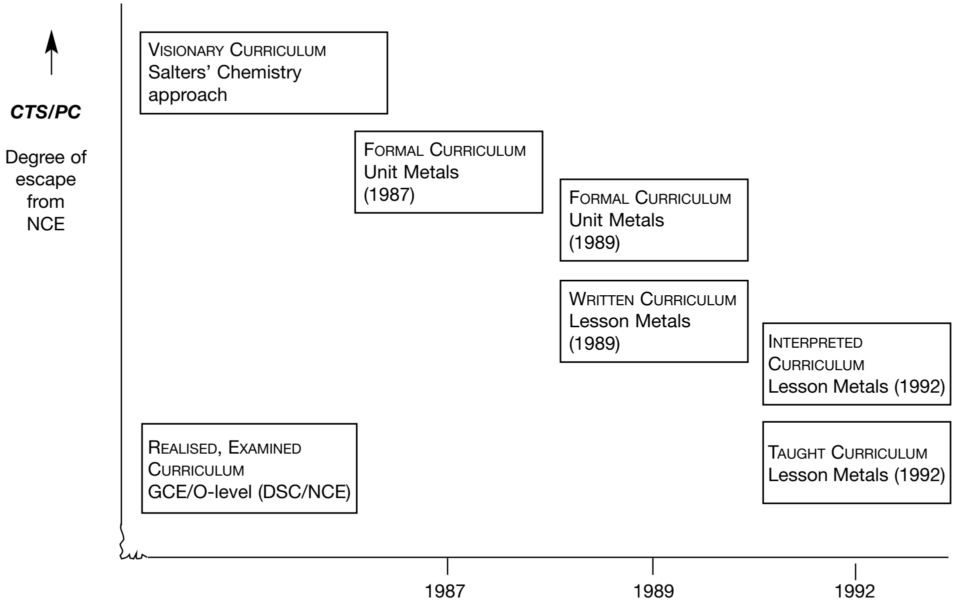
Put in Aikenhead's terms, CTS content is the "focus of instruction" and relevant PC content "enriches this learning" in the unit Metals (1987). Depending on whether one takes a weak or a strong interpretation of the design criteria of the Salters' Chemistry curriculum, the CTS/PC ratio varies thus between 30/70 % and 50/50 % (section 5.1.3). For the *comparison* of the CTS/PC ratio at the visionary, formal, written, interpreted, and taught curricula of the unit Metals, though, I will use the CTS/PC ratio in a *relative* sense, my argument not depending on the use of an absolute CTS/PC ratio (section 5.2.8).[11]

Figure 5.5 is similar to Figure 4.4. In Chapter 4, I described, analyzed, and compared the visionary, designed, written, and formal curriculum levels of the Salters' Chemistry course. My research there focused on the course *taken as a whole*, either on the Foundational course or on the GCSE examination course. Here I am extending the curriculum analysis to the interpreted, taught, and experienced curriculum levels of the unit Metals.

Application of Aikenhead's content distinction to Metals (1989)

The distinction and notation used by the developers in the unit Metals of the Salters' Chemistry course (1987) is *no longer used* in the units of the Salters' Science course (1989), which had to meet the criteria laid down by the recently implemented National Curriculum (1989). For the purpose of content analysis of the lessons of the unit Metals (1989), I will continue to use this distinction and notation, in a form consistent with Metals (1987) and with Aikenhead's STS curriculum scheme. While analyzing the unit Metals (1989) and the adapted unit Metals (1992), I will distinguish between CTS content and PC content in order to find the CTS/PC ratio of the different curriculum levels involved (Figure 5.5).

Figure 5.5 Process of development and teaching lessons Metals



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[11] In this way account is taken of the remark that there are "limitations of counting outcome statements as a way to judge the relative importance of pure chemistry and chemical technology/applications" (W2001).

Although the PC terms are not given an asterisk in the lesson plans (Appendix 5) by the writers of Metals (1989), they will be identified as *fundamental* chemical ideas, principles, or techniques by comparison with Metals (1987) and, further, on the basis of the attention given to these terms in the teacher notes and the student activity guides. The identification of CTS terms, neither indicated in Metals (1989), proceeds along the same lines.

For the unit Metals (1989), a rough idea of the ratio between CTS and PC content can be obtained from an inspection of the overview given by the developers of the unit (Figure 5.6).

Figure 5.6 Overview, chemical unit Metals of Salters' Science (1989)[a, b]

This unit is concerned with:
- *the importance of metals,*
- *the relationship between the properties of metals and their uses,*
- *the problems of corrosion.*

The unit starts with a survey of *the surroundings* in which students familiarize themselves with the *names, *physical properties, and *uses of common metals*. The *use of symbols to represent metals is also introduced. Discussion of the *physical properties which metals have in common then leads to the idea that *different metals can be identified by their chemical properties. Students complete *simple qualitative tests on known metals and *use these tests to identify metals in common objects.*

After this initial study of the *chemical properties of metals, *the processes of corrosion* and burning[b] are investigated and this leads to an introduction of the terms *element, *compound, and *reaction.

Students go on to investigate *rates of corrodibility* and *the reactivity series is introduced. *Methods to prevent rusting* are considered in a homework exercise and further opportunities to study *the methods of rust prevention* are provided in two optional lessons.

Work on corrosion allows further discussion of the *usefulness of metals*; the unit ends with a study of *alloys* in which *solder is prepared* and *the properties of alloys are related to their uses*.

[a] Asterisks are added to denote pure chemical (PC) content; italics to denote chemical-technological-societal (CTS) content.

[b] As with Metals (1987), the meaning of some terms is difficult to decide without the context of the lesson, e.g., the term burning (see 5.3).

The first impression one gets from the distribution of CTS and PC terms in the overview of the unit is that CTS and PC content are addressed about *equally* in Metals (1989). Some CTS terms are addressed in the more detailed lesson plans of Metals (1989) but not in its overview. For example, some metal *is used up* in corrosion; corrosion occurs at the *surface*; air and water are both needed for rusting. Again, comparison of terms used in Metals (1989) with the CTS and PC terms used in the lesson plans of Metals (1987) proved helpful.[12]

Thus, it seems that CTS and PC content receive about equal emphasis if we look at the overview and the lesson plans of Metals (1989). Corrosion as a chemical-societal problem emerges as the leading theme or context, both in Metals (1989) and in Metals (1987). In view of the constraints, in particular the assessment procedures set by the

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[12] Only a few PC terms, for example chemical properties, mentioned in the overview of Metals (1989) are not mentioned as such in the lesson plans of Metals (1987).

National Curriculum (1989), we can assume that the CTS/PC ratio for Metals (1989) is somewhat smaller than for Metals (1987). That is, prior to the content analysis of the lessons of the unit, Metals (1989) will be considered as an example of a CHEMISTRY ALONG WITH CTS CONTENT unit.

Using the distinction between CTS content and PC content, design criteria two and three, and the research questions one and two stemming from them, address the following relationships between CTS contexts, CTS content, and PC content.

- PC content *arises naturally* from a CTS *context*.
- PC content is used *only when needed* to make sense of CTS *contexts*.
- CTS *contexts* justify the introduction of CTS content and of PC content used in the unit.

In order to see whether the *prima facie* balance found so far between CTS content and PC content in Metals (1989) is operationalized and visible at the level of concrete lessons, a detailed consistency content analysis of the lessons of the unit Metals (1989) is called for. I analyze therefore in the next section (5.2) the *written curriculum* of Metals (1989), that is, the specific contexts, activities, and concepts treated in the eight lessons of the unit in order to see to what extent the relationships among CTS contexts, CTS content, and PC content stated above apply in a concrete case. In other words, I want to determine the extent to which the developers have been able to adhere *consistently* to design criteria two and three in a concrete unit, by answering the two research questions stemming from these design criteria.

Forms of consistency analysis

As we will see, the consistency analysis of the lessons of the unit Metals (1989) and the unit Metals (1992) will takes three, interrelated forms. In section 5.2, I will limit myself to the first two forms, giving only a rough outline of the third.

1) *Consistency Analysis*

Starting from the adopted set of design criteria, a *content* analysis is made of the *lessons* of the unit Metals (1989) in order to see the extent to which the design criteria in the chosen interpretation are consistently operationalized in the content (context, concepts, and activities) of the lessons. In one of the few studies I have found in which a similar analysis is performed, this method is described as follows:

> ... the method of this research entails *a content analysis of the material in the light of the objectives* as further specified by the original developers in interviews (Joling et al., 1988, p. 6)

As explained above,, for research purposes I take a *strong* interpretation of the Salters' design criteria which is shared by some but not all of the original developers.

2) *Reversed design analysis*

The lessons are analyzed, as it were in reverse, from content to design criteria. Starting from the content used in the lessons of the unit (contexts, concepts, and activities) an analysis is made in order to uncover any design criteria used implicitly or tacitly by the developers, which might have led to unintended, unforeseen, or, perhaps, unwanted consequences (Van Berkel, 1999).

As we saw in Chapter 4, the various developers felt they had to design the Salters' Chemistry course in accordance with the "structure of school chemistry as they all perceived it" (L92); this goes against their design criterion one, *no preconceptions*, interpreted in the strong sense.

3) *Redesign*
Starting from the screened set of design criteria, that is, screened for consistent and tacit use of design criteria, an attempt can be made to redesign the unit. Such an attempted *design sketch* has of course to be trialled for effectiveness in teaching and learning; as with any other design or redesign, it must be trialled first in the designer's room, then in the classroom.

5.1.5 Pedagogical, philosophical and substantive structures

Finally, I give here a representation of the *content* of the unit Metals as it resulted from the development process guided by the adopted design criteria (Figure 5.7). This is done in the usual format, that is, in terms of the substantive, philosophical, and pedagogical structures. The same format has been used in previous chapters for school chemistry *curricula* such as Dominant School Chemistry in Chapter 2 and the Salters' Chemistry curriculum in Chapter 4. The content specifications were taken from the Foundation Unit Metals (1989), a limited edition produced by the Salters' Science Project for full-course trial, using in particular the key teaching points as stated on the lesson plans (Appendix 5). Figure 5.7 is thus a representation of Metals (1989) in terms of the content specifications as given by the developers.

The consistency analysis of the content of the lessons of the unit Metals will reveal the extent to which the key teaching points, as stated by the developers on the lesson plans, are actually addressed in the lessons of the unit, or whether and how the written curriculum of Metals (1989) differs from the formal curriculum. In brief, this will establish whether the CTS/PC ratio will change. The actual design of the unit Metals(1989) can be considered to have *escaped* NCE to the extent that the developers have been able to operationalize in a consistent way the design criteria guiding the development of the lessons organized around the theme *corrosion*.

5.2 Analysis of lessons of curriculum unit Metals (1989)

In this section, I will perform a detailed consistency analysis of the content of the lessons of a *chemical* unit, Metals (1989) of the Salters' Science Foundation Course (see Figure 5.8 below).

I performed the content analysis of the lessons together with the late Dr. Wobbe de Vos, my 'co-promoter' at the time, under the supervision of Prof. Adri Verdonk, both renowned researchers in chemical education. The supervision of my research was taken over by Albert Pilot, the current Professor of Chemical Education at Utrecht University, who is now my 'promoter'. The results of this analysis will show the extent to which the developers were able to fulfill in a consistent way the adopted design criteria in this particular unit (sections 5.2.1 – 5.2.7).

Figure 5.7 Structure of the formal curriculum unit Metals (1989) – a chemical unit of the Salters' Science Course

Categories	Codes	Specifications used by the developers
SUBSTANTIVE STRUCTURE	[SUB]	IMPORTANCE, USE AND REACTIVITY OF COMMON METALS
Pure chemical concepts	[PC]	Physical and chemical properties of metals Element as simple substance, compound, chemical reaction Pure metal Atoms/symbols; mass/weight Corrosion and burning involves reaction with oxygen: oxidation Metals reacting with water; metals reacting with acid Composition; alloys as mixtures of metals
Chemical-societal concepts	[CTS]	Problems of corrosion, iron is used up at surface Role of air, water, and salt; rate of rusting, 'rust stoppers' Uses of common metals in things; cost, annual production
Pure chemical relationships	[PC]	Reactivity series, involving reactions of metals with water, oxygen Word equations: starting reactants and final products Relationship between composition alloys and properties of alloys
Chemical-societal relationships	[CTS]	Order of corrodibility of metals Relationship between properties of metals/alloys and their uses Role of impurities in alloys
Pure chemical/physical techniques	[PC]	Chemical analysis, i.e. tests to identify metals in common objects Chemical test for hydrogen, using a chemical balance Electrical conductivity
Chemical-societal techniques	[CTS]	Methods of rust prevention: (i) greasing, painting, coating, plating (ii) protecting a metal with other, more reactive metal (iii) making new alloys: different composition/ properties/uses Preparing alloys (e.g. solder)

Figure 5.7 Structure of the formal curriculum unit Metals (1989) – a chemical unit of the Salters' Science Course (continued)

Categories	**Codes**	**Specifications used by the developers**
PHILOSOPHICAL STRUCTURE	**[PHIL]**	**APPLICATIONS OF CHEMICAL KNOWLEDGE**
Foundations of science	[FS]	Social, economic, environmental, industrial, technological emphasis (e.g. galvanizing iron in 'Hot Dip Process')
Methodology of science	[MS]	Practical/experimental skills, e.g. lab. investigations, controlling variables, using a control, interpreting data. Focus on recognizing patterns; some predictions Foundations of chemistry
	[FC]	Word equations summarize a process: starting materials (the reactants) or one side, the final material(s) or the other side (the products)
Methodology of chemistry	[MC]	Macro explanation, e.g. of differences in corrodibility of metals Analyzing/testing of materials made of metals Making new materials made of metals
PEDAGOGICAL STRUCTURE	**[PED]**	**JUSTIFICATION FOR STUDY IN ASPECTS OF EVERYDAY LIFE**
Aims	[A]	To understand how chemistry affects daily life: describe/explain corrosion in order to control it; prevent or treat corrosion; make new alloys
Teaching approach	[TA]	Everyday situations lead to introduction of chemical concepts/ explanations, as and when needed, in order to explain other daily life contexts or to give reasons for use of chemically made artifacts Spiral approach: macroscopic, qualitative introduction
Learning approach	[LA]	Motivation/active learning through relevant contexts and variety of practical work Ask students to present their own ideas, if possible, e.g. on rusting

I will focus the analysis on design criterion two, *Relevance*, and design criterion three, *context-led development of concepts*. In this analysis, I will try to answer the following two questions.

1) Does each *lesson* of the unit Metals have its *origin*, and hence its *justification* for study, *fundamentally* in aspects of *everyday life*?

2) Are all chemical concepts and explanations introduced in the lessons of the unit Metals *needed* for the study of these everyday situations?

In section 5.2.8, I will summarize the results of the consistency analysis of the lessons of Metals (1989), compare the analyzed written curriculum with the formal curriculum of

Metals in terms of CTS and PC content, and discuss to what extent the developers of Metals escaped from (a part of) Normal Chemistry Education. For the purpose of the lesson analysis of Metals (1989), I have given in Figure 5.8 the overall plan of the unit Metals, while Appendix 5 gives the full lesson plans of Metals (1989). For the list of teaching materials and the overview of the unit, see Figures 5.3 and 5.6 above.

At the beginning of my analysis of each lesson (5.2.1 – 5.2.7), I reproduce the lesson synopsis. I further quote relevant excerpts from lesson plans (LP), teacher notes (TN), student activity guides (SAG), and student information sheets (SIS). Occasionally, I will refer to editions of the unit Metals developed earlier, namely Metals (1984) and Metals (1987), and also to the so-called student book (Hill et al., 1989, pp.1-11). The first chapter of this book is titled "Metals", the book can be used in the classroom as a supplementary teaching resource.

Figure 5.8 Metals (1989) – The Overall Plan[a]

M1 WHAT ARE METALS?

Investigation of the properties of metals. comparison with properties of plastics. Symbols.

M2 WHICH METAL IS USED TO MAKE A DRAWING PIN?

Simple chemical tests for metals. Metals used to make common objects.

M3 WHAT HAPPENS WHEN METALS CORRODE?

Examination of corroded metals. Investigation of rusting of iron. Idea of a chemical reaction.

M4 A CLOSER LOOK AT CORROSION AND BURNING

Investigation of the changes during the processes of corrosion and burning.

M5 DO ALL METALS CORRODE?

Investigation of the reactions of metals with air and water. Order of corrodibility (reactivity) of metals. Oxidation.

M5X1 HOW CAN WE PREVENT RUSTING?

Methods used to prevent the corrosion of a bicycle. Investigation of the effectiveness of rust stoppers.

M5X2 DO OTHER METALS STOP IRON FROM RUSTING?

Investigation of the presence of other metals on the corrosion of iron.

M6 WHAT ARE METAL ALLOYS?

The effect of alloying on the properties of metals. Uses of alloys.

[a] Each box of the flow diagram represents a double period lesson (70 – 80 minutes). The lessons M1, M2, M3, M4, M5 and M6 are core lessons, while the lessons M5X1 and M5X2 are so-called *optional enrichme*nt lessons.

5.2.1 Analysis of lesson M1

The synopsis of the first lesson of Metals: WHAT ARE METALS? reads:

> Students complete activities to become familiar with the *names*, *general physical* properties and *uses of common metals*. *Symbols* are introduced.

Metals, common metals or common objects made of metals

In the TN of lesson M1 with regard to the first activity, a survey, it is suggested to "ask students to look at *items* in the *laboratory* and list those they think are *made of a metal*". However, in the overview (Figure 5.6), the developers mention a broader context to start the unit with, namely: "a survey of *the surrounding*s in which students familiarize themselves with the names, physical properties and uses of *common* metals". This broader, chemical-societal context is addressed later in this lesson in a so-called "individual student activity" (LPM1, Appendix 5). This activity, though, is optional, that is, "If there is time available, students could be asked to make a list of the metals *they know* and note what they look like, whether they are hard or soft, heavy or light, etc." (TNM1). This optional activity seems to be more consistent with design criterion two, *relevance*, than the *laboratory* survey.[13] Therefore, one would have expected that lesson M1, and with it the unit Metals as a whole, would have *started* with an activity similar to the optional one. For example, one could ask students to make a list of *common objects made of metals* as present in their *surroundings*.[14]

It should be noted here that common objects present in the surroundings or in homes are in many cases very complex *mixtures* of substances. When they are made of metals they often consist of *alloys*. The latter concept is treated in the last lesson of the unit M6: WHAT ARE METAL ALLOYS?[15], both as a chemical concept in relation to the concepts of mixture and composition and as a chemical-societal concept in relation to use and purpose. I will return to this important point, when analyzing and discussing lesson M2, especially lesson M6.

Properties of metals, and their relation to use

The next activity (SAG M1.1) consists of laboratory-based practical work, and concerns a "comparison of the properties of metals and plastics based on experiments using a metal spoon and a plastic spoon". The experiments deal with the following *general physical* properties: clangs when struck, dense, shiny, reflects light, malleable, good conductor of heat, good conductor of electricity (the *chemical* properties of metals are treated in M2). The last activity of this lesson (SAG M1.3) introduces some *economic* aspects of metals such as cost and annual production. Many of the general physical properties and the economic aspects of metals introduced here can be said to have their *origin*, and hence their *justification* for study, in aspects of *everyday life*. On the other hand, the *differences* in properties of *concrete* objects like a metal and a plastic spoon

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[13] It would also more *actively involve* pupils, and be more consistent with design criterion four, *variety of learning activities*. Metals (1984) calls this type of lesson optional, while Metals (1987) refers to *optional enrichment* as does OGT (p. 13).

[14] The chapter Metals in the student book (Hill et al., 1989) seems to offer more in the way of a contextual, relevant introduction and treatment of metals (see also next note). For example, in the section "Things to do" (p. 11), pupils are asked to "identify five *objects* in your *home* which you think are made of metals" or to "identify, with the help of older members of your family, three *objects* which used to be made of metals". It is important to remember that the student book is not a regular textbook from which the course is taught and learned (4.4.2), but a supplementary resource for pupils. The assessment items of Metals (1989), too, refer to pupils' surroundings. The pupils are asked to "look around the *room* ... and name three *objects* made of metal, which you can see in the room" (item 11) or to "name three *things* you use at *home* or at *school* which could be made of <u>either</u> metal <u>or</u> plastic" (item 16; underlining theirs).

[15] The student book (Hill et al, 1989), though, mentions alloys right at the start of the chapter Metals (p.1), saying that "Now it is possible to obtain specially prepared *mixtures* of metals called **alloys** which have *suitable properties* for *making* everything from a spoon to a spaceship" (about half of the terms in boldface in the student book denote pure chemical concepts, about half denote chemical-societal concepts).

with regard to beauty or taste relevant for situations in everyday life, for example eating, are not addressed.[16] The questions when, where, and for what *purpose,* a metal spoon or a plastic spoon is used are not raised. So, contrary to design criterion two, *relevance*, the everyday aspects of objects such as a metal or a plastic spoon are not fully exploited in this activity; the comparison is not fully set in a CTS context.[17]

Chemical names or symbols

The student activity, titled "HUNT THE METALS" (SAG M1.2), concerns the "completion of a word search for metals" with the help of a list of seventy names and symbols of metals as given in SIS M1.1. With regard to teacher-student discussion 3, the TNM1 read:

> Introduce the idea of a *chemical shorthand* – using *symbols* for metals. You may wish to mention that the symbol for a metal actually stands for one atom of the metal. Hence when writing about metals, it is wrong to put "some Cu" etc. (underlining theirs).

With regard to the latter suggestion, it should be noted that from a chemical point of view it is not wrong to say "some Cu". Chemistry as a science, is not limited to a corpuscular context, but deals with thermodynamic or phenomenological contexts as well. In the latter contexts the locution "some Cu" refers not to one or more atoms, but to an amount of the pure substance copper or element copper (Cu). So, why should school chemistry then be limited to only corpuscular contexts?[18]

In SIS M1.1 it says that the *ten* metals in the list of seventy which carry an asterisk (Al, Ca, Cu, Fe, Pb, Mg, K, Na, Sn, Zn) "are those which you will meet most often in the course". This raises the question whether the other sixty metals listed are really *needed*, in view of design criterion three, *Context-led development of concepts*, in this or other lessons of the unit Metals.

In the last activity (SAG M1.3) students perform a "data analysis and interpretation to explain the *reasons for certain uses* of metals". Students have to answer a number of questions, set in daily life contexts, concerning the *differences* between metals in relation to their *use*, on the basis of a data table containing *economic* properties (cost, annual production) and *physical* properties (density, melting point, best conductor of heat, best conductor of electricity) of nine metals. For example, one question reads: "Give two reasons why we don't use this metal [silver] to make saucepans", and the last question of this activity reads: "For what uses have plastics replaced metals? Why do you think this has happened?" TNM1 lists as answers: "Plastics are lighter, cheaper, more resistant to *corrosion*. Supplies of some metals are dwindling." Coming back to the point made above about the properties of spoons related to the their use, it would have been appropriate to add a question such as: For what uses have plastic spoons replaced metal spoons?

This could then lead into specific daily life properties of spoons in relation to eating.

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[16] It is interesting, that lesson plan M1 of Metals (1984) states in its outline of activity 4 that "pupils are supplied with two *similarly shaped and sized objects* and investigate the differences in properties between them" . The *abstraction* from shape and size favors the treatment of *general* properties of metals and plastics over that of *specific* differences in *use or function* of metal or plastic concrete objects.

[17] The chapter Metals in the student book (Hill et al., 1989) offers supplementary contexts to the economical and technological ones treated in the unit Metals (1989), for example, poisonous metals are set in a social/biological/environmental context, and aluminum production is set in an industrial context.

[18] For a similar point see De Vos et al (1994), where the use of *broken* coefficients in equations is discussed. Although not allowed in a corpuscular context, it is not uncommon among chemists to use broken coefficients in a thermodynamic or phenomenological context.

Summary

Regarding the latter activity, the first research question mentioned in section 5.2 takes the form: Do the introduced concepts *chemical shorthand* and *atom* have their *origin* or arise *naturally* from the study of *everyday* situations?

The answer appears to be negative. Students are *told* something about the concept *atom*, as we saw, and are *given* a list of seventy symbols for metals to help them with their metal 'hunt'.

The second research question mentioned in section 5.2 takes the form: Are the concepts *chemical shorthand* and *atom* only introduced when they are *needed*? Again, the answer is 'no'. All that seems to be needed to make sense of the nature of daily life objects made of common metals such as food cans, of things familiar or *known to students*, is a small set of about ten metals, and their names and relevant properties. The introduction of an almost complete list of symbols of metals as *known to chemists* is thus not needed. The short list of ten *common* metals will probably not include metals such as potassium or sodium. As the writers of the unit say (TNM1): "They are unlikely to be mentioned by students at this stage". We will see, though, that students will meet these metals nevertheless, in lesson M2 and especially in lesson M5. Thus, the concepts *chemical shorthand* and *atom* are introduced in M1, but are not really needed to make sense of daily life aspects of metals.

Some of the contexts used in M1, "laboratory survey" and "comparison of the properties of metals and plastics", do not fully develop fundamental daily life aspects of metal objects such as their composition as alloys and the properties of spoons related to use like eating. Other contexts of M1, "students list metals they know" (optional) and "explain the reasons for certain uses of metals", do address the relationship between the properties of metals and their uses in a sufficient manner.

Thus, judged by criterion two, *Relevance*, and design criterion three, *Context-led development of concepts*, and taken in a strong interpretation, CTS content is not fully developed, and PC content is developed more than needed in lesson M1.

5.2.2 Analysis of lesson M2

The synopsis of lesson M2: WHICH METAL IS USED TO MAKE A DRAWING PIN? reads:

> Students are introduced to *simple tests* for some common metals and then use these *tests to identify* the metals in *common objects*, e.g. a drawing pin.

The key activity (SAG M2.1) of this lesson concerns laboratory-based practical work. Students perform "*simple* qualitative tests on known metals" and identify thereby "the *dominant* metal in a drawing pin", as it says in lesson plan M2 (LPM2). The key point of this activity is that "chemical tests are *often* better than physical tests at *distinguishing* between metals" (LPM2).

The practical work is preceded by a teacher-student discussion in order to help students "recall that metals have common physical properties and many look alike" and to start a "discussion of possible ways of *identifying* different metals" (LPM2). The teacher then suggests "that it is worthwhile to investigate whether chemical tests might give additional information" (TNM2).

At the end of SAG M2.1, students perform a SPECIAL INVESTIGATION (emphasis developers), in which they apply what they have learned in the laboratory in a daily life context.

> Using the *tests* you have just learned, try to discover which metals are used to make the *everyday objects* (e.g. drawing pins, paper-clips, etc.) you have been given.

The last activity of M2, a second teacher-student discussion which comes back to the first teacher-student discussion, addresses the key point that “the use of metals is related to their *chemical* properties” (LPM2). It is recalled from M1 that “the use of a metal is also related to its *physical* properties”. TNM2 suggests: “Bring out the idea that some metals are *more reactive* than others. This will therefore affect the ways in which they can be *used*.”[19] Thus, the important “relationship between the properties of metals and their uses” (LPM2) is reinforced. (See also the overview in Figure 5.6 and Hill et al., 1989).[20] With regard to lesson M2, the first research question takes the form:

1. Does M2 have its *origin*, and hence its *justification* for study, in aspects of *everyday life*?

Although SAG M2.1 ends with an everyday life context (SPECIAL INVESTIGATION), it does not start in such a context. It is in a *laboratory context* that students are introduced “to the idea that a more *precise identification* [of metals] can be made through the study of their chemical reactions” (LPM2). The following point made by the developers is pertinent for the analysis.

> The qualitative tests have been *confined* to the metals iron, copper and lead since there are many *common simple objects* in which these are the *dominant* metals (TNM2).

And students are instructed accordingly:

> You will *first* perform this *test* on *pure* metals and *then* use the same test to identify the metals used to make a drawing pin (SAG M2.1).

The focus of this activity is on *pure* metals, on the identity of metals, not on their use. The chemical tests are not introduced in relation to the use of simple objects made of metals. Furthermore, it seems to be taken for granted that the chosen laboratory context prepares students adequately for applying these chemical tests to everyday life, that is, to the identification of the metal constituents of common simple objects. But this involves, in fact, many assumptions (or reductions) in order for the chemical analytical identification to succeed:

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[19] Instead of pointing this out at the end of M2, it would have been more appropriate to do it instead at the end of M3, that is, after students have had some *experiences* with differences in reactivity or corrodibility of metals.

[20] The relation of properties and use of metals is formulated by Hill et al. (1989, p. 7) as follows: “Although metals have a lot of similarities, they also have a lot of differences. These *differences* are *important* when deciding which metal to *use* for which *purpose.* For example, some metals are stronger than others, some are heavier than others and some are *more resistant to attack by air*”.

1) A *small* sample of a daily life object is required, such that fits in a test tube. A bridge, an airplane, or even a spoon as a whole are difficult to analyze.

2) A *sample* is taken form the *bulk* of a metal object, not from its surface which might be coated or corroded.

3) A sample should consist of one dominant metal, while other metals present should not interfere with the identification of the *dominant* metal.[21]

4) A small pre-selected number of *pure* metals are analyzed in order to form a "confined" or closed group of metals distinguishable by simple, qualitative chemical tests.

These assumptions about the *analytical route* from surface, bulk, sample, pure metal, closed group to precise identification are hardly addressed in TNM2. Thus students are not made aware that the chemical tests they perform in SAG M2.1 are less easily applied to common metal objects such as a bridge, plane, or spoon. The CTS context of common objects gives way to an analytical context introducing pure chemical concepts.

As pointed out above, most objects used in everyday life are quite *complex* mixtures or, in the case of metal objects, consist of alloys. In view of design criterion two, *relevance*, and design criterion three, *context led development of concepts*, one would have expected that the concepts *mixture* and *alloy* would have received more attention in the first lessons of the unit.

As we will see, the central theme *corrosion* of the unit Metals is not introduced until lesson M3. Differences in corrodibility or reactivity between metals, and thereby important chemical and societal properties of metals, are not treated earlier in the unit.[22] It would have been more consistent with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, if students had first gained the CTS *experiences* of lesson M3, and subsequently had performed the laboratory-based practical work. This would have *justified the need* for the introduction of the chemical analysis in relation to the theme *corrosion*.

Specific to this lesson, the second research question takes the form:

2. Are the chemical concepts introduced in M2 *needed* for the study of everyday situations?

As argued above, the central context of this lesson is a classical chemical analytical context, namely, identification of a set of pure metals, and the related chemical concepts (chemical test/property/reaction, dominant/pure metal) are introduced for that reason.

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[21] This point is addressed briefly in the teacher notes: "Since some objects tested may be alloys or plated, you may prefer to refer to the dominant metal so that contradictions are not made later when referring to alloys (emphasis theirs)". When referring to the composition of a common object such as a drawing pin, the developers often use the plural, i.e. metals, while the title of the lesson refers to the singular, i.e. to metal. The title of this lesson, therefore, seems to presuppose the concept *dominant metal*.

[22] In Metals (1984), lessons M3 and MX3.1, students do gain some relevant experiences with chemical reactions of aluminum, iron, and copper. In this way the conclusion: "Metals have *different chemical properties* and cannot all be extracted in the same way" (MX3.1), is supported by empirical evidence.

These concepts do not *arise naturally* from the study of *common simple metal objects*, and are, therefore, not needed to make sense of them.[23] Secondly, the chemical names and terms mentioned in the lesson (dilute nitric acid, sodium hydroxide, decant and precipitate) are not needed. These systematic names and chemical terms can easily be replaced by *common* names such as acid and base, and the technical term precipitate by the locution "a solid in a liquid" (SAG M2.1).

Summary

The main concept in this lesson, chemical analysis, does not arise from the context of the chemical properties of metal objects as they occur in daily life. The analytical concepts appear as it were *sui generis*: chemical concepts and terms introduced such as *identification*, *dominant metal*, *pure metal*, *precipitate* are not justified in relation to everyday life aspects of metals.

The concept of *analytical route* is not developed, nor are the concept of *alloys* and the relationship between the properties of metals/alloys and their societal use (CTS content).

Thus, judged by criterion two, *relevance*, and design criterion three, *context-led development of concepts*, taken in a strong interpretation, CTS content is underdeveloped and PC content is overdeveloped in lesson M2.

5.2.3 Analysis of lesson M3

The synopsis of Lesson M3: WHAT HAPPENS WHEN METALS CORRODE? reads:

> Students consider what happens during *corrosion* and this leads to an introduction of the terms element, compound and reaction (emphasis developers). The rusting of iron is then investigated practically.

The unifying theme of the unit Metals, *corrosion* (SLB, p. 8), is addressed in lesson M3 for the first time.[24] This CTS theme is introduced by the teacher in the context of a set of corroded metals, and is elaborated by students in another CTS context, that is, the exploration of a *specific* case of corrosion, namely, the rusting of iron.

M3 starts with a teacher-student discussion in which "samples of corroded metals are displayed". (LPM3). The teacher should "Have ready a display of as many *corroded metal items* as are available. Students can look at the display and suggest where such samples might have come from" (TNM3).

Students are not invited to think about or to organize a display of *corroded metal*

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[23] The student book (Hill et al., 1989) discusses differences of chemical reactivity in the context of toxicity of metals as well as in the context of corrosion of metals, but does *not* deal with differences in chemical properties in the context of chemical identification.

[24] In lesson M1 the theme *corrosion* only surfaces in the answer given to question 9 (SAGM1.3): "Plastics are lighter, cheaper, *more resistant to corrosion*." (TNM1). In lesson M2 there is no reference at all to corrosion despite the focus of the lesson on chemical properties and reactions. As we saw, the focus there is strictly on chemical properties relevant for chemical identification.

items that they can find or have used in their own surroundings at home.[25] Such an activity would have been more fully in accordance with design criterion two, *relevance*, and would also more *actively involve* students (design criterion four). It is further to be noted that the corroded forms of *pure* metals (rusty iron, tarnished copper, corroded zinc) have been chosen as samples of corroded metal *items*. The teacher demonstrates the "removal of corrosion by rubbing with an emery cloth" (LPM3) and directs the attention of students to the color of the *surface* "before and after rubbing" (TNM3). The key point of this activity reads, therefore, "corrosion occurs at the *surface* of metals". It is noteworthy, that in this activity *visual inspection* seems to suffice, whereas in M2, as we have seen, the technique of chemical identification, directed at *bulk* properties such as the composition of pure metals, was invoked. Thus, the technique of chemical identification introduced in M2 is not used in M3 (or in other lessons of the unit) which seems to underline the conclusion in M2 that it is not *needed.*

In the teacher notes (TNM3) are stated the purposes of the teacher demonstration:

1. to show that corrosion produces a new substance and to establish the idea that corrosion is a chemical reaction (emphasis theirs).
2. to explain that, when the corrosion is removed, a substance remains (the metal) which cannot be made any simpler. This substance is called an element (emphasis theirs).
3. to explain that the new substance(s), which form during corrosion, is called a compound (emphasis theirs).
4. to show that when the corrosion occurs, *metal is used up*.

Firstly, it is to be noted, that the theme *corrosion* is addressed in this lesson in two different contexts: (i) in a purely chemical context, that is, as just an example of a chemical reaction involving the formation of a *new* substance, a compound derived from the pure metal; (ii) in a chemical-societal context, that is, as a socially unwanted chemical change occurring at the surface of metal objects. The phrase "*metal is used up*" which turns up frequently in the unit Metals is very intriguing but also ambiguous. In one sense, the metal is *not really* used up during corrosion. The metal is only converted but at the same time conserved. This implies a concept of *element* as a *principle of conservation*, that is, the metal element is conserved in the corroded substance or compound. In another sense, metal is used up, namely, part of the metal is converted to another substance, losing its luster and gaining a socially unwanted rusty surface. The phrase "*metal is used up*" appears to imply the second sense of the concept of element, described by the developers as a substance "which cannot be made simpler" (TNM3). Since corrosion appears to occur mainly at the surface of metals, (part of) the original *surface* of a metal object is no longer available: the metal *surface* is *used up*. Corroded metal objects are often no longer useful for the purposes for which they were originally designed and used.

Looking at corrosion from a CTS point of view leads quite naturally to another worthwhile chemical-technological-societal context, namely the recycling of metal objects. For example, corroded piles of scrap metal ("used up") can be processed by chemical and physical means in order to win back the valuable metals they still contain.

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[25] Hill et al. (1989, p. 7) refer to the use of metals in "countless everyday objects used in the home, at work and in leisure pursuits".

The context *recycling metals* teaches clearly that corroded metals have been converted and at the same time conserved, which would *justify the need* to introduce the concept of the conservation of elements.[26]

Secondly, the observations made available to students in the teacher demonstration: changes in color and texture ("pitting", "thinning") seem not to be sufficient "so that the *conclusions* stated [1-4] above can be made" (TNM2). With regard to the second conclusion, it does not follow from the ability of a metal material to corrode that it is an element. It could also be a compound or an alloy. The conclusion that a metal is an element only follows from its inability to decompose. Neither is it possible for students to decide on the basis of these observations whether the corroded metal is a compound or maybe a mixture/alloy (conclusion 1), or whether the metal has undergone a chemical reaction or another physical process (conclusion 3). Conclusion four is reasonably supported by the visible evidence presented to the students, but only if we take the phrase "*metal is used up*" in the second sense discussed above.

The wish of the developers to address in lesson M3 both the *basic* chemical reaction concept and the *fundamental* CTS theme *corrosion* introduces two tensions discussed in general terms in Chapter 4: (i) the tension between *concept and context*, which shows up in the two different meanings of the concept corrosion and in the conceptually ambiguous phrase "metal is used up"; (ii) the tension between *concept and process,* which shows up in a certain lack of evidential teaching with regard to the conceptual development of the fundamental chemical concepts element, compound, and reaction.

In the next activity, laboratory-based practical work (SAG M3.1), "students set up an investigation into the *extent and rate of rusting of iron nails* in the presence of combinations of air, water and salt" (LPM3). Prior to that, students are asked, in teacher discussion 2, to suggest "what sort of substances *the metals* might be reacting with when they *corrode* and suggesting what type of investigations might be carried out to test their ideas." This question is phrased in a rather *general* way which might make it difficult for students to answer. Which metals react with what substances during the process of corrosion can differ from case to case, often involving water and/or carbon dioxide and/or oxygen. The *rusting of iron*, the central topic of this activity, is a very *special* case of corrosion, both in its chemical and in its chemical-societal effects. It should therefore be treated accordingly.[27]

The investigation is set up as depicted in Figure 5.9 (left). For the sake of comparison I have added a similar experiment (Figure 5.9, right) taken from a traditional textbook, "General School Chemistry" by Clynes and Williams (1960). In this textbook the conclusion of the rusting experiments is simply *given*, as is the reasoning leading to it.

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[26] The theme of recycling is addressed in other units of the Salters' Chemistry course e.g. in the units Plastics (recycling plastics) and Minerals (recycling glass, winning metals) but without the context-led development of the concept of the conservation of elements (see also Hill et al., 1989, pp. 77 & 122). Similarly, Holman (1991, p. 122) discusses the recycling of metals but without mentioning the concept *element conservation*.

[27] The student book (Hill et al, 1989, p. 4) briefly addresses the *special* status of iron and rusting, when it says that "corrosion of iron is commonly called rusting", and it deals with how other metals such as tin or magnesium can be used to protect iron from rusting. In TNM4 word equations are given, both for the oxidation of magnesium and the corrosion of iron, but the latter equation does *not* mention the presence of *water*, which was an important key point of lesson M3. Thus, here the general case of oxidation appears to take full precedence over corrosion and rusting.

> After a week it will be found that none of the nails in the first two tubes have rusted, but those in the third are covered with rust. Hence, both air and water are needed for rusting (Clynes & Williams 1960, p. 54).

In other words, the logic here is that the iron nails do *not* rust with just water or just air, but only when both water and air are present.

In Metals (1989) students are led to the conclusion that "air and water are necessary" by way of three consecutive questions they have to answer (SAG M3.1). Question 1 reads: "From the appearance of the nails in tubes A [no change] and C [some rust], do you think that water is needed for iron to rust?" The TNM3 gives as answer: "Water should emerge as being necessary for iron to rust". A more accurate answer would be, the presence of water is necessary but not sufficient. After all, in tube B [no change] water is present. Question 2 reads: "From the appearance of the nails in tubes B [no change] and C [some rust], do you think that air is needed for iron to rust?" TNM3 gives: "air should also be necessary for rusting". Again, a more accurate answer would be, that the presence of air is necessary but not sufficient. After all, in tube A [no change], air is present. Question 3 reads: "What are the conditions for rusting? TNM3 give as an answer that "air and water are necessary". The answers given to questions 1 and 2, though, do not seem to lead logically to this conclusion. This would take the *simultaneous* comparison of three tubes A, B and C, using all the available observations.

How the changes with iron in tubes A – D come about is another matter. Is it by way of a chemical reaction with air and water, or perhaps catalytically, involving salt? Again, students will not be able to tell from the evidence provided. For example, students have to take it on trust that the drying agent in tube A only reacts with air and is not a condition affecting, in whatever way, the nails even though it is in contact with them, as is the salt in tube D, which does affect them.

So, this seems to be a second example in this lesson of the tension between *context and process* mentioned above which shows itself as engendering a certain lack of evidential teaching, which will probably also affect the quality of the learning process of students.[28]

The striking resemblance of the 'rusting' experiments used by the developers of the unit Metals of Salters' Science (1989) and by Clynes and Williams (1960) in their textbook "General School Chemistry" almost thirty years earlier, seems to indicate that the structure of school chemistry not only determines the choice and sequence of chemical concepts and techniques, but also the choice of experiments used, and perhaps even the way in which they are depicted. This shows that standard experiments from traditional textbooks are used by developers of an alternative approach to school chemistry, without adapting the experiment specifically to their purposes, except for the added role of the salt. Further, it would be more in accordance with design criterion two, *relevance*, to replace systematic chemical terms by common names: "anhydrous calcium chloride" by *drying agent* and "paraffin oil" by *oil* (see 4.5.2).

The use of systematic names and technical chemical terms, not only here but also in SAG M2.1, is probably also a consequence of importing standard experiments into the unit Metals.

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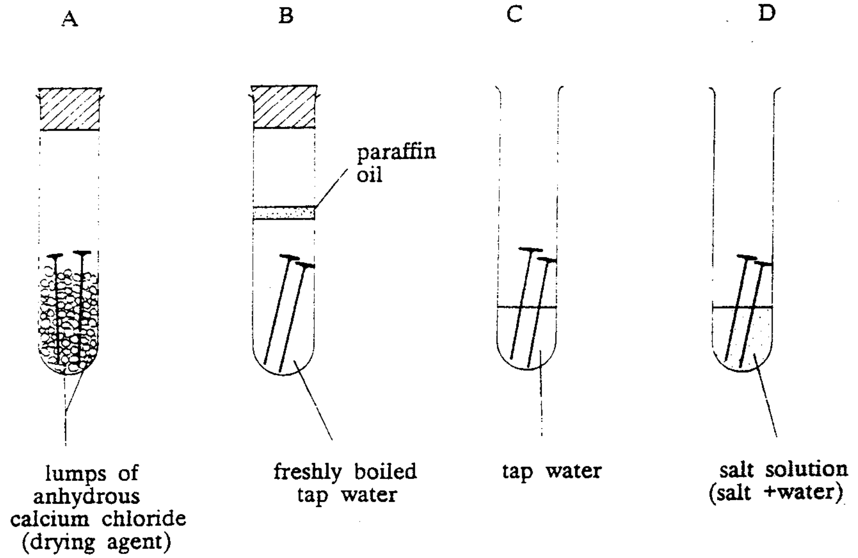
[28] Garforth (G92b:17) points to a kind of trade-off between *context and process* when remarking on the place of the chemical industry in school chemistry: "It's always been there but we ... perhaps in the Salters' course *we made more of it*. Nuffield – *they rather played it down*, because they were so hung up on explanation ...". In other words, the Nuffield approach emphasized processes over relevance, whereas the Salters' Chemistry approach emphasized relevance over processes.

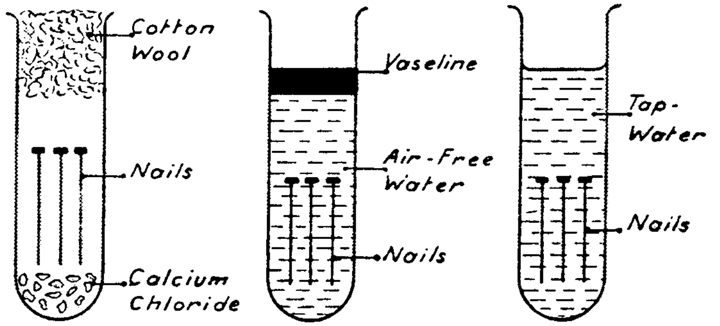
Figure 5.9 Experiments on the Rusting of Iron

Top figure: From *Salters' Science* (1989), UYSEG, Unit Metals, SAG M3.1, Side 1/2.
Bottom figure: From *General School Chemistry* (1956), Clynes & Williams, 5.10 Rusting and Burning, p. 53.



CONDITIONS

A	B	C	D
iron	iron	iron	iron
dry air	air−free water	water	water
		air	salt
			air



Conditions for Rust. The third tube acts as a control for the others, because no special precautions are taken.

SAG M3.1 ends with a question which addresses, in accordance with design criterion two, *relevance*, a chemical-societal context and, in a student-centered way, in accordance with design criterion four.

> Suppose you work in the marketing department of a company that makes cars. The company is trying to think of ways they can explain to the public why it is important to hose down the underneath of cars in bad winters. Produce a leaflet or poster which attracts attention and show why this hosing down process is so important.

Having learned, in the previous activity, the causes involved in rusting, students are offered here a chemical-societal context in which they can apply/transfer their newly won chemical knowledge.[29]

Summary

Lesson M3 starts with a chemical-societal context, corroded metals, followed up, after the introduction of the chemical concepts *element, reaction, and compound*, by another, more specific CTS context, the rusting of iron, in which students investigate the possible causes or factors affecting rusting. The lesson concludes with a chemical-societal context from daily life, the hosing down of cars. Thus, here we have a good example of a *sequence* of chemical-societal contexts, and of the introduction and application of chemical concepts in accordance with design criterion two, *relevance*. So, lesson M3 does have its origin fundamentally in everyday life contexts.

Secondly, do the chemical concepts introduced in lesson M3 arise naturally from or are needed for the study of the everyday contexts mentioned above, in accordance with design criterion three, *context-led development of concepts*? If we focus on the specific case of the rusting of iron, it is clear that the factors or *causes affecting rusting* arise naturally and are needed for students to make sense of chemical/societal phenomena of rusting. As for the basic chemical concepts involved in corrosion in general, the concept of chemical reaction seems to be crucial to make sense of corrosion being a socially unwanted chemical change of the surface of metals. The concept of an element as "the simplest possible substance" does not appear to be necessary in the context of corroded metals or rusting. The concepts of pure metals, pure substance, and compound, might not be needed either. A general concept of substance or material will do. Thus, a discussion in terms of metal *materials* (pure, mixed, or alloyed) and their chemical *changes* would probably be sufficient to deal with the contexts of corrosion and rusting in this lesson. On the other hand, the concept of an element as a principle of conservation of matter, although not developed, arises naturally from the context of recycling, if such a context were to be added.

5.2.4 Analysis of lesson M4

The synopsis of lesson M4: A CLOSER LOOK AT CORROSION AND BURNING reads:

> After looking at the results of the *rusting* experiments, students investigate the burning of magnesium and *compare* the *processes* of burning and corrosion. Ideas about elements and compounds are reinforced.

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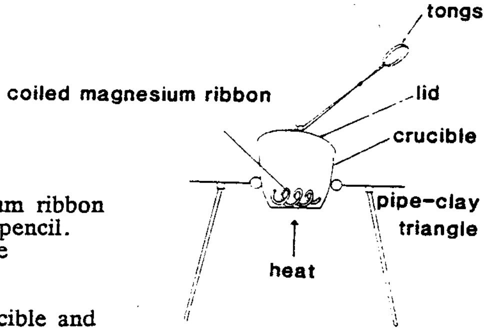
[29] Garforth (FG92a:15) remarks that "it was definitely intended" by the developers to solve the problem of application, or transfer, in this way.

The lesson starts with a teacher-student discussion from which should emerge the key points of the students' experiments with rusting iron nails (SAG M3.1). These will be summarized by the teacher as (LPM4): "Air and water are both needed for *rusting*. Salt makes *rusting* happen more quickly. Iron is used up during *rusting*. A new substance is formed when iron *rusts*". And TNM4 adds: "As *air* generally contains *moisture*, iron *objects* will therefore rust in air."

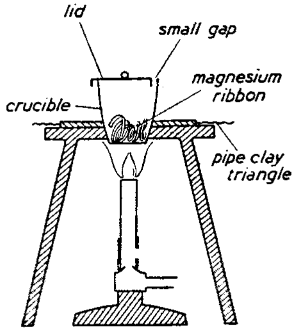
The *specific* chemical-societal (CTS) context *rusting*, stressed by the points above, is abandoned, as we will see, in the main part of lesson M4 and is replaced by the *general* pure chemistry (PC) context *oxidation*. The latter context is preceded and prepared by the context of burning, which can be treated either in a chemical-societal context such as the operations of the fire brigade or in the purely chemical context of oxidation. It is the latter context, illustrated by the burning of a piece of magnesium ribbon in a classic experiment, which is also used by Dingle and Simpson (1959, p. 51) in a book called *Basic Chemistry* intended "for the first two or three years before O. L. [O-level]". Again, as with the experiments on rusting (SAG M3.1), there is a striking resemblance between the traditional experiment, used by Dingle and Simpson, "To Discover if Metals gain in Weight when Heated" (ibid., p. 51) and the experiment in the unit Metals of Salters' Science (1989) used to study "possible changes in mass during burning and rusting" (TNM4), as a simple inspection of Figure 5.10 shows.

Figure 5.10 Experiments on Burning Magnesium

Left: From *Salters' Science* (1989), UYSEG, Unit Metals, SAG M4.1, Side 1/2
Right: From *Basic Chemistry* (1959), Dingle and Simpson, Experiment 31, p. 51.



1. Make a coil of magnesium ribbon by winding it around a pencil. Put the ribbon inside the crucible.
2. Place the lid on the crucible and weigh the crucible, lid and ribbon together.



Combustion of Magnesium.

The demonstrated experiment should illustrate, and in a spectacular way, the *process* of burning (see synopsis). Students are invited to observe what happens "without looking at the burning ribbon directly" (TNM4, their emphasis). This is of course good safety advice, but it has the unfortunate effect that the students are provided with experiences, mainly of the initial *state*, the "starting materials (reactants)", and of the final *state*, the "final materials (products)". These are easily and safely observable, as against aspects of the *process* in between, except for the fact that "the magnesium flares up" (TNM4) while burning in *air*. The purpose of the teacher demonstration of the burning of a piece of magnesium ribbon in air is to show that: "(i) magnesium *is used up* during burning; (ii) a new substance is formed when magnesium burns; and that (iii) *air* is needed for magnesium to burn." (TNM4).

In the small group discussion following the demonstration, groups of 4-5 students are invited to discuss "what they have seen in the rusting and burning experiments" (TNM4). Students are encouraged to come up with hypotheses on the process of burning and with ways of testing them.

A remark about the place of this activity seems to be in order here. At this point in the unit Metals, students have acquired some *experiences* with the *specific* chemical-societal case of the *rusting* of iron (SAG M3.1) and are now asked to compare these *direct* experiences with the limited and indirect experiences gained from the *demonstration* experiment of the phenomena of *burning* magnesium ribbon. Later in the lesson, the teacher may decide to let students perform the experiment of burning magnesium coil in a crucible (SAG M4.1). Students are encouraged to do the experiment themselves "rather than just observe the teacher demonstration" (TNM4). It seems to me, that the discussion in small groups could be more productive for students after having collected direct experiences with both the experiment on rusting of iron nails and the burning of magnesium coil in air.

In the subsequent teacher-student discussion, addressing the question: "How can we prove that iron and magnesium gain something from the air during rusting and burning" (LPM4), the teacher "may need to direct the discussion towards the consideration of possible changes in *mass* during burning and rusting" (TNM4). So, the comparison between "the *processes* of burning and rusting" (synopsis) focuses on just one similarity, namely that of changes in mass or weight, a similarity which is indeed of crucial importance for the *purely chemical* context of oxidation. The *differences* between the processes of rusting and burning, important for societal uses and applications of metals and (in this case) also fuels, hardly receive any attention.

The next activity consists of laboratory-based practical work (SAG M4.1) and/or a teacher demonstration which aims to provide students with evidence of "possible changes in mass: (i) as magnesium burns, (ii) as iron rusts" (LPM4). The key points are: "When a metal corrodes or burns it [sic] gains *mass*. Corrosion and burning involve reaction with *oxygen. When elements* react with *oxygen* compounds are formed. Reactions with *oxygen* are called *oxidation* reactions."

It should be noted that these key points imply that the concept of corrosion of metals is now *subsumed* under the general chemical concept of oxidation of all metals or even of all chemical elements. Earlier in lesson M3 the rusting of iron was subsumed under the general phenomenon of corrosion.[30] Students can only observe in these experiments

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[30] Garforth (FG92a:15) stresses the *gradual* development of a "generalised chemical concept of reaction, the generalised chemical concept of oxidation" starting with daily life phenomena such as the rusting of iron nails or the browning of apples.

that the starting material increases in weight and that there is a change in color and/or texture. They have no way of telling, though, that it is “something in the air” (LPM4), called oxygen, which reacts in a process called oxidation, with metals such as magnesium and iron to form compounds, called oxides. Hence, in the concluding third teacher-student discussion all this chemical knowledge must simply be transmitted to the students.

Corrosion, burning or oxidation

The teachers’ notes accompanying the third teacher-student discussion contain much which is worth commenting upon (see Figure 5.11 in which I use bold numbers in parentheses to refer to points discussed in the text immediately below the figure; my comments follow the figure). The outline of this activity reads: “Discussion should allow the production of word equations to summarize the processes of corrosion and burning and should reinforce the ideas about elements and compounds from M3” (LPM4). This should lead to the key point: “Elements can combine to form compounds, but they cannot be made to *weigh* less” (LPM4).

Figure 5.11 Teachers’ notes for teacher-student discussion three (Metals, 1989)

The reactions which have taken place can be summarized as word equations (underlining by developers). These also serve to reinforce the ideas covered in the previous lesson.

	magnesium	+	oxygen (1)	→	magnesium oxide (1)
i.e.,	element		element (2)		compound
	iron	+	oxygen (1), (3)	→	iron oxide (1)

Word equations summarize a process (4). They show the *starting* materials (the reactants) on one side of an equation and the *final* material(s), the products, on the other side. Sometimes more information is added to an equation by including state symbols as a subscript after the name of the substance.

State symbols are:	(s)	for solid
	(l)	for liquid
	(g)	for gas
	(aq)	for a solution of a soluble solid in water

e.g.	magnesium (s)	+	oxygen (g)	→	magnesium oxide (s)

Generally speaking, an arrow (→) is used when the equation is used to describe a qualitative reaction, whilst an equals sign (=) is used when the equation is being used to describe a reaction quantitatively (i.e. formulae are included, and the *equation* is *balanced* (5) in terms of reactants and products). These word equations show what happens when the *element is burned* (6), and *the reaction with oxygen* part (7) of the corrosion process. Reactions in which metals combine with oxygen are examples of OXIDATION reactions.

Comments

(**1**) In this lesson no evidence is presented to pupils for the part played in the process of corrosion or rusting by "something from the air", called oxygen. The role of *air* is introduced to students in lesson M3, and mentioned several times in lesson M4, up to and including SAG M4.1. At the end of M4, students are simply told about the existence, role and name of oxygen.

(**2**) There is no evidence presented for the claim that the metals mentioned (or the nonmetal oxygen) are elements. Students have to accept on authority, of text or teacher, the key point: "Elements can combine to form compounds, but cannot be made to weigh less"(LPM4).

(**3**) The role of water, crucial to rusting, is left out in this word equation (see also point 7). The developers illustrate here the point I made above about the implicit assumption of the concepts of rusting and corrosion under the general concept of oxidation. In brief, the specific and concrete CTS context *rusting* full*y* gives way to the general and abstract PC context *oxidation*.

(**4**) The (qualitative) word equations do "summarize processes", but by reducing the processes to the *states before and after* the actual chemical change. The chemical process itself is not represented in the word equation (see Chapter 2).

(**5**) The concepts associated with (quantitative) balanced equations such as formulae, state symbols, and equals signs do not seem to be needed at this stage for students to understand the processes of rusting/corrosion and burning (or even of oxidation).

(**6**) The phenomenon of burning seems to be extended or generalized from metals to *all* elements.

(**7**) In these word equations the complex processes of the corrosion of metals are simplified or reduced to the reactions of pure metals with just oxygen, thereby *making* corrosion processes *identical* to oxidation reactions.

Summary

In lesson M4 of the unit Metals (1989) the initial chemical-societal context of rusting of iron has almost completely given way to the classical purely chemical context of oxidation, covertly bridged by the ambiguous concept of burning. The lesson offers little by way of specific, local chemical-societal contexts. Thus, design criterion two, *relevance,* is not followed by the developers.

As for developers' adherence to design criterion three, *context-led development of concepts*, many of the chemical concepts introduced in M4 are related only globally and rather tenuously to the fundamental chemical-societal theme of corrosion. Therefore, the source of the justification for a number of the fundamental chemical concepts introduced, such as oxidation and balanced equations must lie elsewhere, perhaps in the perception the developers have of the structure of school chemistry, as commonly perceived or because of external constraints.

Except for the concepts of chemical change, the accompanying change in weight and word equation, most of the chemical concepts dealt with in lesson M4 do not arise naturally from, nor are they needed for, the study of the everyday situations such as the rusting of iron or the corrosion of metals. This leads to the conclusion that the lesson as a whole may not be needed.[31] The lesson lacks the sought for societal justification, and seems to be appealing largely to a chemical *conceptual-structural* justification (see section 5.2.8 for further discussion).

5.2.5 Analysis of lesson M5

The synopsis of lesson M5: DO ALL METALS CORRODE? reads:

> Students carry out a practical investigation to produce *an order of ease of corrosion* of metals. This leads into a consideration of *ways of preventing corrosion*.

This lesson begins, as did lesson M4, with an examination and recording of the results of the rusting experiment (SAG M3.1) performed by small groups of students. The rusting of iron is addressed here for the third time showing the importance of the unit theme *corrosion* in accordance with design criterion two, *relevance*. This time "each group should prepare a *written* report from their results" (LPM5) and "possibly *present* a report" (TNM5) to the class, which provides a good opportunity for students to practice valuable communication skills.[32]

As the synopsis indicates, lesson M5 focuses on a practical investigation by students into the differences in c*orrodibility* as a basis for their understanding of ways of *preventing corrosion*. The laboratory-based practical work (SAG M5.1) is preceded by a teacher-student discussion, in which the teacher reminds students of the display of corroded metals they saw in lesson M3, while pointing out that "differences in the *extent* of corrosion suggests that there might be *an order in ease of corrosion*" (TNM5). Subsequently, the teacher demonstrates (from a display of five metals) the reactions of sodium with air and *water*, which introduces students to the investigation of the "*corrodibility* of the remaining four metals [calcium, magnesium, iron and copper] by observing their action with *water*" (LPM5). So, students first witness that the freshly cut, shiny silvery surface of a piece of sodium "tarnishes as it reacts very quickly with the *air*" (TNM5). Secondly, in the spectacular reaction of a piece of sodium with *water*, they observe, that it "will melt forming a silver ball ... move rapidly across the surface of the water, fizzing as a gas (hydrogen) is produced ... may spark or burst into a yellow flame" (TNM5).

In the ensuing practical work students investigate the corrodibility of pieces of calcium, magnesium, iron and copper by observing the reaction of these metals with *water* (LPM5).

A few things should be noted at this point. First, the student investigation concerns the corrosion of metals in *water*, not in atmospheric air. Second, this lesson deals again

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[31] I found confirmation for this claim in the trial unit Metals (1984), which does *not* contain a lesson dealing with burning or oxidation. Metals (1987), however, does contain such a lesson but as an optional enrichment (M3X). This lesson became lesson M4 of Metals (1989), that is, it was promoted to a core lesson, which means that "the specific content" (OGT, p. 13) of this lesson now had to be *examined*.

[32] Metals (1987, LPM4) describes these skills as "communicating in writing [and] communicating orally". As we saw, the results of the experiments have already been summarized by the teacher in M4.

with *pure* metals, not with metal *objects*. Furthermore, as noted already in the analysis of lesson M1, some of the metals investigated, e.g., sodium, most students will not have met in everyday life nor will they (need to) meet them after their school chemistry days.

Students observe the reaction of small clean pieces of calcium, magnesium, iron and copper with cold tap water by inverting a test tube, fully filled with water and the metal, in a beaker filled with tap water (SAG M5.1). They observe and collect the emerging gas which they test using "a lighted splint", learning thereby to identify the gas as hydrogen. With the help of four questions (SAG M5.1), students are led to the conclusion that the *order of reactivity* decreases from the most reactive metals: sodium, calcium and magnesium to the least reactive ones: iron and copper (the latter two metals show no visible reaction with cold tap water). Or, as the key point of the following teacher-student discussion reads: "The order of decreasing *corrodibility and reactivity with water* of the metals is sodium, calcium, magnesium, iron and copper. This order forms a *reactivity series* for the metals".

Corrodibility of metal objects or reactivity of metal elements

The key point of this lesson, namely, the question of *an order in ease of corrosion* of metals (synopsis), a societal unwanted change of the surface of solid metals exposed to atmospheric *air*, is tackled here by an investigation into the *order of reactivity* of five metals in their reaction with *water*. Thus, the chemical-societal context of *corroded metals* again gives way to a classical pure school chemistry context, this time leading to the concept of *the reactivity series* and the revisiting of the concept of oxidation. The corrosion of metals with water is conceived as the chemical reaction of metals with the element oxygen in the compound water: "so it appears that the oxygen in water prefers to react with sodium" (TNM5).

Furthermore, the developers implicitly assume that the *order of reactivity* of metals found in the latter PC context, in reactions of metals with water, is also valid for the CTS context of corrosion, in reactions of metal objects with atmospheric air, that is, that the order of corrodibility of metals is the *same* as the order of reactivity of metals.[33] In Figure 5.12, I have summarized a number of *differences* between the process of corrosion, taken as a societal unwanted change of the surface of solid metals exposed to atmospheric *air* (CTS context), and corrosion taken as a chemical reaction of pure metals with water (PC context)

In brief, metal objects are reduced to metal elements, corrosion in atmospheric air is reduced to the reaction of metal elements with the element oxygen, and corrodibility is identified with reactivity. These *context switches* are not presented explicitly, but are introduced covertly. Thus, this lesson presents another example of developers leaving a CTS context for a PC context and then returning to the CTS context without much justification or explanation (cp. analysis lessons M2, M4).

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[33] Metals (1984) also states, as the outcome of the pupils' experiment of some metals reacting with *water*, that "metallic elements can be placed in an *order of reactivity*", adding the argument that "since corrosion involves *oxidation*, the order of corrodibility *is the order of reactivity of the metals with oxygen*". There seems to be a covert switch, first from equating reactions of metals with water to reactions of metals with oxygen, and then with reactions of metal objects with atmospheric air (corrosion). Metals (1987) states as outcomes of the class practical: "*The Reactivity Series, *Corrosion involves the reaction with oxygen*, *Gain of oxygen is called oxidation, *Metals (elements) form compounds when they react with oxygen" (asterisk and italics in original).

Figure 5.12 Corrosion in a CTS context and in a PC context[a]

Statements in a CTS context	**Statements in a PC context**
Unwanted change of surface metal objects in atmospheric air.	Chemical reaction of metals with oxygen (air).
Solid metal objects can be elements, alloys, or composite materials.	Metals are elements, solid substances which cannot be made any simpler.
Air and water cause iron objects to rust (corrode); salt increases rate of rusting.	Corrosion and burning involve reaction with oxygen.
Metal objects change color, texture, and weight during corrosion.	Corrosion of metals in air (oxygen) is same as corrosion of metals in water (oxygen).
Degree of corrodibility: metal objects differ in the extent and ease of corrosion (*a kinetic concept*).	*Reactivity series: metals as elements differ in their reactivity towards water (oxygen), a thermodynamic concept.*
A corroded metal object is formed, a combination of the metal object and atmospheric air.	A new substance, a compound of element metal and element oxygen, an oxide, is formed.
A heterogeneous change of solid metal objects in atmospheric (moist) air or in natural (e.g. salt) water.	*A heterogeneous change of solid metals in oxygen or in (pure) water.*
Prevention of corrosion addresses air, water, and salt (*or other ingredients of atmospheric air*).	*Prevention addresses only oxygen, if at all.*
A complex set of processes in which solid metal objects undergo unwanted societal changes, including catalytic changes.	A simple combination reaction of a metal element and the element oxygen, forming a compound called metal oxide.
No gas is produced; ingredients of atmospheric air are used, including gases.	Metals reacting with water produce a gas called hydrogen ; oxygen from the water is used.
A slow process, visible at surface e.g. rusting.	Can be very quick and violent, e.g. reaction of potassium in water.
Focus on the corroded metal object, and on how to prevent the corrosion thereof.	Focus on identifying escaping gas, hardly at all on corroded metal.
Corrosion of metal objects differs from case to case, e.g. copper tarnishing involves carbon dioxide and water.	Involves always oxygen and a metal.
Since corrodibility degree is a kinetic concept, aluminium is not an exceptional metal.	*Reactivity series is based on standard reduction potentials. The behavior of aluminum is taken as an exception to this thermodynamic rule.*
Relates to surface, texture, and internal crystalline structure of solid, e.g. nickel.	*Relates to bulk of pure substance, element.*

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[a] Some statements are taken literally or paraphrased from Metals (1989). Other statements, put in italics, are used implicitly in the treatment of the corrosion of metals there, or must be assumed as I have argued in the text.

In accordance with design criterion two, *relevance*, one would have expected that the "practical investigation to produce an order of ease in corrosion of metals" (synopsis) would have focused more on corrosion reactions proper such as the rusting of iron or the tarnishing of copper, that is, on the changes metals undergo when exposed to atmospheric air, e.g. students could have investigated the *order of corrodibility* of the set of corroded metals used in lesson M3.

In the last activity (SAG M5.2) called "Preventing Corrosion", students return to the CTS theme *corrosion* and learn to make sense of a number of methods for preventing corrosion of iron *objects*, such as painting, oiling, plating and alloying, that is, really for the preventing of *rusting*. They are asked to do this in terms of the causes of rusting they have learnt in lesson M3 (and reinforced at the start of M4 and M5), namely air, water and salt, and in terms of the *order of corrodibility* of metals. The method of alloying is introduced as follows: "Iron can be mixed with another element to form an alloy which *corrodes less easily*" (SAG M5.2). Apparently, for their understanding of ways of preventing corrosion or rather rusting, students do not need the concept of the order of reactivity of (pure) metals nor the concept of oxidation. These chemical concepts do not arise naturally from the study of everyday situations used, while the concept of the *order of corrodibility* of metal objects does.

As for the title of lesson M5: "DO ALL METALS CORRODE?", this question is addressed briefly in the last activity (SAG M5.2). There the technique of plating is introduced in which iron is coated with a thin layer of a metal "which does *not* rust" such as chromium. This implies that *not* all metals corrode.

Summary

Does lesson M5 have its origin and justification for study, fundamentally, in aspects of everyday life? The lesson begins by reminding students of the CTS contexts of rusting and corroded metals but quickly leaves these for a classical PC context of reactions of metals in water, a development which is hard to justify in terms of relevant CTS contexts. Lesson M5 does end with a CTS context, prevention of corrosion, in accordance with design criterion two, *relevance*, addressing the properties of metal objects students are familiar with in everyday life, or which they need to know. Thus, the lesson does not consistently develop the CTS contexts rusting and corroded metals along the lines of corrosion and corrodibility of metal objects.

Are the chemical concepts treated in lessons M5 needed for the study of everyday situations in accordance with design criterion three, *context-led development of concepts*? This appears not to be the case for the concept of the order of reactivity of metals nor for the concepts of oxidation, but it is the case for the concept of an *order of corrodibility* of metal objects and the techniques for preventing rusting.

5.2.6 Analysis of lessons M5X1 and M5X2

Lessons M5X1 and M5X2 are so-called *optional enrichment* lessons. These lessons:

> Provide possible extensions of some core lessons either by looking at *more background information* or by giving additional *examples of the development and application of concepts* introduced in the preceding core lesson. These lessons are *not* designed only *for the more able* students *nor* will the specific content of these lessons ... *be examined* on either written paper (OGT, p. 13).

I will return to the italicized points below when analyzing lessons M5X1 and M5X2 (see Appendix 5 for the full lesson plans of M5X1 and M5X2 and).

Lesson M5X1

The synopsis of lesson M5X1: HOW DO WE PREVENT RUSTING? reads:

> After examining the *ways in which a bicycle is protected from rusting*, students investigate the *effectiveness of commercial rust inhibitors*.

This first enrichment lesson offers two CTS contexts for the "application of concepts introduced in the preceding core lesson" (OGT, p. 13). The concepts applied are the process of rusting, the causes of rusting (water, air and salt) and the methods of preventing rusting (painting, oiling, plating and alloying). These concepts, as we saw, have been introduced and developed in lessons M3, M4 and M5. Two earlier applications of concepts learned by students concerned written work: the *making of a leaflet* on the hosing down of cars (SAG M3.1) and *completing a question sheet* on the prevention of corrosion (SAGM5.2). Lesson M5X1 takes this further by providing two CTS contexts in which students perform *practical* work.

Lesson M5 X1 begins with an everyday life context, namely, how to prevent the rusting (of parts) of *a bicycle*, whereas the sequel of the lesson is also devoted to a context in which chemical, technological and commercial aspects of a number of rust inhibitors are explored. The examination of a bicycle, to be carried out by students (SAG M5X1), is introduced as follows:

> You will be shown a bicycle whose frame, cranks, chain and gears are made of *steel*. If these are allowed to go rusty, *iron in the steel* will be *used up* in making the rust and the bicycle will wear out more quickly. Different parts of the bike have been prevented from rusting in different ways.

Students are then asked to "state how the parts are prevented from rusting and why the method stops the corrosion" (SAG M5X1), while using a table with the following headings: Part of bicycle, How is rusting prevented? and Why does this method stop the rusting? This examination brings home to students by way of practical work on a bicycle, an everyday life *object* or "machine" (LPM5X1) made of predominantly metal materials, that "rusting is prevented by excluding air and/or water" (LPM5X1). Thus, students meet here a very clear example of a familiar daily life metallic object, many parts of which are made of *alloy*s, especially of steel. In the context of preventing the rusting of metallic objects such as cars or bath taps through alloying students have been informed of the *fact* that "stainless steel is an alloy" (SAG M5.2). The developers add that "[d]uring lesson M6 you will be looking at the *properties* and *uses* of alloys".

As we have seen earlier, in lessons M1 and M2, students have met several other daily life metallic objects, such as sauce pans and drawing pins of which they learned to identify the *dominant* metal by way of simple chemical tests or analysis. As I argued there, the method of chemical analysis puts the emphasis on the concept of *pure* metals (pure substances), whereas in daily life, as is clear from examples such as a bicycle, the metallic parts are often alloys. Thus the concepts of mixtures and of alloys arise quite *naturally* from the study of everyday objects made of metal, more so than the concept of pure metals/substances. The former concepts should therefore, in accordance with design criterion three, *context-led development of concepts*, receive not only more emphasis but also earlier treatment in the unit Metals (see also discussion M6).[34]

It should be noted that the "*iron* in the steel" has to be present as the element iron, taken in the sense of a pure substance or "the simplest possible substance" (M3). After all, only the pure substance iron can be "used up in making the rust" (SAG M5X1.1).

The second part of this lesson consists of laboratory-based practical work for students set in a CTS context of "commercial rust inhibitors" (synopsis). The student activity, titled "DO 'RUST STOPPERS' WORK?" is introduced as follows (SAG M5X1.2):

> Many *makes* of rust stoppers are sold to *treat* rust on metal, usually in cars. In this experiment you are going to try to find which rust stopper works best.

In the experiment students file away a layer of tin off the sides of two tin cans and make three patches halfway each can.[35] Two of these patches are covered, each with a different rust stopper (seven commercial brands are mentioned), while one patch remains untreated. The cans so treated are put in a plastic bowl of salt water in such a way that the water covers half of each patch. Students then compare, each day for about a week, the treated and untreated patches, while using the unfiled parts of the tin cans as a control. In a presented table they write down "when each patch starts to rust" and "how rusty each patch is" (SAG M5X1.2).

Having completed their experiments, students are asked the following questions:

Q1. Which is your best rust stopper?

Q2. Which is your most expensive rust stopper?

Q3. Is this experiment a *fair comparison*? Could you improve upon it? Explain your answer.

Q4. Tin cans are made mostly from steel. Did the unfiled parts of the can go rusty?

Q5. Which parts of a car are protected from rusting by covering them with another metal?

Students can answer the first question on the basis of their observations which might include weighing the amount of (rubbed off) rust formed after a week (cp. lesson M4). The second question can lead into other economical and commercial aspects of rust prevention. For example, which rust stopper has the lowest price/performance ratio? And, whether 'rust stoppers' are really rust *stoppers*. If not, why are they called that way by their manufacturers, and not, for example, rust *inhibitors* as it says in the synopsis of

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[34] In the chapter Metals (section "In brief") of the student book (Hill et al., 1989, p. 7), the concept *alloy* is defined as follows: "An alloy is a mixture of two or more metals." It is added that "Alloys have different properties from any of the metals they contain."

[35] The tin layer on the iron can is very thin. Thus, in contrast with the analytical context of lesson M2, the (implicit) focus is here clearly on the 'recessive' metal (tin), not on the dominant metal (iron).

lesson M5X1. The third question leads into “the usual issues about the use of identical tins, identical thickness of rust stopper layers” (TNM5X1). Students practice scientific *process* skills such as “controlling variables [and] using a control” (Metals, 1987) needed to make a fair comparison of the rust stoppers. The developers further point out that (TNM5X1):

> ... students should be encouraged to think about the instructions for the use of the rust stoppers. Some commercial brands are designed to be placed onto clean iron and steel surfaces (as in this experiment) but others have *a different mode of action* and are painted onto *surfaces which are already rusted*. A *comparison* of the effectiveness of rust stoppers can only be *fair* if the instructions for use are identical.

Students will learn more about this other way to ‘stop’ rusting, that is, to slow down or to inhibit rusting in the next lesson (M5X2). The last two questions require no comment, except that students need to (learn to) make careful observations to be able to answer them.

Summary

The context *prevention of rusting of a bicycle* is a good example of a CTS context, in which relevant chemical concepts (rusting, its causes and methods of prevention; alloys, i.e., steel) acquired by students in earlier CTS contexts are applied. The same can be said for the context *rust stoppers* for which the first context forms an excellent preparation. Apparently, students do not need other chemical concepts in order to understand the ways in which metal objects such as bicycles or cars are prevented from rusting. The *process* skills *controlling variables* and *using a control* are needed to make a fair comparison of rust stoppers.

This leads to the conclusion that design criterion two, *relevance*, and design criterion three, *context-led development of concepts* are adhered to consistently in this enrichment lesson.

Lesson M5X2

The synopsis of lesson M5X2: DO OTHER METALS STOP IRON FROM RUSTING? reads:

> The *effect of the presence of another metal on the rusting of an iron nail* is investigated. The results are then related to the *order of corrodibility* of the metals, and their *use in protecting iron*.

The lesson begins with a teacher-student discussion. The teacher (TNM5X2) is advised to:

> Remind the students of the need *to cover iron* and *steel* to prevent rusting. *Tell* the students that other metals (such as zinc, tin and chromium) are often used to coat iron, though plastic is a cheaper alternative. Perhaps there is another reason for using other metals in addition to simply *covering the iron*.

Actually, students have already answered some questions related to the technique of coating iron with zinc, tin or chromium (SAGM5.2). They have gained *experiences* with tin coating in M5X1.2, and have previously met a few examples of coating or plating in M1 (tin coating) and M2 (e.g. copper coating). The teacher could also come back to the investigation on rust ‘stoppers’ (SAG M5X1.2), especially on those brands that can be applied to already rusty surfaces. This kind of rust ‘stoppers’ might contain, if and when inspected by students, as an important ingredient some other metal, which could lead students to the idea of a different mode of (inter)action than simply *covering* the iron.[36] Students could find out this way that in some 'rust stoppers' it is the metal ingredient which slows down rusting. Some students might even note that these metals belong to the more reactive metals in the *order of corrodibility* they have met in lesson M5. Thus, the previous chemical knowledge and experiences could be used to elicit ideas from students about the effect of some other reactive metals such as magnesium and zinc on iron rusting.[37] And this activity would also prepare students for the practical investigation which addresses the effect of some other less reactive metals such as tin or chromium on iron rusting.

In the laboratory-based practical work SAG M5X2.1 (or teacher demonstration) with the title: DO OTHER METALS STOP IRON FROM RUSTING,[38] the students (or teacher) investigate the rusting of iron in a salt solution in the presence of a second metal. They set up five test tubes which contain "clean" iron nails in a salt solution with "tightly wrapped" strips of a second metal around them, namely zinc (1), tin (2), copper (3) and magnesium (4). The students are instructed to look at the their test samples each day for a week, and to record their "observations each time in the results table" which has as headings "appearances of iron" and "appearances of the other metal" (SAG M5X2). Students are then asked:

Q1. Which metals *speeded up* the rusting of iron?

Q2. Which metals *slowed down* the rusting of iron?

These two questions are answered as follows in the TNM5X2:

> Copper and tin should speed up the rusting process. These metals are less reactive than iron.
> Zinc and magnesium slow down rusting process. These metals are more reactive than iron.

At the start of lesson M6, the students' results are discussed and generalized. This leads to the "explanation of the differences in behavior of metals in terms of differences in *corrodibility*" (LPM6), that is, to a macroscopic explanation. Students learn the phenomenological generalization: "Metals above iron in the reactivity series slow down rusting; those below iron speed it up" (LPM6).[39]

As noted above in Figure 5.12, the thermodynamic PC concept of reactivity series should be replaced, in the context dealing with corrosion and rusting, by the kinetic CTS

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[36] The teacher could also use the argument mentioned in the student book (Hill et al., 1989, p. 4) to elicit ideas from students: "The lumps of magnesium are obviously not covering the whole of the ship (...) and so they must be protecting the iron in another way."

[37] Maybe pupils could also be asked, at this stage, to make some suggestions about the *kind* of interaction between iron and the second metal, which must be different from simply covering the surface of the iron.

[38] Lesson MX6.1 of Metals (1984) is simply titled: "What is the effect of other metals?" This title leaves open the nature of the effect (positive, negative, or neutral) which would be more in accordance with an *open-ended* type of investigation (OGT, p. 62).

[39] Further explanations, in terms of the thermodynamic potential differences between metals or in terms of corpuscula (electrons, ions, and atoms), can be dealt with, if needed, in units of a further course which would build on the chemical knowledge acquired in lesson units such as Metals. For an example of corrosion phenomena in an experiential, electrochemical, *societal* context from which a corpuscular explanation *arises naturally*, see Acampo (1997).

concept *order of corrodibility* (see synopsis). The latter concept is developed from CTS contexts, is used in activities by students, and is all they need. The lesson ends by asking students the questions:

> Q3. A tin can is really an iron can coated with tin. In a damp atmosphere what would happen if some of the tin was scratched off one part of the can?
>
> Q4. Galvanized iron is coated with zinc. In a damp atmosphere what would happen if some of the zinc was scratched off one part of the iron?

By answering these two questions, students learn to apply their newly acquired corrosion 'law' to the chemical-societal contexts described in these questions. In the first case, that there is indeed another reason (besides simply covering the iron) for using the metal zinc. More reactive than iron, zinc *slows down* the rusting process. Secondly, other metals such as tin and chromium are, in fact, simply covering the iron surface and protecting thereby the iron for rusting. After all, when tin does *not* fully cover the iron, as in the case described in Q3, it will, being a less reactive metal than iron, actually *speed up* the rusting process.

Summary

Out of the investigation into the effect of the presence of another metal on the rusting of an iron object *arises naturally* the phenomenological generalization that *metals above iron in the order of corrodibility slow down rusting, while those metals below iron speed it up*. This generalization is all that students *need to know* to make sense of the chemical-societal corrosion phenomena related to the prevention and treatment of corrosion treated in the last three lessons of the unit Metals. Thus, also in this second enrichment lesson, design criterion two, *relevance*, and design criterion three, *context-led development of concepts* are adhered to consistently, except for the confusing reference to the PC concept reactivity series in the teacher student discussion.

Since lessons M5X1 and M5X2 are *optional enrichment* lessons, the specific lesson content is *not* to be examined (OGT, p. 13). It will therefore strongly depend on the teacher's views on school chemistry and on the constraints operating on her or him when teaching real children in a real classroom in a real school whether or not these optional lessons will be taught, and if so, in what form (section 5.4). This is much to be regretted, because, as we have seen above, these two lessons are good examples of *relevant*, *context-led development of concepts* and should therefore be really part of the *core* of the unit Metals, taken as a unit focused on the fundamental theme *corrosion*.

5.2.7 Analysis of lesson M6

The synopsis of lesson M6: WHAT ARE METAL ALLOYS? reads:

> (If the M5X lessons have been followed the results should be discussed at the start of this lesson). Solder is used to investigate *the effect of alloying on properties*. Students then use data on alloys to suggest appropriate alloys for particular *purposes*.

Lesson M6 begins with a teacher-student discussion, for which TNM6 suggest to:

> Introduce the word alloy: a *mixture* of two or more different metals or a metal to which carbon has been added. Mixing other metals or carbon with iron appears to *prevent rusting*, e.g. stainless steel (iron with chromium and nickel) cutlery does not *rust*.

This is the first time students are introduced to the *general* concept *alloy*. In lesson M5 they have been given a description of alloying specified to iron: "Iron can be mixed with another element to form an alloy which corrodes less easily. Stainless steel is an alloy." (SAG M5.2) In lesson M5X1 (if covered) students have investigated the prevention of rusting of bicycle parts made of steel (not specified which *kind* of steel). As we have seen in the analysis of lesson M2 (5.2.2), the introduction of the concept alloy was circumvented there by the introduction of the concept of *dominant* metal which was needed to make sense of the chemical identification of the *dominant*, *pure* metal in metallic objects such as paper-clips and staples.[40] Thus the essential role of other elements or ('recessive') metals for the properties of alloys is not discussed until the last lesson.

The introduction to SAG M6.1 reads: "Most of the metallic *materials* used today are *not pure metals but mixtures* of a metal with one or more other elements. These mixtures are called ALLOYS" (last emphasis in original). As I will argue, it would have been more in accordance with design criterion two, *relevance*, and design criterion three, *context-led development of concepts* to give the concepts of alloys an earlier and more central place in the unit Metals.

The next activity is a teacher demonstration showing "the bendability and brittleness of a paper-clip and a darning needle" made of *different* kinds of steel, that is, both iron based alloys. The key point of the demonstration is that "the *composition* of an *alloy* determines its *properties*" (LPM6). The presence of a small amount of carbon and/or other metals turns out to be crucial since it changes the properties of the object made of the alloy. For example, the alloy *mild steel* (iron and some carbon) is used to make a paper-clip which easily bends but is difficult to break. The alloy *stainless steel* (iron, chromium and nickel) is used to make a darning needle "which is difficult to bend but snaps cleanly if it does break" (TNM6). This is to be contrasted with lesson M2 where, in the context of the chemical identification of the dominant metal of a metallic objects, the effect of 'recessive' metals was neglected.

Lesson M6 continues with a second demonstration in which the teacher prepares the alloy solder by pouring molten tin (5 g) and molten lead (5 g) into a mould of sand. The casting of solder is compared with the castings of tin (10 g) and lead (10 g) in terms of two properties: their melting point and "the ease with which the samples are dented by a weight" (TNM6), a measure for their hardness. The key point of this activity is that "the melting point of a metal can be lowered by the presence of a second metal." (LPM6). Both teacher demonstrations stress the important chemical relationship that "the *composition* of an *alloy* determines its *properties*" (LPM6).

Let me note at this place, that it would have been more consistent with design criterion four, variety of teaching and learning activities, if the activities used so far would have been performed not by the teacher but by the *students*; and also in reverse order thereby

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[40] TNM2 refers to brass and solder, but students meet in these alloys only the dominant metals copper and lead. Looking back, one must also note that many of the iron objects students meet in the unit Metals, such as spoons (M1), paperclips (M2), and nails (M3, M5), are really made of one or another kind of steel.

increasing the active involvement of students. Thus, students *prepare* alloys, after which they *compare* the properties of differently composed alloys, followed by the formulation of the *definition* of alloys.

The last activity of this lesson consists in a homework suggestion for students (SAG M6.1) and concerns the completion of a question sheet, called "ALLOYS". The activity is introduced to students by three important statements. The first, as we already saw above, reads:

> Most of the *metallic materials* used today are *not pure metals but mixtures* of a metal with one or more other elements. These mixtures are called ALLOYS.

The concept of pure metals which students have met earlier (SAG M2.1) is not explicitly defined in the unit Metals. The implicit suggestion is that pure metals consist of one kind of element or maybe one kind of atom (see 5.2.2.). Another implicit reference to the concept of purity is made in TNM6 in the following answer to a question put to students about the production of iron:

> Iron produced in a modern furnace contains a very high proportion of *impurities*. This makes the iron brittle [breaks when struck with hammer].

What this quote brings out is that in a CTS context a distinction is made between apparently unwanted *impurities* as in the case of the 'iron' production in a modern blast furnace and wanted *'impurities'*, as in mixing iron with carbon forming steel. The distinction is made in relation to the *purpose or use* of the product formed. Steel is useful, brittle iron is not. The latter is impure iron, the former is 'pure' steel.[41] But, neither the steel alloy nor the 'iron' produced are pure metals. This seriously raises the question whether the concept of pure metal or pure substance *arises naturally* from societal or technological situations as the one discussed above.

The concept element has been defined as "the simplest possible substance" (LPM3). The concept of mixtures or alloys is defined both negatively, in terms of *not* being a pure metal, and positively as some kind of mixtures of pure metals. What *kind* of mixtures alloys are is not addressed. Are alloys homogeneous mixtures such as a solution of salt in water or heterogeneous mixtures such as wood or rocks or maybe something else? In view of the fact that many of the metallic materials used in daily life are mixtures, it would be worthwhile to explore with students the different characteristics of alloys, metal plated objects and the layers formed on corroded metals.[42] For example, is solder a homogeneous mixture, that is, a solution of one molten metal (tin) in another metal (lead) or maybe a compound with a particular composition? The second statement reads:

> The *elements in the mixture* and the *amount* of each element present affect the properties of the alloy so it is possible to make alloys which have *specific properties needed for a particular job*.

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[41] Another example is pure water. In a PC context this refers to a pure substance (compound or molecules) and in a CTS context to a potable mixture prepared according to societal specifications (De Vos, 1992).

[42] In lesson M3, students have investigated these in the form of rubbed off corrosions of the metals iron, copper, and zinc; or they have met these layers unwittingly, as in lesson M5X2, where they had "to *clean* all the nails and strips of metals", that is, in order to perform their experiments with uncorroded metals.

If an element is taken in the sense used throughout the unit, that is, as the simplest possible substance, retaining, as it would in a 'classical' school chemistry mixture, all its properties, it is hard to see how the elements in the mixture could affect the specific properties of the alloy.[43] After all, as has been shown for example in the teacher demonstrations in this lesson "alloys have different properties from any of the metals they contain" (Hill et al, 1989, p. 7); they are made for that purpose. It is to be noted that the latter definition of alloys is practically identical with the definition of a compound, that is, a combination of elements involving a concomitant change of physical as well as chemical properties of the reacting elements.[44] The weight of metals is conserved, while other physical and/or chemical properties are changed when an alloy or compound is formed. The third statement reads:

> Alloys are usually made by mixing together the *correct amounts* of each of the elements. The metals are *mixed* in their molten (melted) states.

The criterion of mixing *correct amounts* of each of the elements when preparing an alloy is quite similar to the criterion of the fixed *composition* of compounds. Thus mixing molten lead and molten tin gives a 'mixture' or rather alloy which has many characteristics of a compound. In accordance with design criterion three, *context-led development of concepts* one would have expected that the concept of *composition* which emerges as a crucial concept in the contexts of the comparison and the preparation of alloys, would have been given a more central and also earlier place in the unit Metals.

In the last activity of lesson M6, a homework suggestion, students complete a question sheet addressing the relationship between the *properties* of an alloy and the *use* of an alloy in daily life. In other words, to find out "the specific properties needed for a particular job" (SAG M6.1). A similar relationship between the physical and chemical properties of a *metal* and the use of a *metal* in daily life has been addressed in lessons M1 and M2 . In general, the relationship between properties of materials and their use, here of metals and alloys, is an important and recurrent theme of the Salters' Chemistry course fully in accordance with design criterion two, *relevance*.

Students are given a list of eight alloys (SIS M6.1) with their composition and properties. They are asked (SAG M6.1) to decide which alloy they would choose to make airplane wings, kitchen sinks, high speed drills etc. The key point of this activity is to learn that "the *use* of an alloy depends on its *properties*" (LPM6).

Summary

In accordance with design criterion two, *relevance*, one would have expected that the concepts of mixture, alloy and composition would have been developed earlier and more systematically from the CTS contexts presented in the lessons of the unit Metals. Further, one would have expected that once these chemical concepts are introduced they would be

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[43] School chemistry textbooks traditionally state that the substances which make up a mixture *retain* all their properties. A recent textbook states that the properties of mixtures are "*similar* to the substances which make up the mixture". The contrary claim can be defended, namely, that mixtures and certainly alloys, do *not* as a rule have all the properties of their components. For example, iron does rust, stainless steel does not, or the mixture gunpowder is explosive, but its constituents saltpeter, carbon, and sulfur are not (De Vos & Verdonk, 1990).

[44] Another school chemistry textbook (Ainly et al, 1987, p. 250) states, for example, that "[i]n some cases alloying produces marked chemical as well as physical changes".

systematically related to the daily life objects and contexts (e.g. bicycle, nails) met earlier in the unit Metals. Since the concept of pure metal does not arise naturally, it is not be needed here.

Lesson M6 introduces, in accordance with design criterion three, *context-led development of concepts*, both the important chemical relationship, the *composition* of an *alloy* determines its *properties*, and the important chemical-societal relationship, the *use* of an alloy depends on its *properties*. Similar relationships hold between a *metal*, its properties and its use (see M1, M2) which can be seen as a special cases of the relationships holding for alloys.

5.2.8 Chemical concepts developed as needed for context–based unit Metals

For the purpose of discussion, I will first summarize in Figure 5.13 the results of the consistency analysis of the content of lessons of the Salters' Science Unit, Metals (1989). While assuming a strong interpretation of the design criteria described in section 5.1.3, I will compare the written curriculum of Metals (1989), analyzed in sections 5.2.1 - 5.2.7 with the formal curriculum of Metals (1989) as presented in Figure 5.7. This will enable us to see to what extent the developers did adhere consistently to the adopted design criteria in the process of development of *lessons* of a unit of the such Salters' Science course such as Metals (1989).

Secondly, the extent to which the developers adhered de facto to the two *central* design criteria, *relevance* and *context-led development of concepts*, will lead us into a discussion of the first design criterion, *no preconceptions*. The focus of the discussion lies in particular on the role of first criterion, *no preconceptions* in relation to the way the developers used and / or perceived the conceptual structure of school chemistry.[45] In connection with this, I will also discuss to what extent the developers of the unit Metals(1989) escaped from Normal Chemistry Education, as it existed in England at the time.

The consistency analysis of the content of the eight lessons of the written curriculum Metals (1989) was performed while trying to answer the following two research questions related to design criterion two, *relevance*, and design criterion three, *context-led development of concept*.

- Does each *lesson* of the unit Metals have its *origin*, and hence its *justification* for study, *fundamentally*, in aspects of *everyday life*?
- Are all chemical concepts and explanations introduced in the lessons of the unit Metals *needed* for the study of these everyday situations?

Summary of analysis lessons of the unit Metals

In figure 5.13, a brief summary of the results of this analysis is given in terms of the contexts used in the lessons of Metals, the pure chemistry (PC) content and chemical-technological-societal (CTS) content developed from these contexts (see section 5.1.4).

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[45] The role of the fifth criterion, *flexible, teacher-mediated use*, will be discussed below (5.3.2), as will the role of the fourth design criterion, *variety of teaching and learning activities* (5.4.4).

The first column of Figure 5.13 lists the contexts, chosen by the developers for the lessons of Metals, either PC contexts e.g. chemical analysis or CTS contexts e.g. rusting.

The second column, *PC content needed and developed*, lists the chemical concepts, relationships and techniques used by the developers of Metals (1989), and needed according to my analysis, to make sense of the CTS theme of the unit, *corrosion*, and of the contexts used to introduce and explore this theme.

The third column, *PC content not needed, but developed*, lists those chemical concepts, relationships and techniques used by the developers of Metals (1989), and *not* needed according to my analysis, to make sense of the CTS theme of the unit, *corrosion*, through the contexts used to introduce and explore this theme.

Inspection of the third column shows that there are three main PC concepts which are developed and *not* needed, namely: *chemical analysis, oxidation and the reactivity series*. Some other PC concepts in this column, such as atoms, symbols and systematic chemical names, although introduced in the unit Metals are developed to a much lesser extent.

Thus, design criterion three, *context-led development of concepts*, has *not* been fulfilled in a *consistent* way. The PC content in the unit Metals is developed more than needed. In brief, PC content is *over*developed.

Figure 5.13 Summary analysis lessons Metals (1989), a unit of the written curriculum

Context Lessons	PC content needed and developed	PC content not needed but developed	CTS content needed and developed	CTS content needed and not developed
M1 lab survey; comparison metal/plastic; student survey; use of metals	about ten common metals and their names; physical properties	atoms; symbols (shorthand), names of most metals	metal items in the lab; use of common metals; economic properties; relation physical properties with use	familiar metal objects from surroundings; useful properties, e.g. spoons used for eating; alloys/mixtures
M2 chemical analysis, application in daily life	physical properties; chemical properties (differences); some metals more reactive	chemical analysis, tests, identification; pure metal; systematic chemical names		analytical route: composition alloys; relation chemical properties with use; kinetic reactivity
M3 investigation corroded metal samples; rusting	chemical reaction	pure metal; element as simplest substance; chemical compound; systematic names	corroded metals corrosion: chemical reaction surface metal; metal is used up; causes, rate of rusting	corroded metal objects from surroundings; recycling (element as conservation principle); alloys/mixtures

Figure 5.13 Summary analysis lessons Metals (1989), a unit of the written curriculum (continued)

Context Lessons	PC content needed and developed	PC content not needed but developed	CTS content needed and developed	CTS content needed and not developed
M4 corrosion burning; oxidation	chemical reaction; change in weight; word equation	burning,oxidation; states (initial/ final); role oxygen in rusting		chemical change/ reaction as a process; role water in rusting
M5 reactivity of metals in air/ aqueous solution; prevention corrosion	common metals: calcium, iron, copper, zinc, chromium; iron based alloy steel	reactivity series metals; oxidation reinforced; reactions of metals in aqueous solutions; some metals (sodium)	techniques for preventing rusting; causes rusting: air, water and salt are reinforced	place of iron in order of corrodibility metals
M5X1 investigation rusting bike; 'rust stoppers'	iron in steel alloy; controlling variables, using a control		causes rusting; preventing rusting; commercial aspects of produced materials	alloys/mixtures; element as principle of conservation of matter
M5X2 investigation effect of other metals on rate of rusting	common metals; controlling variables, using a control	reactivity series metals	order of corrodibility; more reactive metals than iron slow down rusting; less reactive metals speed it up	kinetic reactivity
M6 metal objects often alloys; steel alloys; preparation of solder	general concept alloy; macroscopic explanation differences in corrodibility metals		composition alloy determines properties; composition alloy determines use	alloys/mixtures; element as principle of conservation matter

The fourth column, *CTS content needed and developed*, summarizes CTS content needed, according to my analysis, to make sense of the corrosion theme which arises naturally out of the theme *corrosion* and its contexts. The fifth column, *CTS content needed and* <u>*not*</u> *developed*, summarizes additional CTS concepts which according to my analysis arises naturally out of the theme *corrosion* and its contexts, and which therefore seems to be needed to make sense of the latter: the composition of metal objects, the process of chemical change, and the order of corrodibility. These worthwhile CTS concepts or relationships could be expected to occupy a more central place in the unit Metals as reconstructed in the light of the results of the analysis performed in this section.[46] Thus, design criterion two, *relevance* and design criterion three, *context-led development of concepts* have not been fulfilled in a consistent way. The CTS content in the unit Metals is developed less than needed, or CTS content is *under*developed.

As we saw above, in the analysis of lessons M2 and M4, CTS contexts had to give way to PC content. Thus, the lesson analysis discloses in the unit Metals a *tension* between the PC content factually used and the CTS content actually needed conform design criteria two and three. The use of PC content in the development process clearly tends to dominate over the need to develop CTS content. CTS content being underdeveloped and PC content being overdeveloped, I conclude that the CTS/PC ratio of the written curriculum of the unit Metals (1989) has decreased by a fraction or two compared to the CTS/PC ratio of the formal curriculum of the unit Metals (1989), which is graphically illustrated in Figure 5.5 above. This conclusion remains the same whether we would choose as starting point for the CTS/PC ratio,**1/1**, categorizing the Salters' Science as a "SCIENCE ALONG WITH STS CONTENT" course, containing about 50% STS content and about 50% pure science content, or whether we would choose, with Campbell et. al (1994), as starting point for the CTS/PC ratio,**1/2**, categorizing the Salters' Science as a "SCIENCE THROUGH STS CONTENT" course containing about 30% STS content and about 70% pure science content (see section 5.1.4). In both case there is a substantial decrease in CTS/PC ratio moving from the formal to the taught curriculum level of the unit Metals.

No Preconceptions and the Conceptual Structure of School Chemistry

As I have argued above, the presence and use of the excess PC content developed in the lessons of Metals (1989) cannot be justified in terms of contexts related to the theme *corrosion*. So, why are these PC concepts developed in the unit Metals? Why are they included as "being worthy of study" as it says, for example, in Metals (1984)? Do the developers give, either implicitly or explicitly, another justification? Perhaps in terms of the *conceptual* structure of school chemistry as they perceive it? If they do, to what extent can we say that the developers have escaped from the tradition of normal chemistry education (NCE) as described in Chapter 2?

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[46] This additional CTS content can be seen as part of a proposal to *redesign* the unit Metals around the theme *corrosion*, to be consistent with the design criteria of the Salters' Chemistry course (cf. 5.1.5). This proposal for redesign evolves, as it were, 'naturally' from the consistency and reversed design analysis as undertaken in this section. In order to find out whether these suggestions are effective, the proposal must be developed in more detail and trialled in practice (see also section 5.1.4).

Comparison of successive units of Metals

At this point it is interesting to compare (Figure 5.14) the three units of Metals developed successively in the period from 1984 to 1989: the Salters' Chemistry trial unit (Metals, 1984), the Salters' Chemistry revised unit (Metals, 1987) and the Salters' Science Foundation unit (Metals, 1989). This comparison enables us to see whether the two earlier units of Metals (1984 and 1987) develop the same PC concepts and CTS concepts as the later unit (Metals, 1989).

We must also bear in mind that the successive units of Metals were developed under different external constraints. Thus, Metals (1989) had to comply with the rather strict requirements of the National Curriculum (DES, 1989), while Metals (1987) had to fulfill the National Criteria of Chemistry (1985) which "were not very prescriptive at all" (G92a:8). As for the trial unit Metals (1984), no specific external constraints operated on its development. However, the developers realized that a Year Three unit such as Metals "had to come out with some kind of basis for going on to O-level" (G92b:10). The developers added that "at that point *our* external constraints came in (…) we had to bear in mind what pupils who had gone through a *standard* chemistry course would in fact have been exposed to" (G92b:10).

Figure 5.14 Comparison of the main PC and CTS concepts developed in successive units of Metals

Metals (1984)	**Metals (1987)**	**Metals (1989)**
elements, symbols; Periodic Table	atoms, elements and symbols	atoms and symbols; elements
systematic chemical names	systematic chemical names	systematic chemical names
testing	chemical tests are better than physical tests; testing in solution	chemical analysis pure metal/substance
oxidation/burning: no lesson	oxidation/burning: optional lesson	oxidation/burning: core lesson
order of corrodibility/reactivity	reactivity series	reactivity series

Inspection of Figure 5.14 shows that, the same PC concepts which were developed in Metals (1989) were also developed in Metals (1984) and in Metals (1987), except for the concepts of oxidation and burning. The trial unit Metals (1984) did not contain a lesson devoted to the latter concepts, while in Metals (1987) they were addressed in an *optional* lesson, and in Metals (1989) in a *core* lesson, called: "A CLOSER LOOK AT CORROSION AND BURNING".

Metals (1987) has *three* optional lessons; two have a CTS emphasis and are taken over as such in Metals (1989). The other lesson, "A CLOSER LOOK AT CORROSION AND BURNING", has a strong PC emphasis, and has been promoted to a *core* lesson of Metals (1989). Thus, the arrangement of lessons in Metals (1987) seems to give more room for developing the fundamental theme *corrosion* than the arrangement of lessons in Metals (1989). For example, teachers could easily skip a PC lesson in Metals (1987), thereby making room for at least one of the optional CTS lessons.

Metals (1984), on the other hand, had seven core lessons and two optional lessons: "HOW CAN WE EXTRACT IRON?" and "WHAT IS THE EFFECT OF OTHER METALS?" Besides the latter lesson, which mentions explicitly the CTS concept *order of corrodibility* as a key teaching point, some of the core lessons of Metals (1984) seem to have a strong CTS emphasis too, for example, lesson five: "HOW CAN RUSTING BE PREVENTED?", a lesson which became optional as lesson M5X1 in Metals (1989). It appears, therefore, that the earlier a Metals unit has been developed, the more it has been possible for the developers to address CTS content in the lessons of the unit related to the CTS theme *corrosion*. In brief, CTS content decreases, while PC content increases in the consecutive units of Metals in the period from 1984 to 1989.

The comparison also shows that even in the early period which was relatively free of external constraints, the developers felt the need to introduce traditional PC concepts such as chemical analysis and the reactivity series which are, as we have seen, only tenuously related to the theme *corrosion*. This leads to the conclusion that these PC concepts have been introduced, not just under the influence of external constraints, but also under the influence of an 'internal' constraint, namely, the conceptual structure of school chemistry as used and/or perceived by the developers. When no prescriptive external constraints apply, the developers' perception of the conceptual structure of school chemistry often seems to function as a kind of internal constraint (see also Chapter 4). This *conceptual-structural* mechanism then determines to a large extent the introduction of PC content in the unit Metals, that is, chemical content which is not really needed for students to make sense of the corrosion contexts chosen. At the same time, some of the CTS content needed to make sense of the corrosion *contexts* remains underdeveloped, or is deleted.

Thus, the main result of the consistency analysis of lessons of the unit Metals (1989) performed in sections 5.2.1 – 5.2.7, namely, the incomplete and inconsistent operationalization of design criterion two, *relevance* and design criterion three, *context-led development of concepts*, might very well be attributed to the largely implicit role of the conceptual structure of school chemistry on the process of developing a new, relevant school chemistry course.

No Preconceptions

It is remarkable, certainly in view of design criterion one, *no preconceptions*, that the PC content in Metals is *over*developed and CTS content *under*developed. In brief, that PC content came to dominate the CTS content. Could it be that the developers have not been able to fully rid themselves of their preconceptions with regard to the structure of school chemistry?

Before we try to answer this question, it is important to remember that the developers came to make a distinction between two kinds of preconceptions.[47] As mentioned above (5.1.3), the developers came to stress a distinction between, on the one hand, the attempt *not* to have or use preconceptions with regard to the *coverage* of chemical concepts, and on the other hand, the need to have and use their preconceived ideas with regard to the r*elationships* between chemical concepts. John Lazonby put it as follows:

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[47] The following paragraphs have been written while taking into account the critical comments which David Waddington, John Lazonby, and Peter Nicolson have made on earlier versions of Chapter 4 (W97) and Chapter 5 (W2001) of this thesis.

> We had no intention of escaping from relationships between concepts, that is, we did not want to go against the order of concepts (personal communication, Lazonby, 1997).

But, as argued in Chapter 2, relationships between chemical concepts can refer either to:

- the *sequence* of chemical concepts, as used in teaching and teaching materials;
- the *logical* relationships between concepts, which together comprise the structure of school chemistry.

In the quotations used, the developers sometimes seem to refer to the sequence of chemical concepts as in “certain concepts require a *prior* understanding of other concepts” (personal communication, Waddington & Lazonby, 1997). In other quotations they seem to refer to the logical relationships between concepts, as in “not go against the order of concepts” (ibid.). The distinction between sequence and logic of concepts is clearly made and used in the following quotation taken from the Salters’ Chemistry Overall Guide to Teachers (1988):

> In some cases the *logical* development of concepts does dictate a teaching *sequence* (OGT, p. 22).

With this distinction in mind, we should ask two things. One, how did the developers use their preconceptions with regard to the sequence of chemical concepts current in school chemistry courses? Two, how did developers use their preconceptions with regard to the logical development of chemical concepts?

From the very start of the Salters’ Chemistry Project it is clear: the developers did not *want* to use their preconceived ideas about the traditional sequence of concepts (see Chapter 2). They were strongly against a “science first” (Holman, 1987) approach and sequence and very much in favor of an “applications first” (ibid.) approach. Having chosen a radically new starting point (design criterion two), the development of chemical concepts from daily life contexts and from applications (design criterion three) was bound to lead to a different sequence of chemical concepts in the units of the course.

Thus, in order to construct a new chemistry course *relevant for all* pupils, the developers intended, needed, and got a different sequence of concepts: context-led, ‘drip-feed’, and spiral. They conjectured that “[t]his spiral development may be more effective at establishing and reinforcing ideas, than the traditional, linear approach” (Holman, 1987, p. 437). At the same time, they realized that any sequence of concepts ‘discovered’ during the development of the Salters’ Chemistry units had to be based on, or at least be compatible with, the *logical* development of concepts. During the development process, the order of concepts, both sequential and logical, was monitored at a central control point (Chapter 4). The result made sense to the developers since it provided the necessary *coherence* to the course. At the end of the development of the Salters’ Chemistry course, at a second editorial stage, the *conceptual coherence* of the course was strengthened again, and also made accessible to teachers planning to use the course in the Overall Guide to Teachers (1988, pp. 22-29). Therefore, as the developers have emphasized themselves, they both intended and needed to use the *logical relationships between concepts*. As a consequence, they used and largely retained “the structure of chemistry as we all perceived it” (L92).

Conceptual structure of Dominant School Chemistry

The analysis above leads us back to the *logical* conceptual structure of *dominant* school chemistry as described in Chapter 2, in particular to the explicit and implicit relationships between chemical concepts this structure contains. In the following I will discuss in what way the developers of the unit Metals implicitly used, or explicitly appealed to, several of the these relationships that are part of the currently dominant school chemistry curriculum. I will thereby try to answer the two questions:

- To what extent did the developers used use the relationships contained in dominant school chemistry, represented in England at that time by the core chemistry syllabus?
- To what extent did the developers escaped escape, not only from the coverage and sequence of concepts, but also from the relationships between concepts present in Dominant School Chemistry?

Dominant School Chemistry, compared with the *coherent* conceptual structure of school chemistry, turned out to have quite an implicit, incomplete, and incoherent structure. As we saw (Chapter 2), it can be characterized by the following relationships:

– explicit demarcation from physics, common sense, and implicit demarcation from technology and society;
– implicit, incomplete, and incoherent relations between the concepts of chemical reaction, chemical, pure substance, and chemical element;
– reaction conditions often implicit, isolated, incomplete, and incoherent;
corpuscular theory dominates (e.g. symbolic notation, balancing equations), while the relationship of descriptive chemistry with theoretical chemistry lacks coherence.

The core chemistry syllabus (1979), mentioned in Chapter 4, is taken here as a representation of *dominant school chemistry* in England in the 1970s. It is from this core syllabus that the developers tried to escape while articulating and operationalizing a set of five design criteria in units such as the unit Metals (1989) analyzed in this chapter.

1. *Demarcation*

Design criterion two, *relevance*, entails a wish to escape from the demarcation or isolation of school chemistry by bringing in five relevant aspects: social, economic, technological, environmental, and industrial aspects (Metals, 1989). This intention is realized through the number of CTS contexts actually used in the Salters' Chemistry course, and in the standard PC content and CTS content actually developed from those contexts.

The traditional demarcation of physics as a school subject from chemistry as a school subject is not *explicitly* addressed in the design criteria or in the text of the unit Metals (1989). The unit does, however, implicitly introduce in lesson M1, the distinction between physical and chemical properties by starting with a set of some standard physical properties, to be followed (in lesson M2) by a set of chemical properties (tests, reactions) as is customary in traditional school chemistry textbooks. Lesson M2 mentions as *grounds* for this distinction, that "*physical* properties do not always differ sufficiently from metal to metal to allow *one metal to be distinguished from another*". This leads to the suggestion that "a more precise *identification* can be made through study of their *chemical* reactions" (TNM2). Since it can be argued that the distinction between physical and chemical properties loses its meaning in a CTS context, its introduction in lessons M1 & M2 might have been made on other grounds. A probable reason is the wish to introduce some simple qualitative tests needed for chemical analysis. Such chemical methods are needed to distinguish common metal objects by assuming they contain one dominant, pure metal. In brief, the distinction between physical and chemical properties is mainly introduced to underpin the PC concept of chemical analysis, and is only weakly justified in relation to the CTS theme *corrosion*.

It is to be noted that the most obvious *chemical* property of solid metallic or alloyed objects is not mentioned in the *analytical* context of lesson M2, namely, the corrodibility of different metal objects on attack by air; this in spite of the thematic and central role this chemical property takes on in the unit Metals. The chemical properties which *are* used in lesson M2 are certain chemical reactions, not of solid metals (of metal atoms at a surface), but of metals (ions) in dilute (aqueous) acid *solution* reacting with a sodium hydroxide *solution*. These reactions are important for purely chemical reasons, that is, to make possible a simple identification of the (dominant) metals present as elements in either metal objects or as metal ions in solution. They are not of primary importance in a chemical-societal context as are the corrosion processes of metal objects. Thus, analytical objectives seem to replace the attention given earlier, in lesson M1, to societal purpose or use of metals. It is for the purpose of chemical analysis that specific chemical reactions/tests are used. By contrasting physical properties/tests with chemical properties/tests the developers seem also to appeal implicitly to the demarcation of school chemistry from school physics.

2. *Relationships between the concepts of chemical reaction, chemical substance and chemical element*

The introduction of a simplified method of chemical analysis involves a complex *analytical route* from texture/surface to a sample in solution, to pure substance, to a closed group, to precise identification (5.2.2). The concept of chemical analysis is really a cluster of related chemical concepts, the most important of which are chemical or pure substance, chemical reaction, and chemical element. Thus by introducing chemical analysis, the developers appeal implicitly to the latter concepts, including some of their relationships. The concepts of chemical reaction, chemical compound, and chemical element ("simplest possible substance"), receive systematic and explicit attention in lesson M3. The concepts of pure metal and substance, and the concept of element, as a principle of conservation of matter, remain implicit, as do the *logical* relationships which pertain between the concepts of chemical reaction, pure substance, and chemical element. As argued in Chapter 3, the concepts chemical reaction and pure substance presuppose each other; while the concept of chemical element requires both these basic concepts. Thus, the context of the identification of common metal objects, taken as consisting of dominant metals, leads to the introduction of a simplified method of chemical analysis which in turn involves a partly implicit use of a number of basic chemical concepts and their relationships present in dominant school chemistry.

The introduction of the concept oxidation is also meant to "reinforce ideas about elements and compounds from M3" (LP M4). Again the developers appeal implicitly to some of the relationships between the concepts of chemical element, compound (pure substance), and chemical reaction. For example, in the context of oxidation reactions, students learn that a metal "gains mass" (LP M4). When a metal burns or corrodes, it forms a new substance or a compound. On the other hand, as we have seen in lesson M3, when a metal corrodes "some metal is used up". Further, metals being elements "cannot be made to weigh less" (LP M4). Thus, metals seem to weigh more, less, or the same during corrosion. This paradox can only be resolved by observing the distinction between elements/metal in the sense of non-decomposable pure substances and elements/metal in the sense of a principle of conservation of matter. In de the latter sense metals are conserved; in the former sense metals are used up during corrosion while the resulting compound weighs more than the metal initially present. Again, the concepts of pure substance and elements are not addressed explicitly, nor are the relationships between chemical reaction (oxidation, burning) and pure substances (chemical compounds, oxides), and chemical elements (oxygen).

Thus, by introducing the concept oxidation in the context of corrosion of common metals, a daily life context in which the role of air would have sufficed, the developers of Metals (1987, 1989) appear not to have escaped from (i) covering this classical topic of school chemistry; (ii) the chemical concepts involved, and (iii) the partly implicit and/or inconsistent relationships as characteristic for Dominant School Chemistry (Chapter 2).

3. *Reaction conditions*

As we saw in Chapter 3, school chemistry textbooks address the reaction conditions in an isolated, incomplete, implicit, and incoherent way. As I will argue below, the same applies to the Salters' Chemistry Course. The argument is based on a document analysis of the formal, written curriculum (OGT and SLB), and on the results from the analysis of the unit Metals (1989) and of relevant parts of some Salters' Chemistry units such as Minerals (1987).

The first reaction condition, element conservation, is not dealt with in the unit Metals (5.2.2), or in other units of the Salters' Science course, such as Mining and Minerals (1990 – an adaptation of Minerals, 1987.) As in Metals (1989), the concept *element* is treated as "a substance which cannot be split into simpler substances" (LP MM1). It is not treated as a principle of conservation: not in the context of extracting iron from its ores as in the blast furnace (MM6), not in the context of extracting aluminum from bauxite (MM7), nor even in the contexts of the recycling of glass, plastics and metals (Hill et al, 1989, pp. 76, 120). As argued above, while extracting or recycling metals, the metals (conserved) in the ores or scrap metals reappear as *elements* in the sense of simple substances. In the preparation of alloys such as bronze or solder (M6), the reverse is the case: reacting metals (elements) disappear as simplest substances to form alloys with different, useful properties, while the metals taken as elements, in the sense of a principle of conservation of matter, are preserved.

The second reaction condition, the decrease of Gibbs energy during a chemical reaction, as well as the third reaction condition, kinetic activity, are not addressed explicitly in England before upper secondary level, that is, not before A-level. For example, this condition is addressed in Salters' Advanced Chemistry, under "Chemical Ideas" (1994, p. 6), in terms of the total entropy change (which must be positive in order for a chemical reaction to proceed). On the other hand, the developers of Metals (1989) appeal to the second reaction condition *implicitly* when they introduce the reactivity series, because that concept is derived from thermodynamic data, namely, from standard electrode potentials. This is done explicitly in, for example, the Salters' Advanced Chemistry course Chemical Ideas (1994, p.164), where it says: "with the most positive potential at the bottom, the series is called the electrochemical series", while giving a series of metals (Mg, Zn, Cu, Ag) that coincides with the reactivity series introduced in

Metals (1989).[48] Thus, the concept of *reactivity* used in the reactivity series is a thermodynamic concept, not a kinetic one. It is only against this *thermodynamic* background that the behavior of such metals as aluminum or tin, and also in everyday life contexts, must be seen as exceptions to the thermodynamic rule.

As Ainly et al. (1987, p. 168) explain in their textbook for the new 16+ examinations, when dealing with the reactivity series of metals: “the positioning of aluminum is not straightforward as the metal is covered with a layer of aluminum oxide which is very resistant to attack”. They continue, “observations of reactions of aluminum would lead you to think that it ought to be placed lower in the series” (ibid., p. 168). So, the reactivity series does not portray an order of actual or kinetic reactivity, and therefore, it cannot, without further explanation or assumptions, be equated with the actual order of corrodibility, which is a kinetic as well as a chemical-societal concept.

By introducing the concept of the *reactivity series* in the context of corrosion of common metal objects (a daily life context in which a kinetic concept of corrodibility would have been appropriate in accordance with the design criteria), the developers do not appear to have escaped from the thermodynamic concept of *reactivity* as formulated in the second, thermodynamic reaction condition.

Finally, there is a zero condition for most reactions (except for decompositions) which seems almost too obvious to deserve separate mention, namely, that chemical reactants should be in *contact* with each other. This condition is easily fulfilled for reactants in aqueous solutions or for reacting gases, but can be quite difficult to realize for solid reactants. In lesson M6, there is an implicit reference to the condition of contact, where it says (SAG M5 X2.1) to “wrap the end of the strip of zinc [or tin, copper, magnesium] *tightly* round the middle of another [iron] nail”. It is also an important condition for reactions which occur at solid/gas or solid/liquid interfaces, such as corrosion, and for understanding the prevention of corrosion by *covering* the solid metal surface with paint, grease, or another metal.

To sum up: The zero condition of contact between reactants, the first reaction condition of conservation of elements (metals), and the third kinetic reaction condition are all needed or can be justified in the contexts of corrosion and the recycling of metals, but the second, the thermodynamic reaction condition, *cannot be justified* because is not needed to make sense of the corrosion phenomena studied at this stage. In so far as PC concepts are not needed to make sense of chosen daily life contexts of corrosion, but are still developed either explicitly or appealed to implicitly (concepts such as the reactivity series, chemical analysis, and oxidation in Metals, 1989), one can say that the developers *do not escape* from these chemical concepts and the relationships they entail. The developers operate, as it were, under an *internal constraint* consisting of the relationships between chemical concepts as they perceive them, that is, by the conceptual structure of school chemistry to which they are accustomed. It is apparently very difficult to escape from this *internal constraint*.

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[48] Hill et al. (1989, p.171) state that there is a “similarity between the electrochemical series and the reactivity series”, while describing the former in terms of cell voltages.

4. *Role of corpuscular theory*

As we saw above in lesson M1 of Metals (1989), it is explicitly stated that the symbols for metals refer to "<u>one atom</u> of the metal" (TNM1). In lesson M4, in the context of balancing equations, there is a reference to formulae, that is, chemical formulae in terms of number and kind of atoms. But apart from these two allusions, Metals (1989) does not refer or develop corpuscular concepts, nor does it develop, therefore, the relationship between macroscopic and corpuscular concepts. Rather, in these lessons there is strong emphasis on empirical, macro relationships:

(i) relationship between the physical or chemical properties of metals/alloys and their uses (M1, M2);
(ii) the causes or factors which influence rusting (M3, M4, M5);
(iii) the trend of decreasing corrodibility (reactivity) within the series of metals (M5);
(iv) the generalisation that metals above iron in the reactivity series slow down rusting, metals below iron in the reactivity series speed up rusting (M6);
(v) the composition of an alloy determines its properties (M6); the 'identity' or elemental composition of a metal determines its properties (M2).

Thus in the sense described above, the developers of Metals (1989) escape almost completely from the traditional dominance of corpuscular theory in school chemistry by *not* introducing, in the chemical-societal context of corrosion, either corpuscular concepts or the relationship between macroscopic and corpuscular concepts.

Concluding discussion

I agree with the developers, that it is *not* possible for teachers or developers "to *forget* all they [know] about how an understanding of certain concepts *require* a *prior* understanding of other concepts" (W97). As I argued in Chapter 3, teachers and developers of school chemistry curricula should be fully aware of the chemical concepts and the *particular temporal* relationships between them which are implicit in current textbooks or in the teaching materials that they have *chosen* to develop or use for teaching school chemistry. Furthermore, teachers and developers of school chemistry curricula should also be fully aware of the *logical relationships* that hold between the chemical concepts used in school chemistry curricula. Finally, it is important for teachers and developers to realize that several *temporal or teaching sequences* are compatible with the same logical conceptual structure of school chemistry. Thus, teachers as well as developers need to have detailed knowledge of the *coherent conceptual structure of school chemistry* in order to use this knowledge consciously and selectively, especially for the design of new school chemistry curricula that deviate radically from traditional school chemistry. The vision or design criteria of the new school chemistry curricula will determine the choice of chemical concepts and the *temporal and logical* relationships between them needed to realize these aims.

Waddington remarks that "in a couple of instances *slightly different relationships between concepts* did emerge" (W97) during the development of the units for the Salters' Chemistry course. For example,

> A macromolecular model for polymers which was used to 'explain' some physical properties *prior* to pupils meeting atomic structure and theories of bonding; and it was realized that the calculation of reacting quantities could be justified and done without introducing the *mole* concept.

In the first example, the physical properties of polymers are explained, not as in traditional courses by recourse to atomic theories, but by a *newly* introduced low level macromolecular model of polymers (another example is the deletion of the concept of the *Periodic Table* mentioned in Chapter 4). In the second example mentioned here, the decision is made *not* to use the traditional chemical concept, the *Mole*, usually present in school chemistry courses. Hence, sometimes the development of logical relationships between chemical concepts is not needed to make sense of the selected contexts, *just as* it is not necessary for the development of some chemical concepts. The examples the developers give here bear out what is argued above, namely, that it is the chosen CTS emphasis, theme, and contexts which will determine not only which concepts, but also which *temporal and logical* relationships between chemical concepts, are justifiably needed in teaching, and which concepts and logical relationships are not needed to make sense of the selected daily life contexts. In view of the analysis (Chapter 2) into the structure of school chemistry, this is not unexpected. Basic chemical concepts, for example the concept of *chemical reaction*, entail logical relationships with other chemical concepts, namely the concept of a pure or chemical substance and the concept of a chemical element. To sum up, in a few cases the intention of the developers to have no preconceptions with regard to the coverage of concepts was extended to the logical relationships these concepts have to each other.

When we take a strong interpretation of the Salters' design criteria, this means that only those *concepts and relationships* should be used which are needed for the chosen contexts, that is, concepts and relationships which arise naturally from the study of everyday situations, consistent with design criterion two, *relevance*, and with design criterion three, *context-led development of concepts*. In view of this discussion, the latter design criterion must be taken to refer to both the *context-led development of chemical concepts* and the *context-led development of relationships between chemical concepts*. In brief, design criterion one, *no preconceptions*, should extend to coverage, sequence, and logical structure.

Developers' adherence to design criterion one, *no preconceptions*, did clearly result in their escape from the traditional *linear sequence*. Their escape from the traditional coverage of concepts and relationships, whether they intended to, as with concepts, or whether they did not intend to, as with relationships, was less complete. Of course, this must be attributed to the force of external constraints working on the developers, but only partly, as we saw. A most important cause lies in the *internal* constraint the developers chose to follow. As Waddington put it :

> There is a much more powerful reason if you find that we have not escaped from your web [i.e. my curriculum framework] – ourselves and our own history (W97).

This statement appears to confirm remarkably well, Garforth's conjecture which she made just before the start of the Salters' Chemistry Project:

> Equally it may be that by our own schooling, subsequent training, and teaching we cannot see anything different adequately filling the space called chemistry at this level (Garforth, 1983, p. 29).

Reflection on the unit Metals: the developmental process

In section 5.1.1, I argued that the unit Metals can be seen as a representative unit within the set of Salters' Science units, as designed by the developers following a number of selected design criteria. This does not exclude, of course, that a consistency analysis of other Salters' Science units would not reveal a smaller degree of slippage. Nevertheless, I think the analysis points to an important phenomenon of which, especially in the *process of design and development*, a project must take serious account.[49] As noted above (Figure 5.14), the phenomenon of slippage can occur even when external constraints are weak. It is a curriculum phenomenon which must be attributed for an important part to an internal constraint, here called the *NCE-reflex*.

5.3 The interpreted and taught curriculum of the unit Metals

In this section I describe and analyze the process of transformation of a unit of the formal curriculum, the Salters' Science unit Metals (1989). The changes made to the unit of the formal curriculum by the Department of Science of the school I visited in Yorkshire, England led to the unit Metals (1992), a unit of the *interpreted* curriculum, based on the Salters' unit Metals (1989).

Metals (1992) was used in the science classroom in the form of a study guide or student booklet by the chemistry teacher, also heading the Department of Science at the time, and became the point of departure of the taught curriculum.

The analysis will focus on the design criteria *relevance*, *context-led development of concepts* and *flexible teacher-mediated use*. The aim is to find out to what extent a teacher, congenial to the Salters' philosophy, is able to teach the interpreted curriculum in accordance with these Salters' design criteria, to students in one particular class and school.

I will begin by giving the reasons for my choice of this chemistry teacher and school (5.3.1). Secondly, I will describe and analyze the interpreted curriculum of the unit Metals (1989), *as interpreted* by the science teachers of this particular school, by analyzing the lessons of Metals (1992), a student booklet based on the Salters' Science Foundation Unit Metals (1989), but adapted to the goals of the science staff at the time. For that purpose I will also use the interview I held with the chemistry teacher who agreed to participate in the classroom based research (5.3.2).

Thirdly, I will analyze and discuss the actual lessons of the unit Metals (1992) as *taught* by the participating chemistry teacher, that is, the taught curriculum of this chemical unit of the Salters' science course. This time, I will look into the process of transformation of the interpreted curriculum into the taught curriculum of the unit Metals (1992), on the basis of audio tapes of the teacher-student discussions, classroom observation and teacher interviews (5.3.3).

Fourthly, I will summarize and discuss the results of the analysis in section 5.3.4.

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[49] Another example occurred in the Dutch "Techniek 15+" Project (De Beurs et al., 2003, p. 27) aimed at the development of units providing upper secondary students (aged 15-18) with learning experiences of the 'cycle' of technological design. In the initial phase of the project some of the developers used more science content than students would need for the design of the artifact in question.

5.3.1 Choice of teacher and school

In section 4.1.2, I explained the rationale for choosing Salters' Chemistry as an object of study, and in section 5.1.1 for performing a qualitative case study based on the classroom-based research of a chemical unit of the Salters' Science course, Metals (1989). I will now give my reasons for the choice of chemistry teacher and school participating in this study.

In 1992, Lida de Gier performed, as part of her teacher training, a small classroom based research study on the teaching of chemical units of the Salters' Science / Chemistry course. Her pilot study (De Gier, 1992), for which I acted as supervisor, prepared the way for my own more extended case study research of the unit Metals (1992) at the same school.

The participating chemistry teacher had been involved for some time in innovation projects, in particular, with regard to the elementary chemistry course for Year Three. What is relevant, too, the school had acted as a Salters' Project School in the years 1985 – 1987, trialling units of the Salters' Chemistry course. Prior to the De Gier's pilot study the school had hosted the research project of Christie Borgford (see further section 5.4.4). Hence, the chemistry teacher agreeing to participate in my research study was not only willing, but also accustomed to having an educational researcher in his classroom. He could thus be expected to act naturally in his classroom teaching during the research period, hardly being disturbed by the research setting.

Furthermore, since the teacher was familiar with the Salters' approach to chemistry teaching, he could be expected to teach the adapted unit Metals (1992) in accordance with the Salters' educational philosophy as characterized by the Salters' design criteria described in Chapter 4. Thus, this teacher would probably emphasize as much as possible relevant contexts and the CTS concepts needed to make sense of them. A chemistry teacher with a neutral or reluctant attitude to the Salters' approach, on the other hand, could be expected to teach Salters' units with a focus more on traditional PC concepts, adding on some CTS content only if thought expedient. In other words, the former kind of teacher will probably make an attempt to break away or escape from NCE, while the latter kind of teacher would have no such motive. As such the former kind of teacher would be the more relevant to observe in the classroom, the findings would probably say more about the conditions for a successful escape of the teacher.

Since the Salters' Science courses aim to provide science education to students across the full ability range, it was appropriate that the research would take place in a comprehensive school. Finally, on a more practical note, the school was located in Northern England, within commuting distance of the University of York, the venue I wanted to use to interview the developers and study relevant teaching materials produced by the University of York Science Education Group (UYSEG). Both the teacher, acting also as Head of Science, and the Head of the School were informed beforehand on the precise nature and duration of my research project, while anonymity of the collected data was assured to all participants involved: students, teachers, and school.

5.3.2 Interpreted curriculum

The changes made to the unit of the formal curriculum, Metals (1989) by the Department of Science of the school led to the student booklet, Metals (1992), a unit of the *interpreted* curriculum. The latter unit was one of the chemical units of a new science course which used at its starting point twelve units from the original twenty-one Salters' Science Foundation Units (1989). The new science course was developed "in order to make the change to balanced science up to GCSE level" (Hill, 1991, p. 4) as it was put by one of the science teachers of the school, and as required by the National Curriculum (1989). The resulting course was taught for a period of two years, from 1989–1991, by the science staff of a comprehensive 13 – 18 upper secondary school situated in North England.

In order to promote "self-motivated learning" (ibid., p. 5), students were given so-called study guides (student booklets) based on the Salters' Science Foundation Units "with some *additions* by our staff to guide them from one activity to another" (ibid., p. 4). The two upper bands of pupils "are told that they were going to *work like real scientists*" (ibid., p. 4) while using these study guides[50]. The pupils did form groups of three and were divided into four laboratories with four members of staff and the appropriate apparatus. Since everyone and everything had to rotate in this system, this new and radical approach to teaching science using Salters' Science units received in the school in question the nickname the "Circus".

Prior to the "Circus" (1989–1991), the *chemistry* teachers of the school had taken initiatives to become a trial school for the Salters' Chemistry GCSE course (1985-1987). In fact, the positive response from science staff and pupils to this trialled chemistry course led to the idea of using Salters' Science Foundation Units for the teaching of the Circus approach. As the teacher said in the interview, "the Salters' philosophy of guiding each unit with relevant and important questions, with *realistic* experiments and with varied teaching styles" (T92) was taken over. The changes the teachers made to the unit Metals (1989) were to encourage and support self-study by students using the student booklet Metals (1992), a compilation of Student Activity Guides (SAG) and Student Information Sheets (SIS), largely taken over from Metals (1989). Teacher demonstrations of Metals (1989), though, were *replaced* by student activities, mostly by laboratory-based practical work in Metals (1992).

As in section 5.2, in the analysis of the lessons of Metals (1989), I will try to answer here too, in the analysis of the lessons of the unit Metals (1992), the two questions stemming from design criterion two, *relevance*, and design criterion three, *context-led development of concepts*.

- Does each lesson of Metals (1992) have its *origin* and *justification* for study, *fundamentally*, in aspects of *everyday life*?

- Are all chemical concepts and explanations treated in the lessons of Metals (1992) *needed* for the study of these everyday situations?

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[50] The lower band of pupils, the less able pupils, followed special courses such as Working with Science (1978).

The student booklet Metals (1992) contains the same number and sequence of lessons as the unit Metals (1989), while largely the same order of activities is followed. There are some changes in the student booklet Metals (1992), either additions to or deletions from the formal curriculum unit Metals (1989). I will use in this section for Metals (1992) the same codes for the lessons and activities as in section 5.2 for Metals (1989) - the context of the discussion will make clear to which unit I refer. The lessons of the unit Metals (1992) are introduced as follows:

> In this unit you are going to think about metals: how *important* they are, the link between kinds of metals and their *uses* and the problems of *corrosion*. Remember when you think you have achieved a *skill* to have your work checked by the member of staff and the box initialed (Metals 1992, p. 1).

The first part of this quote follows the contextual theme of Metals (1989) on the importance, use and corrosion of metals (see Figure 5.6). This theme is already set by the cover of the student booklet which depicts the industrial process the winning of iron starting from ore to the production of metal objects used in daily life such as nails and hammers. The second part of this quote refers to the emphasis on scientific skills (and processes) required from students working "*like real scientists*" in the Circus, an emphasis well tuned to the National Curriculum (1989), mandatory for schools from 1990 onwards. The following *skills* are explicitly mentioned in the lessons of Metals (1992) for students to have checked by a member of staff: *drawing conclusions* (M2), *making accurate observations* (M3) and *using apparatus safely* (M4).

In terms of Roberts (1982) one could say that the science staff of the school was putting a SCIENTIFIC SKILL DEVELOPMENT emphasis or interpretation ('science as process' approach) on the original EVERYDAY APPLICATIONS and SCIENCE/TECHNOLOGY DECISIONS emphases of the Salters' Science Foundation Units (see Figure 3.4). Thus, right from the inception of the student booklet, Metals (1992), there seems to be a dual emphasis, on the one hand, on daily life contexts and, on the other hand, on scientific skills or processes. On the basis of two years experience with the Circus approach Hill (1991, p. 5) remarks that "the mixture of Salters' Science and self-motivated learning is a happy and productive one". The question here is to what extent this claim is supported by the research reported on below.

Before answering this question, I will first describe and analyze, for each lesson of Metals (1992), the addition or deletion of CTS contexts used, and of PC content and CTS content developed from the selected contexts in comparison to the formal curriculum unit, Metals (1989), as analyzed in section 5.2.

Changes in lesson M1

Activity M1.2 of Metals (1992), "Hunt the Metals", a word search puzzle, contains an additional assignment, namely: "Write down the 16 metals you find in this table [puzzle] in your notes and after each one write its chemical symbol" (Metals, 1992, p. 4). This assignment directs the attention of the students to the relationship between the metals (and their names) and their symbols, that is, to a PC relationship. The activity M.1,"Symbols for Metals", contains an extra assignment with regard to the list of seventy symbols for metals:

> The metals which are asterisked are those which you will meet most often in this unit. For each one of those write down a common everyday use (ibid., p. 7).

This time the focus is on the relation between common metals and their use, a CTS relationship.

Deleted from lesson M1 of Metals (1989) are: the laboratory survey in which students list things which they think are metals and the ensuing teacher-student discussion, the optional student activity, and the teacher-student discussion on metals and properties familiar to pupils.

The addition of the first two assignments does not change the balance between PC content and CTS content in Metals (1992) but the deletions of the aforementioned activities does, namely, in the direction of using more PC content and less CTS content (see also Fig. 5.15 below).

Changes in Lesson M2

Again, there are two additions, this time to lesson M2 of Metals (1989). First, at the end of the laboratory-based practical work (M2.1) students are asked to:

> Construct a table from your experimental results which can be used as an information sheet for the Special Investigation below (ibid., p. 9).

The *active* construction of such a table should help students to act as scientists in *drawing conclusions* from the practical work about the identification of metals in common objects.

Secondly, the special investigation at the end of the lesson contains the extra assignment:

> Try not only new drawing pins but also ask the member of staff for a solution of nitric acid in which *worn* drawing pins (emphasis theirs) have been dissolved" (ibid., p. 9).

As the teacher later explained in the interview, the purpose of this additional activity is to show that in both cases, whatever the appearance of the pins, iron can be identified as the dominant metal since "the coating does not show up at all" (T92). Thus, one of the choices involved in the analytical route going from sample to dominant metal is explicitly addressed here (see section 5.2.2). The added experiment justifies the neglect of any 'recessive' metals present, and clarifies thereby the CTS concept of dominant metal. The addition of these two assignments hardly changes the balance between PC content and CTS content in lesson two of Metals (1992).

Changes in Lesson M3

This lesson contains two major additions, that is two *new* activities, labeled M3A and M3B. The first activity, "What happens when metals corrode?", is a practical activity. The second activity, "Elements, Compounds, and Corrosion", deals with the *theory* of oxidation in relation to the corrosion of metals, especially iron. It is a text added for students to read as an alternative to the teacher-student discussion which was part of lesson M3 of Metals (1989).

In accordance with the self-motivated learning approach of the Circus the teacher demonstration of Metals (1989) is *replaced* by the student activity M3A in the form of laboratory-based practical work. Students receive the following instructions:

> You will need to collect a sample of each of the corroded metals and some emery cloth.
> *Look carefully* at the corroded metal and enter your observations in a table like the one below.
> Rub the surface with emery cloth and collect anything that comes from the metal on some clean white paper.
> *Look carefully* at the material coming from the surface and at the surface you have rubbed. Your results should again be entered into your table (Metals, 1992, p. 10; emphasis theirs)

There follows a table with the headings: "Name of metal, Color of corroded metal, Can the corrosion be rubbed off?, Color of substance rubbed off, Color of metal after cleaning, Is the metal used up when it corrodes?, headings taken over from lesson M3 of Metals (1989).

Transforming the teacher demonstration of Metals (1989) into this student activity also offers the teacher the possibility to test students' skill at *making accurate observations*. No questions are asked here to direct students to the theoretical purpose of the experiment, understanding the chemical concepts of reaction, element and compound as stated in the original teacher demonstration (TNM3, see section 5.2.3).

It is the newly added activity M3B which deals with these chemical concepts (reaction, element and compound) and which also introduces some additional chemical concepts and terms. For example, after having pointed out that some elements such as gold are not reactive, the text continues:

> Other metals do react with the atmosphere and COMBINE with the oxygen and water (and sometimes carbon dioxide) to form COMPOUNDS. These compounds are usually the METAL OXIDE but may be a HYDROXIDE (due to water) or a basic CARBONATE (due to the carbon dioxide). We could write a simple CHEMICAL EQUATION:
> metal + oxygen —> metal oxide (ibid., p. 11, emphasis theirs).

As argued above (section 5.2, see also Figure 5.12), in a chemical-societal context it is sufficient to explain the phenomenon of corrosion by referring only to the action of the atmosphere. So, the chemical concepts emphasized above are not really needed, not even the concept oxygen.

Further on the text of the student booklet, Metals (1992), offers a simple qualitative answer to the question, "Why the rusting of iron is a problem unlike the tarnishing of silver or the oxide coat on aluminum" (p. 11).[51]

> When most metals tarnish or corrode they do so at the *surface* of the metal and form a layer of metal oxide which prevents any further reaction between the metal and the air. In the case of iron the metal oxide *expands* when it forms and this causes the surface to *flake off* and so exposes more iron to react and so on.

Note that this explanation could work just as well without using the technical term oxide, using instead a term as the combination of a metal with the atmosphere. Activity M3B further contains representations of double bonds in oxygen gas molecules, of lattices of metals and metal oxides, concepts equally unnecessary for students to make sense of corrosion phenomena at this stage. On the other hand, it is pointed out there that "mixtures with copper such as brass" (ibid., p.11) also corrode, so not just pure metals, and that this is important in daily life.

Activity M3B thus explicitly addresses the role of oxygen (which is not mentioned in

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[51] As the teacher later explained, "they [the teachers] felt that they really needed to explain why it is a problem that iron corrodes and that other metals such as aluminium do not cause a problem" (T92). I take it they meant why the rusting of iron is such an important *chemical-societal* problem.

lesson M3 of Metals, 1989) and offers students additional PC content not needed to make sense of corrosion. On the other hand, by explaining that the rusting of iron forms a special chemical-societal problem, activity M3B also addresses the CTS aspect of corrosion. The last activity, M3.1, "What happens when iron rusts", has been taken over unchanged from Metals (1989).

Together these additions tend to reinforce the tension, already present in Metals (1989), between PC content and CTS content, while the balance between PC content and CTS content is tipped in the direction of the former.

Changes in Lesson M4

Again the teacher demonstration from Metals (1989) is replaced by a student practical. The activity M4.1, "A Closer Look at Corrosion and Burning", is preceded by two instructions.

> First hold the shortest length of a magnesium ribbon [2.5 cm length] in the Bunsen flame using tongs and wearing eye protection. Don't look at it *directly* but of course notice what happens.
> Before you do anything else find out the *mass* of the crucible and the lid by themselves and make a note of it. You will need it later (Metals (1992, p. 14; (emphasis theirs).

As pointed out in section 5.2.4, the intense flaring up of magnesium will hinder the accurate observation of the *process* of oxidation. The second instruction focuses the attention of students on the change in mass involved, that is, on the crucial aspect within the context of oxidation. Other aspects relevant to corrosion and burning are thereby excluded (see also Figure 5.12).

To replace the teacher-student discussions of Metals (1989), activity M4.1 is followed by four extra questions after the seven questions taken over from Metals (1989). These are:

Q8. "What is meant by the word 'OXIDATION'?" (ibid., p. 15, emphasis theirs). Thus, after having met the terms oxygen and oxide in activity M3B, students are now invited to reflect on the concept of oxidation.

Q9. "What is the link between burning and oxidation?" (ibid., p. 15). The focus being on oxidation, the process of burning is taken as a special case of the former. The comparison between the processes of burning and corrosion is not addressed.

Q10. "If two elements join to form a compound, what can you say about the mass of the compound?" (ibid., p. 15). The focus is on the increase in quantity of mass, possibly also on the conservation of mass, during chemical reactions. Students are given the assignment:

> Work out the mass of the magnesium used. Work out the mass of the oxygen it combined with. Plot your results on the master graph in Room 103 (ibid., p. 15).

Q11. "What do you notice about the results which everyone else have already plotted?" (p. 15).

As the teacher explained in the interview, the students, working like real scientists at the time of the Circus, were supposed to find out that "everybody's points were on a straight line" (T92). The 'master graph' would illustrate another important mass relationship which holds for chemical reactions, namely, that the reactants combine in fixed proportions by mass. It adds another PC relationship (Proust's Law) and thereby removes further from sight the relationship between corrosion and burning, the title and intended context of the original lesson in Metals (1989). Lesson M4 of Metals (1992) bears no title, the title of Metals (1989), "A Closer Look at Corrosion and Burning", is not being taken over, nor is the experimental study of the changes in mass as iron rusts. By adding Proust's Law the balance between PC content and CTS content shifts to the former, and away from the latter.

Changes in Lesson M5

This lesson of Metals (1992) begins with activity M5, "Corrosion rate". This is a practical for students that replaces the teacher demonstration of Metals (1989) on the reactions of calcium, sodium, iron, copper, and magnesium with air and with water. The practical is introduced to students as follows:

> Ask the member of staff for the display of five metals which you are going to investigate. You should not only have a sample of each of the five metals but also a sample of each of them which have been left open to the *atmosphere* for some time (p. 16).

Thus, students first compare freshly cut, clean samples of these *solid* samples of metals with corroded ones, and try to answer the questions: "Which of the metals seems to have changed the most and which the least?" (Q1, p. 16) and "What can you say about the *rate* at which metals *corrode*? (Q2, p.16).

This activity gives an idea of the differences in *corrodibility* of solid pieces of metals when exposed to the *atmosphere*. It is followed by experiments of freshly cut pieces of sodium first with air and then with water performed by students who are wearing eye protection and taking great care. They answer the following questions:

Q3. What happens to the sodium [exposed to air] over a period of 10 minutes?

Q4. What happens to the sodium placed onto the surface of 100 mL of water?

Students are told in the booklet that, "It [sodium] is being oxidized". This is followed by the questions, "Where is the oxygen coming from? and What must this leave behind? (Hint: What two elements combine to make water?)". Note that in the reactions of metals such as sodium with water the oxygen comes from the water, and not from a gas in the atmosphere, as with corrosion in a CTS context (See again Figure 5.12). Activity M5.1, "Do all metals corrode", and activity M5.2, "Preventing corrosion", are taken over unchanged from Metals (1989).

In spite of both the promising title, and the beginning of activity M5 in a CTS context (the corrosion of five solid metals exposed to the atmosphere), the focus of the lesson shifts quickly to the reactions of these metals *in water and the order of reactivity*, thus giving little emphasis to the order of corrodibility of metal in the air. Again, concepts related to oxidation are reinforced. As in lesson M5 of Metals (1989), the CTS context corrosion is used to develop mostly PC concepts. The CTS context is really addressed in activity M5.2 , "Preventing corrosion", tipping the balance between PC content and CTS content again in the direction of PC content.

Changes in Lesson M5X1

The second investigation of lesson M5X1 of Metals (1989), "Do 'rust stoppers' work?", has been left out. The first activity, on how rusting is prevented, is here introduced to students as follows: *Consider* a bicycle whose frame, cranks, chain and gears are made of steel (ibid., p. 22), whereas Metals(1989) had as an introductory line, "You will be *shown* a bicycle, etc."

Thus, the second CTS context of this optional lesson has been deleted, and the first CTS context seems to be introduced (*pace* the Circus approach) more as a thought experiment than as a hands-on one. Deleting the context 'rust stoppers' also deletes the CTS concept 'commercial aspects of produced materials'. Again, PC content prevails over CTS content.

Changes in lesson M5X2

Activity M5X2.1, "Do other metals stop iron from rusting", is taken over from Metals (1989). At the end of the lesson is added the remark (Metals, 1992, p. 24):

> You should be coming to the conclusion that not all metals react as well or as quickly as each other. We can put them into a sort of "league table" with the most reactive first. The following list is known as *the reactivity series* for metals: K, Na, Ca, Mg, Al, Zn, Fe, Pb, Sn, Cu.

The metals listed above in *the reactivity series* coincide with the set of asterisked metals mentioned in lesson M2 of Metals (1992), that is, metals students "meet most often in this unit" (ibid., p. 7), put here in an order of decreasing reactivity from left to right. Lesson M5 has established this order, empirically, namely for Na, Ca, Mg; Fe and Cu. Lesson M5X2 teaches students that Sn and Cu are less reactive than Fe, and that Zn and Mg are more reactive than Fe. The metals K, Al, and Pb are *not* empirically addressed in the unit Metals, nor are comparisons made between Zn and Mg or between Sn and Cu.

Students are subsequently asked, "Can you name them all without looking back?" This question gives the impression that the reproduction of an important PC relationship such as the reactivity series is considered as more important than the acquisition by students of all the evidence on which it is based. Furthermore, the emphasis on the reactivity series, rather than on the order of corrodibility, detracts from the CTS aim of the unit Metals, that is, to make sense of corrosion phenomena in daily life such as the prevention of corrosion and the specific problem of rusting. Thus a PC concept suppresses a CTS concept, as a consequence of which the balance between them shifts towards more PC content.

Changes in Lesson M6

The first teacher demonstration, on the comparison of the bendability and brittleness of a paper-clip and a darning needle, is deleted, as is the second teacher demonstration on the preparation of solder. Both experiments would have shown empirically that the different properties of alloys depend on their composition, an important relationship relevant to the use of metals. The lesson is limited to activity M6.1, a homework assignment taken over from Metals (1989). Pupils complete a question sheet on the use and properties of alloys. The key point here is that the *use* of an alloy depends on its properties, and that "it is possible to make alloys which have properties needed for a particular job" (ibid., p. 25).

The deletion of the teacher-student discussions of lesson M6 of Metals (1989) leads to a serious neglect of important CTS concepts: the prevention of rust, the explanation of differences of metals in terms of difference in corrodibility, and the definition of an alloy. Deleting the teacher-student discussions and the teacher demonstrations and the CTS concepts arising from them, definitely tips the balance in this lesson in the direction of PC content over CTS content, if we compare Metals (1992) with Metals (1989).

Summary and discussion

The changes made to the formal curriculum unit Metals (1989) by the science staff of the school which led to the student booklet, Metals (1992), the *interpreted* curriculum, are summarized in Figure 5.15 below.

The first column shows the contexts deleted from the lessons, in casu, M1, M5X1, and M6. The second column mentions PC content added but *not* needed. The third column mentions additional CTS content needed and developed in Metals (1992) such as corrosion rate (M5) and the explanation of the problem of rusting (M4). Finally, the deletion of CTS contexts implies that some CTS content although needed for the theme *corrosion*, is *not* developed as indicated in the fourth column.

From the lessons analysis of Metals (1992), summarized in Figure 5.15, it is clear that not each lesson of Metals (1992) has its *origin* and *justification* for study, *fundamentally*, in aspects of *everyday life*. See especially lessons M1, M5X1 and M6 where CTS contexts, present in the unit Metals (1989), have been deleted. Inspection of Figure 5.15, the second column, also learns that not all chemical concepts and explanations treated in the lessons of Metals (1992) are *needed* for the study of the everyday situations used in the unit Metals (1992).

To conclude the analysis of the lessons of Metals (1992), the interpreted curriculum contains a somewhat different configuration of CTS contexts, PC content and scientific skills, and CTS content than the formal curriculum, Metals (1989). The curriculum emphasis appears to have been shifted in almost each lesson to more PC content and skills and to less CTS content. Thus, the CTS / PC ratio of the interpreted curriculum, Metals (1992), seems to be substantially smaller, from what it was for the formal curriculum unit Metals (1989), as analyzed in section 5.2 (Fig. 5.5). To put it in Roberts' terms, there appears to have been added a SOLID FOUNDATION emphasis by the science staff of the school to the original unit Metals (1989) besides the SCIENTIFIC SKILL DEVELOPMENT emphasis mentioned above (Figure 3.5).

The unit Metals (1992) presents a good example of how design criterion four, *flexible teacher-mediated use*, is interpreted and operationalized by science teachers planning to use Salters' Science Foundation units with their students in a "self motivated learning" approach (Hill, 1991, p. 5). The unit Metals (1989) is adapted to the conceptions of the teachers involved, while at the same time, as Hill (1991, p. 5) says, "it clearly fits the National Curriculum".

The students are to work at their own pace, in groups of three, doing the experiments and other activities as explained in their booklets while learning chemical concepts and skills with the teacher in a new, supporting role. Because teachers "needed to be experts in practicals that the pupils themselves were designing" (Hill, 1991, p. 5) they did not always know the 'right' answer. Students clearly expressed "enthusiasm for the new regime, working very hard to explore possible solutions in open discussion" (p. 5), trying to "work like real scientists" (p. 4).

In the student booklet, Metals (1992) there is no explicit reference to teacher-student or group discussions. The analysis in section 5.3.3. will show whether they took place or not.

Figure 5.15 Metals (1992): The Interpreted curriculum of Metals (1989)

Lessons Metals (1992)	**Contexts deleted from Metals (1989)**	**PC content added, but not needed**	**CTS content added and needed**	**CTS content deleted though needed**
M1	lab. survey of things made of metal; survey of common metals and properties	relation 16 metals – symbols ('chemical shorthand')	relation common metals with everyday use	
M2			dominant metal in drawing pins	
M3		oxidation / chemical equation; systematic names; double bonds / lattices	mixtures (brass) corrode; explanation of problem of rusting	
M4		constant proportion by mass (Proust's law)		
M5			corrosion rate	
M5X1	'Rust Stoppers'			commercial aspects of produced materials
M5X2		reactivity series		order of corrodibility
M6	properties steel alloys; preparation of solder			prevention of rust; composition alloy determines properties order of corrodibility

5.3.3 The taught curriculum

The lessons of the unit Metals (1989), *as interpreted* and taught by a particular teacher to a particular group of students at a school in England on the basis of Metals (1992) became the object of my classroom-based research performed in the months October and November 1992.

As we saw above, Metals (1992) is an interpretation of Metals (1989) to the desiderata of the Circus approach (Figure 5.15) and the requirements he National Curriculum (1989) in England. The resulting student booklet (Metals, 1992) has been used by the teacher for the teaching of his Year Nine science class within the constraints of the revised National Curriculum (1992).

The question I try to answer here is: to what extent would a teacher, congenial to the Salters' Science approach, teach a chemical unit of the interpreted curriculum, Metals (1992), in accordance with design criterion two, *relevance* and design criterion three, *context led development of concepts*.

Background teacher

As a pupil the teacher was taught Nuffield O-level biology, chemistry and physics.

> They were the great new course of that time. They were very much based on experiments and drawing the ideas out of the experiments. Whereas other groups did more traditional courses, the *top* group in science did Nuffield. We were given experimental sheets, did the experiments and then had to try to explain it with the chemistry teacher (T92).

Doing lots of experiments, not having to learn a lot of facts, and getting good grades: this was what the teacher enjoyed in the Nuffield course at the time (1970s). His A-level course was more traditional with lectures, note taking and "a fair amount of practicals" (T92). At university he studied chemistry majoring in inorganic chemistry with a special interest in the topic transition metals; his minor subjects were mathematics and geology. As a teacher trainee in science education, he was tutored by a chemistry teacher and did his teaching practice mainly with chemistry groups, including *teaching* Nuffield Chemistry.

> Funny enough, in one teaching practice I used Nuffield. Perhaps because I was comfortable with it ... someone else had taught me, so I know this (T92).

He also gained teaching experience with traditional chemistry courses and received subsidiary qualifications for teaching integrated science and physics courses.

In his first school he taught "a traditional 16+ syllabus (O/CSE), a forerunner of GCSE" (T92), made his own teaching scheme for both the O-level and CSE chemistry courses and also one for CSE physics, and taught an integrated humanity course (11 – 13). For A-level he taught a traditional syllabus, simplified the textbook used, lectured, and gave notes to his students. After about two years (in the mid '80s) he left to join the science staff of his current school, expressing a wish "to be a proper science teacher" (T92). Together he and a colleague devised their own Third Year Chemistry course: students would perform experiments presented to them on overhead sheets. Some years later he supported an initiative of two of his fellow chemistry teachers to trial the Salters' Chemistry GCSE course; as a result, he became enthusiastic about the Salters' approach to teaching chemistry.

The positive experiences of chemistry teachers and students with Salters' Chemistry as a trial school led science teachers of the school to the decision to offer, from 1987 onwards, their KS4 students (14 – 16) the Salters' Science GCSE course; as we saw above, it also led to the short reign (1989 – 1991) of the Circus.[52] Salters' Science was preferred over Suffolk Science, another alternative course considered, because the

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[52] The Circus probably stopped because of the constraints the National Curriculum came to impose on the teaching of science. As Hill (1991) remarked, "while heading towards external examinations [in Year Five] we [the staff] will now work in groups which are larger – they are *class-sized*".

science staff felt that the latter course was less appropriate for the middle and high ability band of the school population. Another course, Science at Work, was already offered, from 1985 onwards, to the lower band of students. The science teachers felt that this course – because of the reading level and reduced conceptual loading compared to other courses, including (later) Salters' Chemistry – clearly motivated students of lower ability and also seemed to work for them in terms of results.

At the time, the teacher was in his thirties and was Head of Science. He was teaching: (i) Salters' Science Foundation units to Year Nine (KS3), using the student booklets such as Metals (1992). Thus, although the *practice* of teaching a 'supported self study' approach had disappeared by 1991, the 'Circus' booklets remained available and were used for teaching science from 1992 on, in Year Nine to 13 – 14 year old students;
(ii) Salters' Science Double and Single Award using Salters' Science units (1990, 1992) to the middle and upper band of Year Four and Five (KS4) and Science at Work to the lower band; (iii) Salters' Advanced Chemistry to his A-level students.

Methods and set-up used in the education experiment

The classroom-based research for Metals (1992) entailed, first and foremost, the tape recording of all the lessons of the unit, that is, of all teacher-led explanations and also of a few student discussions. Secondly, I made additional notes of what happened in the classroom, what the teacher put on the blackboard and some of the reactions of students (cf. 5.4.3). Thirdly, I interviewed the teacher about the way he had chosen to teach Metals (1992), and about his background as a chemistry teacher relevant to the way he adapted and taught the observed and analyzed unit Metals (1992).

As is customary in England, the science class observed contained a number (4) of laboratory tables provided with gas and water taps. Students, seated on stools, work at these tables, either individually, in pairs or in groups. Since the case study focused on the performance of the teacher, a tape recorder was placed at the teacher's bench with two microphones at each side. Most of the teacher-student discourse in the lessons of Metals (1992) could be recorded this way; some student group discussions were recorded by placing a small tape recorder on a lab table among a group of students. It was decided not to use an extra microphone on the teacher. Both teacher and researcher felt this might disturb the regular teaching-learning processes. The researcher was situated at the left side of the teachers' bench in order to make observations in the classroom. In between short 'plenary' sessions, students worked most of the time at their lab tables with the teacher assisting them. Quite soon the researcher felt free to walk around in the classroom in order to make additional observations with regard to the teaching-learning process.

The quotes used below come, unless otherwise indicated, from audiotapes made of the lessons of Metals (1992). If it is not clear from the context, the teacher is referred to as T. Students are referred to as S1, S2, etc., the numbers starting afresh for each excerpt of the tape. For details of the lessons of the unit Metals (1989), see sections 5.2.1 to 5.2.7, and Appendix 5.

Lesson M1

The teacher briefly introduces the theme of the unit Metals (1992) as follows:

> In my opinion one of the most important units ... some of the most important materials around us, and at home ... numerous articles e.g. cars ... are made of metals.

Beyond this introduction, the chemical-societal theme is not further explored in this lesson. The survey of things made of metal is deleted, as we saw above. Also, the teacher does not ask students "to make a list of metals they know and note what they look like", as in Metals (1989).

Thus, the lesson begins almost immediately with laboratory-based practical work (M1.1) in which students "first find out what makes them [metals] different, special, beautiful". Metal and plastic spoons are compared, and students do six tests, the results of which are recorded on a summary chart they copied from the booklet Metals (1992). The latter is done by putting in a "tick or a cross as instructed". Most students have no problem with the activity in this form. One student does not understand the term "dense", so the teacher explains it to him.

The lesson continues with a teacher-student discussion on the relationship of symbols to (names of) metals. The teacher asks the students what the symbols Al, Au, Fe, Cu, mentioned in M1.3, stand for. Most students can answer this. He further asks: "what is the third most expensive metal"?, pointing to the Data Table in Metals (1992, p. 6). A student answers, "Sn". Teacher: "What?" Students then says, "Tin". Another student is not familiar with lead (daily life!). The teacher subsequently refers students to the list of seventy symbols for metals in their booklet (p. 7). Students complete the word search, "Hunt the Metals". They seem to enjoy this activity and are able to find most of the names of the sixteen metals hidden in the puzzle. The last activity, M1.3 "How do metals differ from one another", explores the relationship between the physical properties of metals (listed by symbol) and their use; this is given as homework, as suggested in Metals (1989).

With the surveys about metals as widely used materials and the teacher-student discussions deleted, most teaching time is spent on the laboratory-based practical work and on the symbols representing metals. The teacher revealed to the researcher afterwards, "The next lesson about drawing pins, that is more like chemistry, the lesson about spoons is not chemistry" (T92).

Only the teacher-student discussion on the relationship between symbols and metals ('shorthand') is added prior to the extra assignment on finding the symbols for 16 metals. However, the extra assignment on the "common everyday use" of the term metals which pupils will meet most often in the unit (and in their daily life?) is not done. As we saw, the symbols of metals are not really needed – their names are sufficient – to make sense of metals in everyday life, while the CTS relationship of metals to their use *is* needed. Thus, lesson M1 is not taught fully in accordance with design criterion two, *relevance*, and design criterion three, *content-led development of concepts*.

On the whole chemical concepts and skills receive more emphasis than chemical-societal concepts, as can be concluded from the choices made by the teacher for the activities of lesson M1. During the lesson the teacher frequently informs, instructs, prompts, and corrects students.

Lesson M2

Like lesson M1, this lesson starts with laboratory-based practical work (M2.1) without first having an introductory teacher-student discussion on why "it is worthwhile to investigate whether chemical tests might give additional information" (TNM2 of Metals, 1989; see section 5.2.2). The teacher gives only a short explanation of the purpose of the activity, "Which metal is used to make a drawing pin?", after which he instructs, coaches, and monitors students working in small groups or pairs. He then gives the "Tip: With the copper and the lead I would keep them for a bit longer than iron [in dilute nitric acid], since it seems to take longer to react." The reaction of a metal solution with sodium hydroxide solution gives rise to the following dialogue:

T:	What is that?
S1:	A solid.
T:	No, what is a posh word ... what do you call a solid inside a liquid?
S1:	A muddle?
T:	A precipitate!
S1:	A what?
T:	A precipitate (while referring to the student booklet, p. 9).

So, here we have an example of the explanation by the teacher of a systematic, chemical term mentioned in the activity M2.1, a term which students do not need in order to make sense of the chemical phenomena of this lesson.

After the practical, the additional assignment "Construct a table from your experimental results" is introduced by the teacher: "I will give one suggestion for a table". He does this while writing on the blackboard three columns with the headings "Metal", "Color of Precipitate", and "Conclusion: Metal made from" (note that metal should be taken as "metal *object*" both times). The teacher continues: "In the next stage (the special investigation) you are gonna do the same experiment all over again using a drawing pin, a paper-clip, and solder." He further explains that "very few things are named metals", although they are made of them.

One student is familiar with the fact that solder is used for welding. The teacher elaborates on this by saying that "it is a very soft metal [*sic*] used to stick bits of metal together". This is one of the few times that a CTS context spontaneously emerges in the lessons taught. Most of the lesson time is devoted to chemical analysis proper. Finally, the teacher points students to the last (added) line of the special investigation, "Write down clearly your results and your conclusions for this investigation" (p. 9). He instructs students that "your results are the colors produced" and "your conclusions are metals made from ....made from iron". The tests comparing new drawing pins with worn drawing pins, the other addition to this lesson, are not executed. The lesson does not end with a teacher-student discussion on the use of metals related to their chemical properties, as it has in Metals (1989). Therefore, the idea of dominant metal is not elucidated.

Thus, not only the format of the table is given by the teacher, but also the general results and conclusions of the experiment, except for the specifics of color and metal present (pace the Circus approach). Chemical concepts/terms and routinized (analytical) skills dominate over the chemical-societal context of the use of metals in relation to their chemical properties. Thus, in lesson M2, the teacher put more emphasis on PC content (precipitate, chemical analysis), and less on CTS content (relationship of metals and their use).

Lesson M3

Students start by performing the activity M3A (5.3.2). They remove the corrosion of the metals iron, copper, magnesium, and aluminium by rubbing the samples with an emery cloth. In an introductory teacher-student discussion the students are asked: "Why do you use plastics sometimes instead of metals?', while the teacher refers to question 9 of activity M1.3 (p. 6), "For what uses have plastics replaced metals? Why do you think this has happened?" Some students answer that "the disadvantage of metals is that they rust". The discussion ends with the conclusion that iron rusts, but other metals corrode.

During the practical M3A students form divergent ideas about the process of corrosion. Some students think it is possible to glue the rubbed off corrosion back on. Others think "It comes out of the iron". Some think that the metal "reacted with water". Their answers to the question: "Is the metal used up when it corrodes?" also points to different ideas as to what happens during corrosion. Several students say "No", it is not used up for all four metals. Some say that iron, copper and aluminum are used up, but not magnesium. Thus, the evidence collected by students in this activity gives rise to various interpretations which make it difficult for them to arrive at the conclusions about chemical reaction, compound, and, especially, chemical element (mentioned in TNM3, Metals, 1989).

In a teacher-student discussion following practical M3A, the teacher asks the question, "Can anybody say what happened to all the metals?" Firstly, he helps students with summarizing their observations: (i) before rubbing they looked dull; after, they are shiny; (ii) most corrosion has come off iron. Secondly, he asks: "Why does it corrode ... what happens when it corrodes?" Since no answer is immediately forthcoming, the teacher gives the students "a clue, it is a chemical reaction. What is it reacting with?" One girl answers "oxygen". The day before students were given as homework to study M3B, a text in which the corrosion of iron and aluminum is explained in some detail. The teacher now discusses the key points with the class, for example, that in the case of aluminum a layer of aluminum oxide is formed. The same girl is asked to make a drawing of this phenomenon on the blackboard. The teacher explains the concepts of chemical reaction and compound but not the concept of chemical element. Another student then remarks that "the oxygen can't get to the aluminum", and when asked about the case of iron he answers, "it keeps on going". This leads to the following exchange between the teacher and this student.

T: Why?
S1: It crumbles.
T: What happens, it flakes off ... makes it thinner, and reacts again.
T: What happens in a car when that happens?
S1: Holes.
T: So, rusting is a problem. Think ... things that are made of iron or steel such as bridges, cars, washing machines, etc., things in the house, they all got steel somewhere. Steel is mostly iron. So it is very important to find out to stop rusting from occurring.

Thus, at this point in lesson 3 of Metals (1992), the teacher returns and addresses more fully the CTS theme *corrosion* by explaining the chemical and *societal* problem of the rusting of iron. The teacher then continues this discussion by remarking, "If you want to know how to stop something you got to know what *caused* it", and asking, "What is causing rusting?" Students offer the following suggestions: damp, oxygen, water, carbon dioxide, gases, air. The past activity M3.1, "What happens when iron rusts", works well; most students enjoy setting up the experiment and checking their predictions on the rusting of iron nails in the following days.

With regard to the question why it is important to hose down the underneath of cars in bad winters (Q5, p. 13), the students are told that they "do not need to do a poster" to answer it. Producing a leaflet or poster would have engaged students more fully with the central CTS theme of the unit, corrosion of metals, but instead the question is answered in a teacher-student discussion. One student thinks it is done "to get salt away". The teacher adds that there is another method to protect steel or iron, namely "to seal it with rubber (underseal)". At the end of the lesson the teacher gives as homework, "Make a list of items made of metals. Try to suggest which metal they could be made from." This is an assignment similar to the survey at the beginning of lesson M1 of Metals (1989), but not executed in the classroom. Thus, in this lesson the students explore, for the first time in some detail, some important CTS contexts about common metal objects in their surroundings, about preventing a car from rusting, and about the societal problem of rusting. Thus, lesson M3 is taught fully in accordance with design criterion two, *relevance*, and largely in accordance with design criterion three, *context led development of concepts*.

Lesson M4

As in Metals (1989), in a teacher-student discussion the results of the students' experiments with rusting nails (M3.1), including questions 1 – 5, are discussed. There is some confusion over the results since they are not the same for all students. The teacher explains that this can happen because "it is very difficult to get rid of the *air*" from the water. For other students, the rubber bungs did not close their test tubes airtight, letting in air and with it water (moisture). The key point, that both air and water are needed for rusting, is made by the teacher while the key points on the forming of a new substance when iron rusts and using up iron are not (cp. LPM4, Appendix 5).

In line with Metals (1989) but contrary to Metals (1992), the next activity is a teacher demonstration in which magnesium and iron are burned in air. The teacher concludes that "magnesium reacts very quickly while iron does not seem to react at all ... it just gets hot". This is followed by a teacher-student discussion:

T: I got a question for you: what is the magnesium reacting with?
S1, S2: Heat, air.
T: What is in the air?
S3: Carbon dioxide, *oxygen*.
T: *We* got the idea.

The teacher then writes on the blackboard the word equations:

magnesium and oxygen —-> magnesium oxide

Then the teacher adds the symbols for the elements, making a chemical equation:

$\mathrm{Mg} \quad + \quad \mathrm{O_2} \longrightarrow \quad ?$

The teacher explains the formula of oxygen by saying "oxygen goes round in pairs", and asks:

T: What is *formula* of magnesium oxide?
S: $\mathrm{MgO_2}$ [a correct addition, mathematically]
T: Nearly just, it is MgO. Because you have to put numbers in front to make it a proper *chemical equation*.

Teaching pupils the general chemical term formula and its specification for magnesium oxide is another example of introducing PC content not needed to make sense of the chemical phenomena at this stage.

Subsequently, the teacher first gives a detailed demonstration of the experiment of the burning of magnesium ribbon in a crucible, before he allows students to perform on the experiment (M4.1) themselves. As in previous lessons the teacher frequently informs, instructs, prompts, and corrects students what to do, and how to describe what they see. The focus of this activity should be on corrosion and burning but is in fact on *oxidation*, as is already clear from the brief teacher-student discussion reported above.

The last teacher-student discussion also puts the emphasis on the concept of oxidation by emphasizing the gain in mass. The (added) question, "What is meant by the word 'OXIDATION'?" (Q8, p. 15), leads to the following teacher-student dialogue:

S: Gaining oxygen.
T: What is the opposite of it?
S1: Losing oxygen
S2: Deoxidation.
T: Good try but it isn't. I will tell you later.
....
T: What is *reduction*?
S3: Take away of air, loosing oxygen
T: Removal of oxygen

Teaching pupils the general term 'reduction', over and above the term 'oxidation', is another example of a chemical concept not needed at this stage in order for students to make sense of corrosion phenomena.

Some of the conceptual difficulties students have in this lesson are revealed by their answers to the (added) question, "What is the link between burning and oxidation?" (Q9, p. 15).

S1: In burning you get rid of oxygen.
T: This is quite important. What did magnesium do?
S2: It glows, it burns.
S3: It is a chemical reaction.
T: Coal, paper, wood react with oxygen. When something burns, it is oxidized.

The teacher skips the last two added questions (Q10 and Q 11).

To sum up, the emphasis of lesson M4 of Metals (1992), as taught in the classroom, is largely on the transmission of basic chemical concepts, namely, the concepts of oxidation, reduction, formulae, and chemical equation. The CTS context of corrosion disappears completely in the background, and the processes of burning and corrosion are not really compared as announced in the synopsis of the lesson in Metals (1989). Students learn scientific processes mostly in the form of routine procedures and skills, and a discussion of their ideas with regard to chemical phenomena and how to test them is not encouraged. Thus, in lesson M4, the teacher puts the greatest emphasis on PC content, and almost no emphasis on CTS content, which is not in accordance with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*.

Lesson M5

The students start with the added practical M5, CORROSION RATE, except for the reactions of sodium with air and water which are demonstrated, the teacher says, "because sodium is quite dangerous". As for the remainder of the practical, the teacher begins by explaining the set-up.

T: We do it a bit differently. Take one of these [samples of *corroded* calcium, iron, copper, magnesium] and describe it ... color, then swot it in your groups and then do questions one and two [Metals, 1992, p. 16]. Don't touch calcium, it is a bit dangerous. I move it around because I don't want it spilling.
T: You have to describe its color [reacting to the student who writes up the *length* of a rusted nail]. Look at title of practical: CORROSION RATE. Which one looks least shiny, is the most corroded? Which one is the least corroded?
S's: Sir, what do they, calcium and copper, originally look like?
T: Well, it's a metal, so it *should* be shiny and silvery.
S2: What color is calcium?
T: It *should* be silvery, shiny. Which metal has changed the most?
S's: Magnesium, iron, calcium, copper [in no clear order].
T: What I have done here ... I put some *fresh samples* of magnesium, iron, copper. Which of these metals seems to have changed the most?
S's: Iron or magnesium.
T: Perhaps magnesium changed the most, it totally lost its shininess whereas with copper and iron there still seems to be some shininess there. Calcium has corroded, changed the most.
S's: The same, exactly the *same* [with calcium]!!
T: Why this fresh calcium looks almost the same as the one which have been out for weeks? A bit of a problem with calcium, only visible with fresh metal, and it [the metal] is hard so I can't cut it.
S3: It [calcium] corrodes straight away.
T: The most corroded metal corrodes the quickest and is the least shiny [demonstrates sodium].
S's: It corrodes more [some say] ... less [others say].
T: Does it, sodium corrodes faster?
S's: It corrodes faster [some say] ... slower [others say] ... magnesium faster.
T: It seems to me and a few other people that sodium corrodes the fastest; then calcium and magnesium, then iron and copper. We can't say exactly now ... further experiments [needed] to find out more precise order.

Thus the students are led, as far as their observations permit, to a decreasing *corrodibility* order of the five metals exposed to the *atmosphere*. The fresh samples are introduced by the teacher halfway through the practical and not at the start as intended in Metals (1992, p. 16); see also 5.3.2. This change is inspired by the skeptical response of the students ("the same, exactly the same"), and it enables students to answer questions they themselves come to pose.

In activity M5.1 question 4 is skipped, and students investigate the reactions of the metals (except for sodium) with *water*. The observations and the questions following the experiments lead students to the order of metals reacting with water: sodium, calcium, magnesium, iron, and copper, with "the most reactive metal at the top of the list and the least reactive metal at the bottom" (p. 18).

T: What can we try to do to sort these [latter] two out?
S1: ... air, hot water
T: Another suggestion happens to be acid. Why acid?
S2: It corrodes metals.

The fact that iron corrodes so much to form the chemical-societal problem of rusting, as explained in lesson M3, is not invoked by the teacher to distinguish iron from copper. Furthermore, it is to be noted that it is tacitly assumed, by unit and teacher alike, that the reactivity order found for metals reacting with water is the *same* as the corrodibility order of the metals reacting with the atmosphere.

Finally, teacher-student discussions following question 5 (Which of the two elements hydrogen or sodium seems to like oxygen the most?) show some of the conceptual difficulties students appear to have with regard to the last practical.

T: Where do you think the oxygen ends up with? Stays with the hydrogen [the other element of which water is made] or goes to the sodium? (cp. Q5, p. 18)
S1: It goes away from the sodium, it comes out the water.
T: What?
S1: ... the hydrogen.
T: The hydrogen?
S1: No, the oxygen
T: Have you worked out which gas popped?
S2: fizz gas.
T: You have a choice of two.
S2: hydrogen?
T: hydrogen or oxygen
S2: [no answer]
T: You are thinking about that ... so it must be hydrogen.

The last teacher-student discussion reveals some interesting reasoning by students:

T: Where does hydrogen comes from?
S's: Sodium, air, metals, water.
T: Water. Why?
S3: Because splint doesn't pop when you light it!
T: Because when you light splint [and held it at top of test tube], it explodes. If air had hydrogen in it, and I did this, you would have exploded!

So, the teacher makes explicit this student's assumption that the hydrogen comes either from water or from air. Activity M5.2, PREVENTING CORROSION, is an activity in which students return to the CTS context rusting and is given as homework, as in Metals (1989).

Although the lesson starts with students trying to find empirically a corrodibility order in five metals reacting with the atmosphere or air, the lesson ends by equating the corrodibility order of metals *tacitly* with the reactivity order found for metals reacting with water. At the same time students have conceptual difficulties with the role of water (and its components) in the corrosion of metals. The latter could have been avoided by following the CTS definition of corrosion as the unwanted change of the surface of metals by the action of the atmosphere. The important CTS activity about preventing corrosion of iron, really rusting – now that students are supposed to know its causes – is given as homework, as in Metals (1989).

Thus, lesson M5 clearly shows the *tension* between traditional PC content (reactivity order, oxidation) and new CTS content (corrodibility order and methods of preventing rusting).

Lesson M5X1

In a teacher-student discussion students *consider* how rusting is prevented on various parts of a bicycle (M5X1.1) and why the method stops the rusting. For example, for handlebars students mention the methods of painting and plating, which "stops air, water getting through", and for rims of wheels they suggest "aluminum, paraffin wax, made of harder metal [and] paint it with aluminum". The teacher explains that moving parts are greased or oiled. A student asks, "what about the rims, they are moving" to which the teacher responds, "yes, but they are not in contact".

This is a good example of a CTS context, for which the teacher could also "have brought a bicycle in the class" (T92). This would have made the activity more experiential for students, of course. Other than that, design criterion two and three are followed in the activities of this lesson.

Lesson M5X2

The students start right away, without an introductory teacher-student discussion on "the need to cover iron and steel to prevent rusting" (Metals, 1989), with the laboratory-based practical work (M5X2.1), an investigation into the effect that other metals (zinc, tin, copper and magnesium) have on the rusting of iron. The results of their experiments are discussed in the ensuing teacher-student discussion. Three test tubes show a brown/orange color on the iron nail (one tube contains a nail and only salt solution), while two tubes show a white color on the other metal (zinc, magnesium), according to the teacher "the best results I ever got" (T92). The latter results are taken as slowing down rusting, while tin and copper apparently speed up rusting. The last two questions (Q3 and Q4), also addressed by the teacher in class, deal with these chemical effects in daily life. Dented tin cans speed up rusting while iron coated with zinc slows it down. This activity teaches students important CTS relationships about the speeding up and slowing down of the rusting of iron on the basis of evidence they gathered themselves, relationships which are subsequently used to explain chemical-societal manifestations of these phenomena. The conclusion: "not all metals react as well or as quickly as each other" (1992, p. 24), is not addressed by the teacher here, nor are the metals looked into in this unit placed in a "league table" as suggested by the addition put in Metals (1992). Therefore, with this extra PC content being skipped, the lesson M5X2 is taught fully in accordance with design criteria two and three.

Lesson M6

The teacher starts by explaining the concept alloys. With teacher demonstrations 1 and 2 being deleted (5.3.2), the lesson is limited to students working on the completion of a question sheet called ALLOYS (M6.1), with question 1 given as homework.

Instead of students discussing their "ideas with other members of the class" (Metals, 1992, p. 25) the teacher helps students with question 2: "Think about the following statements to see if you can explain them. For Q2 (a), "In making steel the amount of carbon added to the iron is very carefully controlled", he gives the answer, "If too much carbon is added to the metal it becomes brittle (weak) and it changes the properties" [quoted directly from one student's revision book]. And Q2 (b), "When iron is produced in a low temperature furnace, it can be beaten into shape. Iron produced in a modern blast furnace breaks when struck with a hammer.", is answered by this student as follows: "Heat will weaken the iron so if too much heat is added the iron will break." The student apparently substitutes heat for carbon in the answer provided by the teacher above. (Actually the iron becomes brittle because of the high amount of impurities formed under these conditions.) This shows that these difficult, although relevant CTS questions, cannot be answered by students on their own if they are not sufficiently prepared for them by text and/or teacher.

With teacher demonstrations 1 and 2 being deleted, the lesson is really restricted to answering the question sheet addressing the CTS relationship between the properties and use of alloys, while the students do not learn much about the other important CTS relationship between the composition of alloys such as steel and their properties such as their strength. Thus, lesson M6 is not fully taught in accordance with design criteria two and three.

5.3.4 Summary and discussion

From the analysis of the lessons of Metals (1992), as provided by the teacher to his students and summarized in Figure 5.16, it is clear that about half of the lessons do not have their *origin* and *justification* for study*, fundamentally*, in aspects of *everyday life*. CTS content is best realized in lessons M3, M5X1, and M5X2, and to some extent in lesson M5.

Inspection of Figure 5.16 below, the second column, also learns that quite a number of chemical concepts and explanations treated in the lessons of Metals (1992) are not *needed* for the study of the everyday situations used in the unit Metals (1992).

Comparing the taught curriculum (Figure 5.16) with the interpreted curriculum (Figure 5.15) of Metals (1992) can tell us whether or not the CTS/PC content ratio has changed. As we saw, the deletion of CTS contexts from the interpreted curriculum has not been undone in the taught curriculum except for the survey of things made of metal addressed in lesson M3. Some of the PC concepts (double bonds, Proust's law), added onto the interpreted curriculum, were not addressed in the classroom. The teacher adds two new concepts, though, reduction and formulae, while the concept of chemical shorthand and some systematic names are given more explicit treatment. Some of the CTS concepts added to the interpreted curriculum are not taught in the classroom; the deletion of teacher-student discussions also means that some CTS content is not taught. Thus, when we compare the taught curriculum with the interpreted curriculum of Metals (1992), the CTS/PC content ratio has decreased again substantially (Figure 5.5.).

The main emphasis is on the PC concepts (analysis, oxidation, and reactivity series) which tends to overshadow the CTS theme of corrosion and prevention of rusting. The analysis of the taught curriculum of Metals (1992) further showed that pupils' learning of chemical concepts and skills were more strongly teacher-directed, compared to the "self-motivated learning" students of the 'Circus', a finding which seems to go against design criterion five, *variety of teaching and learning activities* (but see below).

Discussion

The changes made by the teacher during the actual teaching are a further illustration of the operation of design criterion four, *flexible teacher-mediated use* (cp. 5.3.2). His introduction of new chemical terms, such as reduction, not needed by the students to make sense of the phenomena, seems to violate design criterion one, *no preconceptions*.

Although the Circus, largely a process approach, was no longer followed in 1992, the teacher reinstated only some teacher-student and group discussions that were originally present in Metals (1989). This is to be regretted, in particular for the opportunities lost thereby to develop CTS content out of chemical-societal activities or contexts. Because CTS content is of a different nature than PC content, it needs careful contextual introduction and activities, such as discussions and poster making, in order to get the relevant CTS curriculum emphasis across to students; for example, the fact that familiar metal objects from students' surroundings are usually mixtures or alloys.

CTS content is best realized in lessons M3, M5X1, and M5X2, in other lessons of the unit the emphasis on PC content either overshadows or competes with that on CTS content. As the teacher remarked, a CTS activity is sometimes done, because "it is always handy to have that to fill in a bit of time" (T92). Sometimes the teacher added PC content such as the concepts formulae and reduction. Students spend most of their time on laboratory-based practical work for which the teacher gives elaborate instructions, guidance and corrections. He did this mainly, he said, because he had to deal in this case with "a slightly lower to middle ability group" (T92), not accustomed to deal with a set of varied activities on their own. Thus the level of the class also determines the variety of activities used by the teacher.

Students seemed to experience a number of conceptual difficulties with what goes on during corrosion, rusting and oxidation, for example with the role of water and its components, hydrogen and oxygen. The teacher mentioned in the interview three other examples, which confirm this impression.

The first one concerns the role of water and air during corrosion and rusting. Students "sometimes fail to realize that there is air surrounding all the time ... just the water is seen as important, a piece of iron or steel is damp, they can see the water" (T92). This confirms that the focus of teaching should be primarily directed on the role of air and water during corrosion, taken as a CTS phenomenon, and in accordance with design criteria two and three. As argued above, grasping the role of oxygen is not needed by students in that context.

Secondly, students have problems with the reactivity series. As the teacher remarks, students "having seen orange copper gone green and silvery magnesium gone gray cannot appreciate that magnesium corrodes as much or perhaps more than copper" (T92). Visual inspection alone might indeed not be sufficient here. Furthermore, students, familiar with aluminum window frames and bicycle parts, have difficulty with "the realization that aluminum initially corrodes, forms a thin layer, and then corrodes no more" (T92). A consistently treatment in the lessons of *only* the order of corrodibility of metals in air could maybe help here.

Thirdly, students do not easily grasp that alloys are mixtures of metals. In activity M6.1 ALLOYS they often choose aluminum as the metal to make airplanes wings, and not "Duralumin", the alloy whose composition (Al, Cu, Mg, Mn) and properties (low density, stronger, and more corrosion resistant than aluminum) are *given* on their information sheet.

The emphasis on practicals strongly guided by instructions, with insufficient conceptual development combined by the lack of emphasis on CTS content shows that there is a real danger that this can lead to, predominantly, the reproduction of chemical techniques and facts, especially with students of low to middle ability. This comes close to our characterization in Chapter 2 of dominant school chemistry in terms of students learning propositions and algorithms.

Reflection on Metals: the teaching process

The conclusions I draw for the teaching process of Metals, based on one teacher teaching one unit, can not be considered as representative, as were the conclusions I draw for the developmental process of the teaching units. The population of teachers using Salters' Science units has a much greater variation width than the set of Salters' Science units, as designed by the developers following a number of selected design criteria. Nevertheless, I think that the phenomenon of slippage in the *process of interpreting and teaching* a unit is important enough to draw attention to. Furthermore, it is a well known phenomenon mentioned in the research literature (Goodlad, 1997; Van den Akker, 1988), especially with regard to the teaching process. There will certainly have been teachers who escaped to a larger extent, who therefore showed less slippage. Still other teachers may have shown more slippage.

Figure 5.16 The Taught Curriculum of Metals (1992)

Lessons	**Contexts not taught**	**PC content not needed, but not taught**[a]	**CTS content needed, and taught**	**CTS content needed, but not taught**
M1	lab. survey of things made of metal; survey of common metals and properties	relation symbols to metals; metals/name to symbols		relation common metals with everyday use
M2		precipitate		relation use of metals to chemical properties; dominant metal in drawing pins
M3		oxygen, aluminum oxide	explanation of problem of rusting; prevention rusting; things made of metal	
M4		reduction, oxidation; equation; formula oxygen, magnesium oxide		
M5		hydrogen oxide hydrogen, oxygen	corrosion rate/order of corrodibility; prevention rusting	
M5X1	'Rust Stoppers'		methods of prevention rusting	commercial aspects of produced materials
M5X2	properties steel alloys; preparation of solder		order of rusting iron: more reactive metals slow it down; less reactive speed it up	
M6				composition alloy determines properties

[a] PC content deleted: double bonds, Proust Law.

5.4 The experienced curriculum of the unit Metals

The consistency analysis in terms of the CTS / PC ratio, performed so far, has addressed the various curriculum levels at which the unit Metals (1989) is *offered* to either teachers or students. The formal curriculum unit of Metals (1989), as provided by developers to teachers, was analyzed in section 5.2. The interpreted curriculum and taught curriculum of Metals (1992), as offered by a teacher to his students, were analyzed in section 5.3. In both cases it was found that the CTS / PC ratio decreased in the transformation of the formal curriculum level to the interpreted, and then to the taught curriculum which was accompanied, as we saw, by an increasing tension in the material used in the unit between context and content.

The claims about the quality of the provided curriculum made above are based on my own research, more specifically, on the consistency analysis performed in this chapter on the chemical unit Metals (1989, 1992), taken as a representative unit of the Salters' Science approach. As we will see below, the claims about the quality of the experienced curriculum are to some extent based on my own research, but mostly on the (sometimes extensive) research on the Salters' Science approach performed by others.

It would be interesting to describe, analyze and discuss the relationship between the quality of the provided curriculum as characterized in this chapter and the quality of the Salters' Science curriculum as experienced by students, even though the latter was not the primary focus of my research. On the other hand, the pedagogical structure, part of the theoretical curriculum framework I use in this thesis (see Chapter1), contains as subcategories not only the aims and teaching approach but also the learning approach as used by developers. Furthermore, comments of IF and DF members (see Chapter 2) pertain not only to the formal and taught curriculum of school chemistry but also to the curriculum as experienced and learned by students.

This makes it relevant to look into students' experiences with regard to the content and activities provided in the unit Metals (1992). In other words, what can be said about the experienced curriculum of the unit Metals (1992) is based on my own research while putting it in the context of other relevant research into the Salters' Science curriculum.

In this section, I will address, therefore, the question how the students *receive* the interpreted and taught curriculum: What do students experience and learn when the unit is taught to them by the teacher using the booklet Metals (1992)? More specifically, are students motivated by the kind of contexts and activities provided by the interpreted and taught curriculum? Do they acquire, apply and use the intended content of the unit Metals (1992), as entailed by these contexts and activities, and as interpreted by the teacher?

At the end of the lessons of Metals (1992) the students in the classroom were asked by the researcher to fill in a questionnaire, the results of which are discussed below (5.4.1). Secondly, I refer to some excerpts of teacher-student discussions I audiotaped, showing students' learning experiences with regard to activities of the unit Metals and also to some excerpts of audiotaped student-student discussions in the classroom (5.4.2).

Thirdly, written comments of students on trial editions of Year Three units such as Metals (1984), collected by the developers, are summarized and discussed below (5.4.3). Fourthly, I will discuss the results of a number of other research studies on the Salters' Chemistry or Science courses, especially with regard to students' learning experiences and results (5.4.4). This will make it possible to put into perspective my answer to the question whether and to what extent the chemical unit Metals (1989), a part of the formal curriculum of Salters' Science, has been realized as intended in a particular class of students by a particular teacher of a particular school. Finally, I will draw together the findings from my own research (primary sources) and other relevant research (secondary sources) in order to discuss the relationship between the quality of the Salters' curriculum provided by developers and teacher (Metals, 1992) and the quality of the curriculum as received and experienced by students (5.4.5).

5.4.1 Student questionnaire

The purpose of my questionnaire was, as I formulated it in my notes at the time: "To find out if *newness* of Salters' Chemistry is visible". Thus, the questionnaire was designed to probe mainly the perception and knowledge of students with regard to the new CTS emphasis, earlier called, "Chemistry along with CTS Content" (5.1.4). Thus, the questionnaire was not specifically designed to probe students' learning of PC content nor of *all* CTS content contained in the unit Metals (1992). In the discussion of relevant findings of other research studies below we will see also that the probe used in a research project depends on the research question asked (5.4.4).

The questionnaire consisting of ten questions was introduced to the student (S) as follows:

a) If you fill in this questionnaire you would really help me with my research on the unit Metals.
b) Please work with your usual groups, talk about the questions a bit and then write down what you think is a proper answer (emphasis in original).

The questionnaire was administered by the researcher to a group of sixteen Third Year students, in November 1992, that is, immediately after they had followed the lessons of the unit Metals (1992). Twelve students filled in the questionnaire, two did not, and two were absent.

The questions 1, 2, 5, and 6 below addressed students' *perceptions* of the lessons of the unit Metals in terms of keywords such as enjoy, (dis)like, useful, and choose. The questions 3, 4, 7, 8, 9 and 10, on the other hand, asked students to *use* the CTS knowledge they had acquired in the unit Metals.

The latter questions were designed with the idea that students would be able to transfer relevant knowledge to other CTS contexts if and when they would have acquired or learned that CTS knowledge in a relevant context to begin with. That is, relevant contexts would not only motivate the process of learning CTS concepts, but this process of relevant learning would also facilitate the application or use of the learned CTS concepts in other relevant contexts.

So the general idea of the questionnaire is: do students experience the new CTS emphasis and learn, apply and use some relevant CTS content when taught the unit Metals (1992)?

Analysis of the results and discussion

QUESTION 1: Mention one or two things that you enjoyed doing in the unit Metals.

A great majority of students (9) said they enjoyed the practical work, that is the *experiments*, in the unit the most. The experiments on rust (M 3.1) and on corrosion (M

5.1) were mentioned twice. One student (S5) wrote: "I enjoyed burning metals and putting them in water...", referring to M 4.1. Two other students enjoyed the crossword part of one activity (M 5.2) and the word search, "Hunt the Metals" (M 1.2) the most. One student said he enjoyed "nothing" (S11).

On the whole, students enjoyed doing the experiments, in particular the ones which where set within a relevant context such as rust and corrosion. Providing relevant contexts in line with design criterion two, *relevance*, appears to motivate students the most.

QUESTION 2: Mention also one or two things which you found *useful to know* about metals.

Most students (8) found that it is useful to know something about (prevention of) rusting and corrosion, for example:

> I found out useful things such as air and water is needed to rust. (S4)
> Some things I found useful was what metal rusts the fastest and which metal are easy to use. (S3)

The CTS relationship between properties of metals and their use, hinted at by S3, is hardly visible in other students responses. A number of students (4) found it useful to know the "chemical symbols of the metals" (S7).

Thus, it seems largely the developing and teaching of *relevant* contexts such as rusting, in line with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, which leads to knowledge found useful by most students.

QUESTION 3: Your friend and you have found a very rusty bike. Now you want to fix it up. So you can sell it afterwards for a good price. What are you gonna do about the different rusty parts of the bicycle?

Many students (7) write up that they are going to sand paper the rust away from the rusty parts and then paint / grease / oil / chrome plate the clean parts, for example:

> Sand paintwork down clean and grease some parts and respray. S3
> Get some sand paper and oil and grease to get the rusty parts working. S9

A number of students (4) would just "paint it" (S11), but do not mention they would sand paper the rusty parts first. One student's idea is to "get new parts" (S4).

Apparently, many students use the skill of rubbing corroded metals with sand paper acquired in activity M 3A as well as *transfer* their acquired knowledge of methods of preventing rust to a new daily life situation. Thus, developing and teaching relevant contexts on the prevention of rusting, in line with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, leads many students to transfer their knowledge, that is, applying, in a similar context, their acquired knowledge and skill, showing thereby their understanding.

QUESTION 4: Your mom says that you must not buy *dented* food cans. Why not?

All students report that the can will rust. Most students (7) add something to the effect that the rust might get to the food and "damage" (S3) or "ruin" (S11) it, for example:

> Because rust gets in the groove and might affect food. S4

Again, as in their answers to Question 3, many students *show* in their reply to Question 4 a *transfer* of relevant chemical knowledge. Therefore, design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, effectively guide the developing and teaching process.

QUESTION 5: Name a few things which you did not like to do in the unit Metals.

Students say they do not like homework (4), writing text-related activities (3), and cleaning test tubes (2). Some students (3) say they did not like most of it. As one of them (S10) said: “ I am not bothered with metals”.

From this response, and the response to Question 1, it can be concluded that most students dislike some rather obvious things such as homework but that, on the whole, they do seem to like the practical work, mostly the relevant experiments and some of the other activities.

QUESTION 6: Will you choose science after your GCSE exam? And which science then?

Five students answer that they will not choose science, for example;

> No, what I want to do, I don’t need science. (S 11)

Two students qualify their answer as follows:

> I would not choose science for a job but I would learn more depending on the job I get. (S6, S8)

The remaining students either choose medical science (S1, S2), general science (S7, S12), biology (S3), science for working with computer (S9), or simply say “yes, I will” (S5).

Thus, about half of these students see themselves as taking up some *science* subject after their GCSE exam. Only one student says she will choose a separate science subject, namely biology, and *none* of these students mentions *chemistry* as an option. Having been offered the unit Metals as part of their *science* classes, it seems understandable that Year Three students do not yet perceive particular science topics, e.g., Metals, as belonging to a separate subject or science.[53]

QUESTION 7: Give an example of something you do outside school where you could use the knowledge you learnt about metals.

Some students (4) mention fixing their (motor) bike or its engine. Others (2) mention things other people do: car design, engineer and builders. The other half of the students

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[53] See De Gier (1992) for a similar observation. Pupils, at this stage and age, when being offered a course on (broad and balanced) science do not perceive chemistry or even chemistry teachers but only science and science teachers.

either do not give examples, or do not know, for example, a student (S4) says, "it depends on the metal".

Thus, it seems rather difficult for students to imagine a *new* situation in which they can apply their acquired knowledge about metals. However, students can apply their knowledge to a new situation given or described to them as the responses to Questions 3 and 4 showed.

QUESTION 8: Here is a list of different occupations. Maybe you will choose one of them later in your life. In which occupation is knowledge about metals important? Please give a tick (÷) and explain why you think so. A table of occupations gives: grocer, banker, car mechanic, computer programmer, housewife / man, cook, chemist, engineer, fireman / woman, police officer.

Students 'ticked' most often the occupations car mechanic (7) and engineer (7). Some explained their choice, e.g., an engineer "deals with different metals" (S5). Other occupations were mentioned once: a housewife is "cleaning metal" (S5), a fireman should know "what metal burns fast" (S3), a chemist "experiment with metals" (S12), for a computer programmer it is important to know the "right metal for circuit board" (S9), and for a cook to know "right metal for pans" (S9); grocer, banker and police officer are not ticked at all.

About half of the students answer that they either do or do not like some of these occupations, apparently focusing on the second introductory sentence of question 8. Thus, on the whole they do not answer the intended question about the relevance of metals in common occupations. It seems not clear to most of them that metals can be important in many more occupations besides the rather obvious ones they mentioned, car mechanic and engineer. Even with occupations clearly presented to them, it might still be difficult for students to imagine what role metals play in that occupation. For these students things made of metals seem to be much more visible in crafts and engineering than in chemistry as a science which seems consistent with the CTS approach taken by developers of Metals (1989).

QUESTION 9: Do you know of any other occupation in which a knowledge of metals is useful?

As can be expected by now only a few students come up with suggestions (see discussion Question 7 and 8). They mention plumber (1), architect (2), builder (2) and helicopter pilot (1).

QUESTION 10: Do you know of any other activities in your own life in which a knowledge of metals is useful?

Again, students give only a few suggestions which refer either to their present or future life or to things other people do such as "cleaning a car" (S10), "metal craft" (S11), "working with metals" (S12), "in science" (S10).

Summary and discussion

We will now use the findings of the questionnaire to answer the question to what extent the chemical unit Metals (1989), a part of the formal curriculum of Salters' Science, has been realized as intended in a particular class of students by a particular teacher of a particular school.

The findings show that the teaching of the CTS unit Metals (1992) to a group of 13 – 14 year old pupils can be an effective way to *motivate* the majority of these pupils. Many students also appear to acquire some useful chemical knowledge which they are able to apply to daily life situations, if clearly presented to them and similar to those they have met before. It appears much more difficult, though, for students to transfer their knowledge to unfamiliar situations or occupations, while to imagine new situations for application appears most difficult.

The responses to the questionnaire further show that students are motivated by some specific CTS contexts, from which they have learned some fundamental CTS concepts such as the causes of rusting / corrosion and their prevention, and which they can apply to similar contexts presented to them. The relevance of metals in daily life is recognized by them to some extent. On the other hand, students' responses do not clearly show to what extent students appreciate or have learned PC content, mainly because my questionnaire did not set out to do so (see 5.4.4).

To sum up, relevant contexts do not only motivate the process of learning CTS concepts, but this process of relevant learning also does facilitate the application or use of the learned CTS concepts to a set of similar relevant contexts. One could call this *the principle of local transfer through relevant learning*. The global or general idea of transfer, on the other hand, implies the possibility of a transfer of acquired general chemical concepts to all situations, relevant or not.

In the interview I held with Garforth (G92a:15), she acknowledged that the latter, general idea of transfer underlay the development and units of Salters' Chemistry. She put this in terms of familiar and unfamiliar materials, not as I did in terms of the kind of contexts used:

> It was definitely intended (..) that *we would introduce things*, that were normally introduced in unfamiliar materials, *using familiar materials*, so it was certainly the idea that the chemical concepts, the concepts which came out of and the generalizations which came out of our experiments on rusting and browning apples would be upgraded - would gradually become the kind of generalized chemical concept of reaction, the generalized chemical concept of oxidation in both those two cases (my italics).

It is to be noted that this global idea of transfer implies a focus on the learning of general chemical concepts and generalizations with a primary emphasis of learning PC concepts in and through familiar daily life situations or contexts. The principle of local transfer through relevant learning, on the other hand, focuses primarily on the learning of CTS concepts and of only those PC concepts needed to make sense of the familiar contexts. Thus the tension between CTS context and PC content, referred to many times above, manifests itself also in two different ideas of transfer of knowledge: of local and global transfer.

About half of the students say they will take up science, general or applied, after their GCSE exam, not specifically mentioning chemistry, though.[54] Students do not seem to

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[54] Out of a class of eight A-level pupils, following Salters' Advanced Chemistry at a grammar school I was visiting in October 1991, seven students said they were considering to study some kind of *engineering* at university. A few students were more specific, mentioning: civil (1), physics (1) or chemical engineering (1).

perceive the topic metals as belonging to chemistry taken as a separate science, but rather as a topic having to do with science in general, which includes for them craft or engineering. This perception appears consistent with the intended CTS emphasis in the unit Metals. In line with this, students appreciate, for example, in the contexts of corrosion and burning, the general role of air rather than the specific role of oxygen. The new curriculum emphasis of the unit leads for the greater part of this group of students to an interest in a form of relevant science.

Therefore, on the basis of these responses, it is possible to say that the formal Salters' Science curriculum, as operationalized in the unit Metals (1989, and interpreted and taught through the unit Metals (1992) has been realized with the majority of these students *as far as* the motivation by CTS contexts and the learning of some CTS concepts are concerned. This is a remarkable conclusion, to which we will come back in section 5.4.5, after reviewing other relevant research.

5.4.2 Students' classroom experiences with Metals (1992)

It became clear from classroom observation that most students enjoyed the following activities: M1.2 “Hunt the Metals” (a word search), and the experiments M3.1 “What happens when iron rusts?”, M5.1 “Do all metals corrode?” and M5X2.1 “Do other metals stop iron from rusting?. They did not like so much activity M 6.1, “Alloys”, which is a question sheet with some text introducing the questions. As noted above (5.4.1), students do not seem to *dislike* any of the practical activities of the unit Metals, a perception largely supported by classroom observation. Thus, students liked about half of the activities contained in the unit Metals, while not disliking the other half (M1.0, M1.2, M2.1, M3A, M4.1, M5X1.1, and M6.1).

On the whole, the teaching approach followed by the teacher using Metals (1992) appears to motivate the students in doing the practical activities and helps them also to make sense of the latter, at least of the CTS content. The context-and activity-led approach is facilitated by the arrangement of four laboratory tables surrounded by stools, a facility common in science class rooms in English schools.

Thus, the audiotapes of the classroom discussions of students working through the activities of Metals (1992), partly reported on and discussed in section 5.3.2, and the observations of students' activities by the researcher in the classroom, largely confirm what students *said* they enjoyed as activities in the questionnaire.

On the other hand, the recorded classroom discourse also showed (5.3.2) that students have difficulty understanding, or are confused by the following PC concepts: density (M1), precipitate (M2), chemical reaction, compound, and element (M3), role of oxygen (M4), and reactivity series (M5). According to the teacher (T92) students had also difficulty understanding the concept of alloys, and the role of air, aside from water, in rusting.

Besides the CTS concepts rusting and corrosion and their prevention, emerging as relevant and useful concepts from the student questionnaire (5.4.1), we have seen that students in the classroom were active and successful in constructing the concept of the order of corrodibility of metals (5.3.2). In the lessons some students also came up with things from their daily life relating to metals, sometimes spontaneously, for example the use of solder in welding.

Thus CTS contexts appear not only to motivate students to undertake practical work, they also appear to help students with understanding the CTS concepts involved, apparently more so than with the PC concepts introduced. This conclusion concurs with the tentative conclusion reached above (5.4.1), while adding that CTS concepts appear to be more appreciated and understood than PC concepts.

5.4.3 Students' perceptions of Year Three trial units

The following brief summary of student feedback is based on Garforth's remarks as made in the interviews.[55] For practical reasons the next phase of the Salters' Chemistry Project, the design and trial of the GCSE exam course, used only feedback from teachers (sections 4.4.4 and 4.5.3).

The perceptions from a large group of students from ca. 200 schools, which volunteered as Project schools for the trial of Salters' Chemistry units Year Three (e.g. Metals, Trial Edition 9/84), are that students found the Year Three trial units worthy of study. Students said they enjoyed these units very much because they felt they were using things they understood or knew about. As one pupil expressed it: "This is the best thing I have ever done since I came to school" (G/W 91:18).

Teachers trialling the units said about their students that they were not only very *motivated*, that is, liked and enjoyed the units, but also showed improved practical as well as thinking skills and had learned at least the basic concepts. Some teachers, though surprised by the increased motivation and activity of their students, remarked that students "haven't reached the level of understanding that we would expect at the end of the third year" (G92b).

The latter remark points to a problem these teachers, but not so much their students, may have with a "Chemistry along with CTS content" course. These teachers seem concerned whether the new course would prepare their students adequately for the next level of school chemistry; that is, whether the Salters' Chemistry approach would offer all their students the expected or required level of PC content, i.e. chemical concepts and skills. The finding mentioned above (5.4.2), that students experience difficulties with learning a number of PC concepts, would be a major concern for these teachers. Many students do not seem to share this concern.

Student responses to the questionnaire on the relevance of the topic metals in daily life (5.4.1), students' classroom experiences with the unit Metals (5.4.2), and students' perceptions of the Salters' Chemistry trial units, all seem to point in the same direction. For the majority of students, the CTS emphasis of Salters' Chemistry, such as is present in the unit on Metals, apparently motivates students to acquire and apply relevant chemical knowledge. This makes such a CTS unit a worthwhile experience for them.

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[55] A full analysis of all the student perceptions available is not made here, but would deserve special study.

5.4.4 Review of relevant research on Salters' Chemistry / Science units

In this section, I will summarize and discuss the results of a number of studies into *the effects* of the context- and activity-based Salters' Chemistry/Science courses, in particular on students. This is done only to the extent that as these results are relevant for answering the question raised above, namely, to what extent a representative part of the formal curriculum of Salters' Science, like the chemical unit Metals (1989), has been realized with students in the classroom when taught by a teacher.

I start with the results of the study of Nicolson (1991), following this with a summary and discussion of the results of De Gier (1992), Borgford (1992), and Ramsden (1992, 1994, 1997). As noted above, it depends on the specific research question asked in these studies, and the methods or probes chosen there, as to the kind of results obtained.

Nicolson's study

In this discussion I will follow the summary of Nicolson (1991) as given in Campbell et al. (1994). Nicolson (1991) looks at the success of the GCSE Salters' Chemistry course, first examined in 1988, as measured by:

> … the number of users, and their satisfaction with the course after several years of use [and] … the number of students who choose to continue the study of science after completing their GCSE course (Campbell et al., 1994, pp. 440-441).

With balanced science becoming mandatory in the years before 1990, chemistry teachers, from 207 schools, entered an increasing number of their students for the Salters' Chemistry GCSE exam: 10,558 in 1988; 11,968 in 1989; and 12,177 in 1990. This overall increase of 1619 students (about 15 %) is an indication of the satisfaction teachers felt about the Salters' Chemistry course as "a solution to some of *their* current problems, as *they* perceive them" (ibid., p. 421; italics in original). The problems as perceived by the developers, and shared by the teachers taking up the GCSE Salters' Chemistry course, are:

- to provide a chemistry course which would be more accessible to students by making "links with the lives and interests of young people" (ibid., p. 418);
- to provide a sound basis for, preferably, an increasing number of students to pursue chemistry at a higher level of schooling.

Nicolson also compared (for a sample of 76 schools) the number of Salters' Chemistry students choosing A-level chemistry in 1988 with the number of students choosing A-level chemistry after completing a non-Salters' chemistry course in 1987. He found that the number of students choosing to continue chemistry after their GSCE Salters' Chemistry examination increased from 813 to 1118 students, which amounts to 37.5%. This increase shows that the second problem mentioned above has at least partly been solved. But as Campbell et al. (1994, p. 441) justly remark: "Increases in student *numbers* tell us nothing about the intervening process, or about the experiences of the teachers and the students *during* the course." Thus, whether the increasing student numbers have a sound basis to pursue chemistry at A-level remains a subject for further investigation.

Further, it is to be noted that the number of students choosing A-level chemistry, though considerably increased, constitutes still a minority of about 30 % of the total number of students (10,558) entered for the GCSE Salters' Chemistry examination in 1988.[56] Thus, the majority of students taking the Salters' Chemistry course do *not* choose to continue to study chemistry at A-level. This is quite a significant finding, since it makes the solution of the first problem, of providing an accessible and interesting chemistry course for *all* GCSE students, all the more important and necessary, even if the second problem is solved.

It is difficult to know, to what extent the overall increase of 15% in the number of students entered for the GCSE Salters' Chemistry exam could be attributed to the taking up of a chemistry course which would be more *accessible* to students, by making "links with the lives and interests of young people". How many students took up the course for this reason, and how many students took it because they wanted to continue to study chemistry at A-level? It is likely that the increase indicates that the first problem has at least been addressed, though it is very difficult to say to what extent this more tenacious problem has been solved, based on these numbers.[57]

In brief, the Salters' Chemistry course appears to enhance the interest in chemistry for a minority of students choosing to continue their chemistry study, and perhaps also to a small extent for the majority of students who, though they do not choose A-level chemistry, nevertheless need it as future citizens. As noted above, numbers alone cannot reveal just *what* it is in the Salters' Chemistry approach that works or does not work for either group. Case study research, based on structured feedback obtained by questionnaires and interviews from students and teachers, is needed to record and analyze the experiences of the teachers and the students during the course, preferably in combination with classroom-based research through observing, recording, and analyzing classroom discourse of students and teachers.

De Gier's pilot study

In a case study preceding and preparing for the more extended case study on Metals (1989) reported on in this thesis, De Gier (1992) probed a sample of 22 students using as data collection techniques: student questionnaires and observation and recording of classroom discourse of students, while trying to answer the following questions:

> How do students *experience* the science lessons?
> How do students seem to develop concepts? (ibid., p.1; italics in original)

The first question is very similar to the one I used (section 5.4.1) as a leading question for probing pupils' experiences with Metals (1989). The second question, unlike the questions in my questionnaire, focuses on students' learning of PC concepts.

In May 1992, De Gier investigated a couple of lessons of three other Salters' Science

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[56] This is assuming that the 207 schools entering Salters' candidates for the GCSE examination in 1988 would produce about the triple number of students choosing chemistry as the sample of 76 schools, which produced 1118.

[57] Another indication is given by the examination results of the students who have been taught the Salters' Chemistry course from 1986–1988: about 75 % of these students passed, in 1988, with grades A – D (OGT, p. 6). This result is similar to that found for students following traditional chemistry courses (Borgford, 1992).

Year 10 units: Making Use of Oil (MUO), Mining and Minerals (MM), Seeing Inside the Body (SB); and some lessons of one Year 10 Salters' Chemistry unit, Keeping Clean (KC).

With regard to the first question and based on her analysis of students' responses to the questionnaires she administered in the classroom, de Gier arrives at the general conclusion:

> So, students enjoy the lessons and the lessons do start from where they are and have an impact on their daily lives (ibid., p. 25).

More specifically, "most students think of *concrete, contextual examples* for what they found *most striking, or most important*" (p. 25; italics hers).

These conclusions concur with the ones I reached (section 5.4.1) for Metals (1989), including the effectiveness of some specific contextual examples or CTS activities for the acquisition and transfer of relevant knowledge, such as the practical HOW CAN AN OIL SPILL BE CLEANED UP? (MUO) and HOW CAN WE MAKE A SOAP (KC).

With regard to her second question and on the basis of the analysis of her observations and recorded student-student discussions, De Gier first notes a specific misunderstanding on the meaning of the term "state at room temperature" (p. 26), in connection with the concept of flammability. This misunderstanding hinders students in their execution of the practical, INVESTIGATING SOME PRODUCTS OF CRUDE OIL (MUO). Secondly, in group work on BUILDING MODELS OF HYDROCARBON MOLECULES (MUO), "there was a *tendency to go for easy, concrete explanations only*" (p. 26; italics De Gier).

Thus, she concludes that there are "*still problems with concept development for the students*" (p. 26; italics hers). This concurs with my conclusion in section 5.4.2 on the conceptual difficulties students have with some PC concepts of Metals (1992).

Borgford's study

In a case study, Borgford (1992) describes and analyzes a pilot implementation of a unit of the Salters' Science course, Transporting Chemicals (1990), at a U.S. high school in January-February 1992. In my summary here I will focus on the effects found on motivation and learning of about 100 students (14-15 year olds) in four traditional U.S. chemistry classes. The participating chemistry teacher had over twenty years experience: "he agreed to try something *new* and was intrigued by the *potential* for this approach" (ibid., p. 17).

After students "had completed 18 weeks of introductory chemistry" (p. 15), for five weeks classes were taught the unit Transporting Chemicals (TC) by the teacher and Borgford herself. The research methods used were a student questionnaire, a teacher interview, and classroom observation by the researcher, who also acted as teacher. Thus, in this research design, students experience the teaching of an *applications-first* Salters' Science course unit right *after* they have been taught (and internally examined/graded) an introductory *science-first* course for one semester. These students can therefore make a *direct* comparison, unlike the students experiencing the unit Metals (1992) or the students in the other studies reviewed.

After a unit test covering the work on the unit TC, students were asked to respond to a questionnaire (returned by 83 of 92 students present) consisting of twelve questions, six of which concerned students' experiences. Their responses to question seven and eight are particularly relevant here. With regard to question seven: "What part(s) of this unit, *Transporting Chemicals*, was (were) most interesting to you?", Borgford reports that students expressed most *interest* in the role-play activity about the site of a chemical plant (31), followed by the laboratory activities (16), the activity about hazard warning signs and how to transport chemicals (13), and finding patterns in the periodic table (8). Some students (7) liked all activities, some (3) liked none, some (3) gave no response. Borgford concludes (p. 22):

> The greatest interest was generated by those activities in which students were able to move around, discuss their work with others, use their own ideas and consider *the real world use of the chemicals*.

In response to question eight: "What parts, if any, did you not like – and why, in the unit TC", students responded that they did *not* like: conducting the role play (3), laboratory activities (14); learning about the nature of chemical transport (6); learning about the periodic table (9); work with formulae and equations (7), managing labs: keeping track, uncertain goals (4). A large number of students said they liked all parts (20); some gave no response (10); some (3) said they liked none, it was too easy; some did not like going to the library; one did not like the test.

Borgford remarks that "the number who liked learning about the actual nature of chemical transporting is twice the number who disliked this aspect" (p. 22) and, also, that only three students "specifically cited the role play as one they did not like, while 31 found it to be the most interesting" (p. 23). Both these activities, performed as they are in a CTS context, are much appreciated by the average student. Further, she notes that it is surprising that so few students gave *writing formulas* as an answer to Question 8, "a traditionally unpopular type of drill exercise" (p. 22), maybe because this PC concept is set in "a context like that of transporting and using chemicals" (p. 23). By relating students' responses to students' grades, she notes that the high achieving students, those who earned "A" grades (17), do appreciate all type of activities *equally* well, but "have mixed reactions to the effectiveness of learning through the Salters' approach" (p. 26). For example, one "A" student seems confused with the setting of PC content in a CTS context.

> The last lab had too much uncertainty involved. It was too inconsistent such as the differences between baking soda and club soda, but they were used for the same chemical (ibid., p. 26).

Thus, the appreciation by the average student of the use of CTS contexts for learning chemistry seems more positive than that of high achieving or above average students.

It is important to realize that, because of the research design used, students' responses might have been influenced to some extent by their expectations of what high school chemistry teaching should be about, since they had first been taught an introductory *science-first* course.

On the internal assessment of the unit TC, students performed at least as well on test items that require *understanding and application*, as they had earlier on the test of the introductory chemistry course, with "more traditional items requiring comprehension and recall" (p. 30). The items, used for the internal as well as external assessment of Salters' units such as TC, emphasize "the same higher order thinking skills that form the course" (p.13; p. 35).

The cooperating teacher's perception of the effect of the Salters' Science approach to teaching, using the unit Transporting Chemicals, on students motivation and learning, is on the whole favorable:

> I think most of the kids got a better understanding of *what* they were studying and *why* they were studying it. Kids could relate to some of the products and were really wondering – real inquisitive as to why they put sodium carbonate in Calgon or why this other chemical was in something else. They were genuinely interested in what was going on. *It (the chemical) has to serve a function* (ibid., p. 19).

However, the teacher expressed as a serious concern about whether the unit TC contained enough:

> *Hard college prep type chemistry* [such as] the gas laws ... grams to moles and these kinds of things – formula writing, equation writing, predicting products (ibid., p. 18),

Thus, the teacher is here referring to what I called PC content, preparatory school chemistry which he apparently thought appropriate for high achieving, science prone students.

Discussion

In her study, Borgford (1992) describes the Salters' design criterion two, *relevance*, as follows:

> Perhaps the most significant aspect of the Salters' approach [is] the introduction of basic chemical ideas through *situations in the everyday world* that are of interest to young people" (ibid., p. 9).

She also gives a formulation of design criterion three, *context-led development of concepts*:

> The Salters' approach departs from the traditional, then in two ways: Ideas are introduced in *any sequence* as they clarify chemical phenomena from everyday life and ideas that are *not needed are not introduced, even if they normally are part of a traditional sequence* (ibid., p. 9).

Both formulations imply, what I called (sections 4.1.3 & 5.1.3), a *strong* interpretation of these two central Salters' design criteria. For Borgford in her studies into the use and perceptions of the Salters' Science courses, design criteria two and three (above), together with design criteria four and five: *variety of teaching and learning activity* and *flexibility*, characterize the Salters' approach to science teaching.[58]

The perceptions of students and teacher, and her own classroom observations led Borgford to a conclusion remarkably similar (she notes) to the one she reached in her previous study that involved a number of schools in England in the consequences of adopting the Salters' Science course on science departments of schools, teachers, and their students.

> It seems clear from this and previous research that *general* student motivation *and achievement* is *enhanced* by the variety of activities and the general approach represented by such programs as Salters' for the *"average" or non-science-oriented students* (ibid., p. 28).

Using Roberts' (1988) concept of curriculum emphases, Borgford characterizes the Salters' Science approach as follows:

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[58] Borgford's interview with Francesca Garforth and David Waddington (G/W91) also mentions what I have called the first design criterion, *no preconceptions*, as referred to in Chapter 4.

> *A unique hybrid* of Everyday Coping, Solid Foundation, Science Skill Development, and Science, Technology, and Decisions (ibid., p. 28).

In other words, it was unique in the sense that it was a mix of an *applications-first* approach with the curriculum emphases Everyday Coping & Science, Technology, and Decisions, initially the main emphases of the course, and of a *science-first* approach with the curriculum emphases Solid Foundation and Science Skill Development, which became more prominent later. In Borgford's view, it is the use of chemical applications which leads to: "*fundamental* understanding which lays the *foundation* for further treatment in another *context* later on in the course" (ibid., p. 32).

The "unique hybrid" of the Salters' Science curriculum is, I think, to a large extent the result of the fact that the Salters' Science courses had to meet, more and more, the constraints set first by the GCSE exam, and later on by the successive versions of the National Curriculum (UK).

The GCSE exam brought in the emphasis on Solid Foundation as did the National Curriculum, the latter adding more emphasis on Science Skill Development as well. The latter development led to the so-called "investigative approach" demanding about 30% curriculum time.

It is to be noted that Borgford does not mention in her study on the unit Transporting Chemicals, any examples of an important consequence of the adjustment to external constraints of the Salters' Science course, that is, the introduction of more pure chemical concepts in Salters' Science units than *needed* to make sense of the contextual theme, which I found in the case of the unit Metals (see sections 5.2 and 5.3). In other words, she does not perceive a tension between the CTS contexts used and the PC concepts developed in TC or other Salters' Science units.

> Even with such broad treatment of science and its effects, *student understanding of traditional academic science ideas is a primary goal of the Salters' course.* It could be interpreted that such a course can serve the needs *both* of science education for the citizen and science education for the future scientist, in other words – Science for All (ibid., p. 36)

I see here a change in Borgford's characterization of the unit Transporting Chemicals, taken as an example of a Salters' Science unit. Initially, the unit Transporting Chemicals is characterized by her as an *applications-first* Salters' Science course unit, in which:

> Ideas that are *not needed* are *not introduced*, even if they normally are part of a *traditional sequence"* (p. 9).

Later on, the Salters' Science course is characterized, as we saw, as a mix of an *applications-first and a science-first* course, in which:

> Some would not *immediately* recognize the traditional science subject matter goals" (p. 36).

In Chapter 6, I will come back to this point in connection with some recent views of UYSEG developers on context-based approaches to the teaching of science (Bennett & Holman, 2002 and Millar, 2002).

Ramsden's studies

Finally, I will discuss the results of three studies performed by Ramsden (1992, 1994, 1997), in so far as they are relevant for my research into the experienced curriculum of Metals (1989).

Ramsden's study of 1992

The first study (Ramsden, 1992) concerns "*pupils' reactions* to context- and activity-based science" (ibid., p. 65), as offered by the Salters' Science Foundation full course trial units (1989). The study uses a sample of 124 pupils (59 female [F], 65 male [M]), that is, large enough to determine statistical significant differences in mean responses to the questionnaire (described below). It concerns a population similar to my qualitative research study (5.1-5.3), namely Year 9 pupils (aged 13 – 14, mixed ability, both sexes) being taught similar units in 1989-1990. Therefore, it seems appropriate to compare Ramsden's conclusions with the ones I have reached for the small sample (16) of pupils learning Metals (1992), as summarized above (5.4.1).

Science teachers from six schools, who had used at least eight Salters' Science Foundation units (including the unit Metals) without major alterations, were asked by Ramsden to administer to their students at the end of the school year, a questionnaire consisting of two parts. The first part listed six statements to which students were invited to respond on a five point scale (5: strongly agree; 1: strongly disagree). This generated 800 responses (356 [F], 444 [M]) which were processed statistically, in order to make comparisons *within* the sample in terms of mean responses to each of the statements below, differentiated for girls and boys.

1. I enjoyed this unit.
2. I enjoyed the practical work in this topic.
3. I enjoyed the non-practical work in this topic.
4. I felt the ideas in this unit helped me to understand more about some everyday events and problems.
5. I felt some of the things I learned in this unit would be useful in later life.
6. I felt this unit made me more interested in science (Ramsden, 1992, p. 67).

The second part of the questionnaire invited pupils to elaborate briefly and freely on their responses to these six statements. This generated 122 responses, this time qualitative data, placed by Ramsden into four broad groups: practical activities (50), non-practical activities (10), everyday future relevance (69), and other comments of interest (6).

She arrives at the following conclusions. The first conclusion, with regard to a possible differentiation for girls and boys, is that science appears to appeal equally well to girls and boys as a result of their experience with the Salters' Science Foundation units, though practical activities were "enjoyed significantly more than non-practical activities" by boys (ibid., p. 69).

Secondly, by far the largest number of students (69) commented positively on the "present and future usefulness" (p. 70) of what they had learned in the units. One student (M) really appreciated: "Finding out about things you need to know in our modern world to be able to be a better citizen" (p. 70), while another student (F) remarked: "I like finding out what goes on in everyday world" (p. 70). In my case study on Metals (1989), I was able to specify students' appreciation of "usefulness" by giving some concrete contexts students found relevant and useful, such as knowledge about corrosion, and rusting and its prevention (see also De Gier, 1992).

Thirdly, Ramsden (1992) reports that "one particularly noticeable feature of the responses made was the marked difference" (p. 69) in mean values for overall enjoyment of the units and increased interest in science. More specifically, "pupils' enjoyment of a unit did not necessarily correlate with a corresponding increased interest in science" (p. 69). It might be the case, she remarks, that "there is a mismatch in pupils' minds between the activities they were carrying out and their perception of what was appropriate for science lessons" (pp. 70, 71). Ramsden then draws the conclusion, albeit tentatively, that:

> Pupils appear to enjoy this type of approach but do not feel it constitutes 'science' (p. 71).

In other words, "If it's enjoyable, is it science?" (p. 65), as the title of her paper reads. This is, I think, a very interesting hypothesis[59] with which Ramsden can account for pupils responses:

> The things we did were *not* just what *scientists* need to know, they *help* in later life (p. 70).
> [The activities were] *not* just like *science* – they are *enjoyable and useful* for us (p. 70).

The hypothesis also seems to explain her second conclusion about students' high appreciation of the everyday future relevance of the course, and might even explain the first conclusion on the equal enjoyment of the course by girls and boys. As concluded above (5.4.1), students perceive and experience that, in particular, the CTS contexts and activities (such as the CTS contexts in the unit Metals, 1992) are "enjoyable and useful" for them, and they perceive and experience that they are able to use the acquired relevant chemical concepts in similar everyday life situations.

Ramsden's Study of 1994

The main purpose of the second study (Ramsden, 1994, p. 9) is to explore:

> "... teachers' perceptions of some of the effects of the Salters' Science GCSE course on their 15 and 16 year old pupils by interviewing teachers involved with the teaching of the course in their schools."

Ramsden used "semi-structured in-depth interviews" (ibid., p. 9) with eleven teachers at six *project* schools involved in the trial of the Salters' Science exam course, "providing systematic feedback on the materials as they used them" (p. 9). The basis of the interview, preceded by some questions about teachers' backgrounds, was formed by six general questions (Q7 – Q12) on students' responses to the course. The intent was to probe "initial answers more deeply with specific follow-up questions on particular activities mentioned by the teachers".

Q7 In general, which aspects of the course do you feel students particularly enjoy, and why?
Q8 In general, which aspects of the course do you feel students are not particularly happy with, and why?
Q9 What changes, if any, have you noticed in terms of students' involvement of lessons?
Q10 What changes, if any, have you noticed in terms of students' general attitude to science?
Q11 What changes, if any, have you noticed in terms of students' learning?
Q12 In your view, what has been the most noticeable effect on your students of adopting Salters' Science?

With regard to Question 7, there was a "consensus of opinion about the *motivating* effects of the use of everyday starting points and applications" (p. 10), which is supported by the results of Ramsden (1992) on students' high appreciation of the everyday future relevance of the course. Secondly, "the study also offers some support in very broad

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[59] See also Aikenhead (1994, p. 178) who calls this "an intriguing result".

terms for the *motivating* effects of the use of a wide *variety* of learning strategies in science lessons" (p. 14). With regard to Question 8, teachers' comments were mainly on "the practical aspects of problems associated with a heavily *worksheet-based* course" (p. 12). With regard to Questions 9 and 10, four teachers perceived a specific improvement in pupils' involvement. For example:

> They are in general much more enthusiastic about the subject. It's not difficult to persuade them to opt for science (...). I suddenly thought for the last two years, no one has said to me, '*Why are we doing that, sir?*' – and that happened quite a lot in the past. (Teacher L, School 5)

The majority of teachers, though, said that "they felt it was actually very difficult to make very definite comparisons and judgements" (p. 12). With regard to Questions 11 and 12, teachers experienced a similar problem. Although specifically asked to name any activities "which they felt made a particular piece of science *easier or more difficult for pupils to understand*" (p. 12):

> None of the teachers was able, at this point, to give *an example of an activity* which they felt had either contributed to an improvement in pupils' *understanding* of a particular topic or enabled students to *use* their scientific knowledge to inform discussions on issues of concern. (Ramsden, 1994, p. 12)

This is not only the case, Ramsden notes, for teachers who are relatively new to the materials, but also most striking for the Heads of Science (4) who were responsible for the introduction of Salters' courses in their schools, and for the teachers (3) who had used Salters' Chemistry prior to Salters' Science. What she concludes from the data, is, that: "*the general classroom atmosphere* is of paramount importance to teachers" (p. 13). More particularly, that:

> "... the teachers carry with them an in-built assumption that a classroom atmosphere with 'a real buzz in it', where pupils appear to be engaging readily and with interest in the tasks set, enhances learning and improves pupils' more general views of the subject (p. 13).

My case study on Metals (1989) showed that students in the classroom are "engaging readily and with interest" in the CTS contexts and activities of the lessons of the unit Metals such as the ones on rusting, and corrosion and its prevention. They were able to use or apply the acquired relevant chemical knowledge in similar assignments. These findings, as may be expected from a case study, add some interesting detail to the general conclusion above.

Ramsden's study of 1997

Many teachers take a sympathetic view to the Salters' Science approach, where "scientific concepts are encountered on a '*need-to-know*' basis, as they arise in particular contexts" (Ramsden 1997, p. 697). Some of them, though, such as the American teacher quoted above in Borgford's study, are rather concerned about how well a context-based science course prepares their (more able) students for external examinations (see also section 5.4.3).

Unlike traditional, linear courses where ideas "are generally treated *in depth* as they are encountered" (ibid., p. 698), for context-based courses "it would be difficult to cover all aspects of these ideas in this single context, and they would need to be *revisited* at other points and *in more depth* for understanding to develop further" (p. 698).

In order to investigate the effectiveness of this so-called "'drip-feed' approach to concept development" (p. 698), Ramsden performs a comparative study in which she analyzes the differential effects of the context-based Salters' Science course and conceptually structured traditional GCSE courses on pupils' understanding of pure chemical concepts. In the quantitative part of this study she administers first a set of structured diagnostic questions on four key chemical ideas to a *matched* sample of 84 (2 x 42) students, that is, a sample from each group with a similar "distribution of predicted grades" (p. 702) to enable statistical comparison. With regard to the key chemical ideas, Ramsden states that:

> The four key chemical ideas form part of the *majority* of high school chemistry courses and are *central* to a pupil's understanding of chemistry at 16+. They are also ideas which are necessary for embarking on *further* study." (p. 698).

The diagnostic test consisted of ten questions: two questions per key chemical idea except for the key idea Periodic Table which had four questions. The key chemical ideas were:

- *elements, compounds and mixtures*: microscopic representations of matter (Q1); properties of matter (Q7)
- *conservation of mass in chemical reactions*: precipitation (Q2); as a means of predicting reacting quantities (Q6)
- *chemical change*: formation of new substances in a chemical reaction (Q4, Q5)
- *Periodic Table*: trends down a group (Q3); similarities within a group; as a means of predicting properties of compounds, as a means of predicting formulae (Q8, Q9, and Q12)

The students probed were of upper or middle ability, likely to go on to take A-level, as judged by their predicted GCSE grades, and were drawn from four schools following the Salters' GCSE course and four schools following traditional GCSE courses. The test was given to these 15–16 year old pupils about a month before their GCSE exam. They had about one lesson (40-50 minutes) to complete the test, which they were invited to consider as a kind of revision. Pupils were asked to give short answers to the questions and also to provide an *explanation* for each answer. Pupils' responses were marked (two points maximum per question) and processed statistically.

Ramsden's general finding is (p. 705):

> The average mark for all Salters' pupils completing the questionnaire was 9.22, compared with 9.48 for non-Salters' pupils. [adding that] ... this difference was statistically insignificant.

This is good news, she remarks, since it shows that Salters' pupils do not perform significantly different from non-Salters' pupils with regard to these PC concepts. There is also bad news mixed in, Ramsden notes, since the analysis of the responses also shows that *all* pupils, whether Salters' or non-Salters', have a poor grasp of some key ideas of chemistry, as reflected in their average mark which is about half the maximum mark. The following key chemical ideas appear to be understood by *under* 25 % of the pupils:

- conservation of mass in precipitation reactions, and as a means of predicting reacting quantities;
- the periodic table as a means of predicting properties of compounds, and as a means of predicting formulae; and
- key chemical ideas which appear to be understood by between 25 and 50 % of

> pupils are aspects of chemical change and trends down a group of elements in the Periodic Table.

In the second, qualitative part of this study the pupils of the full sample (216) were asked to mention aspects of their chemistry course which they enjoyed, what courses they intended to follow after their GCSE exams, and to give their reasons for making the latter choices.

In general pupils liked the practical work, and disliked "writing ... calculations, formulae, balancing equations, and 'all that stuff on moles'" (p. 709). Only about 10 % of the Salters' pupils (12 out of 124) explicitly commented on the *relevance* of the chemistry course to their lives, while *none* of the non-Salters' pupils made any such remarks, thus revealing "the one very noticeable difference" (p. 709) in the effect of Salters' and non-Salters' courses on pupils.

Salters' pupils said they appreciated the "real life things ... or things outside school" (p.709), that is, the "relevance to their lives of what they had studied." (p. 710). As one pupil put it:

> I have enjoyed finding out about things which will be *useful* in future. Because it's *interesting* I still try to do it even if it is hard (Ramsden, 1997, p. 709).

Finally, about 15 % of the upper and middle ability students mentioned that they hoped to go on to study A-level chemistry. Just over 80 % said they were not choosing science subjects "because they were not needed for their career plans" (p. 709) in the field of business, accountancy, media studies, and arts subjects.

In conclusion, a majority of upper and middle ability students of the sample of students investigated, experienced conceptual difficulties with about half of the key chemical ideas central to high school chemistry, irrespective of whether they followed a Salters' or a non-Salters' science exam course. A minority of the full sample of students said they would go on to study A-level chemistry, while a small minority, only *Salters'* students, said that they were motivated by the *relevant* emphasis of the Salters' Science exam course.

If these conclusions apply to the more able students, what about the less able students? I cannot help remembering here what Francesca Garforth said, having found out how many conceptual difficulties her O-level students in the seventies still had.

> If the able ones are suffering, the less able ones were probably suffering more (G92b).

5.4.5 Discussion

Having discussed my own findings on the experienced curriculum of Metals (1992) and reviewed the findings of some other relevant studies with regard to the experienced curriculum of Salters' Science/Chemistry, I come back to the questions put forward in the introduction of this section. Are students motivated by the kind of contexts and activities provided by the interpreted and taught curriculum? Do they acquire, apply and use the intended content of the unit Metals (1992), as entailed by these contexts and activities, and as interpreted by the teacher?

Inspection of Figure 5.17 below shows that all studies indicate an overall *positive* *effect* of the context- and activity-based Salters' Science course on students' motivation, with only Ramsden (1997) reporting a relatively small effect. The enhancement of students' motivation has been attributed by Ramsden (1992) to an improvement of the general classroom atmosphere. In the classroom-based case study, reported on in this chapter, I found some *specific* CTS contexts motivating and enabling students to learn some relevant and useful concepts, that is, to acquire some CTS concepts and transfer them to similar CTS contexts (local transfer). Because these selected contexts originate from everyday life, they are perceived by students as worthwhile or meaningful. Students are therefore clearly focused on the activities that explore these relevant contexts from which chemical-societal concepts such as corrosion are developed, and which are needed in order to make sense of those contexts. Students work on these activities, individually or in groups, showing improved practical skills in the process.

Secondly, many of the difficulties pupils have in understanding PC concepts, as found in the case study on Metals (1992), are also found in other studies, especially in the comparative study of Ramsden (1997). The exception here is Borgford (1992) who does not report any learning difficulties.

Thus, pupils have difficulty understanding chemical concepts such as oxidation, reactivity series, alloy/mixture, formulae, chemical reaction/change (see also section 5.3.4). These are all *pure* chemistry concepts, and as such, part of the currently dominant school chemistry curriculum as described in Chapter 2. This is a kind of school chemistry particularly relevant for future chemistry students, usually a minority of the population of the pupils following science or chemistry lessons, and referred to as "hard core college prep chemistry" by the American teacher in Borgford's study.

None of the studies reviewed mention *specific* examples of PC concepts which are introduced but which are not really needed to make sense of CTS contexts, such as the chemical concepts I found in my case study on Metals (1989, 1992), like oxidation, reactivity series, compound, and formulae. Deliberately *not* introducing such PC concepts would be consistent with design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, and could lessen or perhaps avoid a number of the conceptual difficulties of pupils mentioned above. Finally, the Salters' Science course appears to benefit mostly the more able or high-achieving 14-16 year old students, just as a traditional science course would do. On the other hand, the less able or average 13-14 year old students are relatively more motivated by, and derive greater enjoyment from, the Salters' Science course, perhaps because the course communicates to them a non-traditional emphasis in terms of the usefulness of science and its relationship to real life.

This brings us back to the relationship between the quality of the provided curriculum, as characterized in this chapter (sections 5.1-5.3) on the basis of my research, and the quality of the Salters' Science curriculum as experienced by students, based on other research (section 5.4). Thus, with regard to the enhancement of the motivation of the average student, the formal curriculum of Salters' Science, as exemplified and taught by the chemical unit Metals (1992), appears to be largely realized. As for the average student's conceptual understanding, this is largely achieved for a number of CTS concepts such as corrosion and rust and its prevention, but rather weakly for many PC concepts introduced in the unit Metals (1992).

This seems a remarkable conclusion, given that the analysis above has shown that the unit Metals (1989) is not developed (5.2), interpreted (5.3.1), or taught (5.3.2.) fully in accordance with design criterion two, *relevance*, and design criterion three, *context-led*

Figure 5.17 Summary findings experienced curriculum *

STUDY PROBE	GENERAL MOTIVATION BY CONTEXT	SPECIFICALLY MOTIVATED BY CTS CONTEXTS	LEARN, ACQUIRE AND TRANSFER CTS CONCEPTS	LEARN PC CONCEPTS	POST GCSE STUDY CHOICE OF STUDENTS
Van Berkel: Questionnaire sample of 12 students (section 5.4.1)	Eight students	Yes, relevant contexts are effective	Yes, but only with familiar situations	—	Science (7) Not science (5)
Van Berkel: Classroom observation (section 5.4.2)	Yes, on the whole	Yes, relevant contexts	Yes, e.g. corrodibility order	Some difficulties and confusion	—
Evaluation of ca. 200 schools (section 5.4.3)	Yes, enjoyable	Yes, by useful contexts	—	At least basic concepts	—
Nicolson (1991): Comparative study schools (76 out of 207)	Increasing numbers of entries	—	—	—	Choice students for A-level increases 30%
De Gier (1992): Questionnaire (22 pupils)	Yes, enjoyable; impact on daily life	Yes, relevant	—	Some difficulties and confusion	—
Borgford (1992): Case study (100 students)	By CTS contexts, labs, and activities with *function*	Yes, role play transport and labs	—	Concern of teacher; yes, general achievement	—
Ramsden (1992): Questionnaire/ statistical study (124 pupils)	Yes, on the whole equally for girls and boys	Boys more than girls by practicals; usefulness	—	no correlation enjoyment with interest	—
Ramsden (1994): Case study: 11 teachers on their pupils (15 – 16)	Yes, consensus, general classroom atmosphere	Variety, maybe; no specifics	No specifics	No specifics	—
Ramsden (1997): Comparative study (84 able students)	—	About 10% of students	Not probed	Considerable conceptual difficulties	15% chose chemistry

* The symbol (–) indicates that this topic is not probed in this study.

development of concepts. Thus, in view of the relatively low CTS/PC ratio provided by the teacher, it is surprising the extent to which the new characteristics of the Salters' Science foundation unit Metals comes across in students' motivation and learning. It is also interesting that the new CTS emphasis of the curriculum seems to appeal to students regardless of the label put on the curriculum unit used: chemistry, science, or maybe even engineering. In brief, students perceive the CTS content of Metals (1992) as "worthy of study", that is, as motivating and meaningful to learn. At this point Ramsden' s query: "If it's enjoyable, is it science?" again comes to mind.

Apparently, students are able to perceive and experience that they have been offered *something* different from what they would have expected from previous school experience, their expectations perhaps being based on science lessons in the first two years or on an image of science communicated to them at home or by the media. That they enjoyed, found useful, and became interested in the units of the Salters' Science Foundation course such as Metals could mean that *what* they actually enjoyed is indeed different from a traditional or normal science course. Perhaps these pupils did experience to a certain extent an *alternative* science course developed, interpreted, and taught with an emphasis on everyday life, and technological and societal aspects of science as much as on purely scientific aspects,

In view of this, increasing the CTS/PC ratio of the developed, interpreted and taught Salters' Science units such as Metals (1989), in accordance with design criterion two, *relevance*, and consistent with design criterion three, *context-led development of concepts*, is likely to increase pupils enjoyment, motivation, and understanding even more. In Aikenhead's terms (5.1.4), this would mean providing pupils with a SCIENCE ALONG WITH STS CONTENT course rather than with a SCIENCE THROUGH STS CONTENT course.

5.5 Conclusions

In this section, I summarize the findings of the consistency analysis of the Salters' Science unit Metals (1989; 1992), point to *relationships* among these curriculum findings, and to the findings of the curriculum analysis performed on the Salters' Chemistry course in the previous, complementary, chapter (5.5.1). Subsequently, the curriculum findings of Chapters 4 and 5 are discussed and explained in terms of my theoretical curriculum framework (5.5.2).

5.5.1 Analysis of unit Metals and Salters' Chemistry

First, I will summarize the findings of the analysis of the formal curriculum of the *chemical* component of the Salters' Science Foundation course as exemplified by the unit Metals (1989), that is, the findings of the analysis of its operationalization in the lessons of the unit by the developers (section 5.2), its realization in the classroom by the teacher (section 5.3), and in the learning by the pupils (section 5.4). The distinctive curriculum levels – the visionary, written, formal, interpreted, taught, and experienced levels – have enabled me to categorize the curriculum findings in terms of these curriculum levels, and will enable me here to point to relationships among the different curriculum levels, and to explain these curriculum findings and relationships in terms of my theoretical curriculum framework.

Formal and written curriculum

The consistency analysis of the central design criteria two and three, *relevance* and *context-led development of concepts*, of the Salters' Science approach, performed at the level of the *lessons* of the unit Metals (1989), shows that more PC content and less CTS content has been developed than is consistent with these two central design criteria. Thus, the CTS/PC ratio of the *written* curriculum of the unit Metals (1989) at the level of the lessons of the unit is substantially smaller than the CTS/PC ratio of the formal curriculum. See for the latter the content analysis of the *unit as a whole* on the basis of the overview of the unit and the key teaching points of the lesson plan of Metals (1989) as given by the developers (Figures 5.6 and 5.7). As a consequence, a *tension* surfaces in a number of lessons of the unit Metals (1989) between overdeveloped PC content and underdeveloped CTS content.

Written, interpreted and taught curriculum

Secondly, the analysis in section 5.3 showed that the teacher deleted some CTS contexts and added some PC concepts, choices inconsistent with design criteria two and three, *relevance* and *context-led development of concepts* (Figures 5.15 and 5.16). Hence, compared to the *written* curriculum of the unit, the CTS/PC ratio has decreased substantially further, both for the *interpreted* curriculum and for the *taught* curriculum of Metals (1992). Consequently, in the process of teaching Metals (1992), at least in some lessons of the written unit, the tension between overdeveloped PC content and underdeveloped CTS content increases (as mentioned above) to become somewhat larger.

The way Metals (1989) was adapted by teachers and interpreted for the supported self-study approach ('Circus') is a good example of putting into action design criterion five, *flexibility*. It shows that the formal curriculum (Metals, 1989) leaves room for a *science as process* interpretation which leads to a different realization of the Salters' Science curriculum in the classroom. The teaching of Metals (1992), within the constraints set by the National Curriculum, also shows some problems in the teaching-learning process with the implementation of design criterion four, *variety of teaching and learning activities*, in that some CTS contexts are deleted, and some PC concepts are added. Further, the emphasis on teaching *routinely* trained scientific skills leads to a diminishing *variety* of teaching activities and a corresponding decrease in student activity, which could be connected with the decreasing CTS/PC ratio.

Taught and learned curriculum

Students appear to appreciate the CTS content offered to them in the taught curriculum (Metals, 1992), apparently more than they would have expected from their previous school experience with science curricula. They perceive in the classroom teaching, as it were, a higher CTS/PC ratio than they would have expected, and they achieve better learning results with the CTS contexts and activities than with the PC concepts. Ramsden (1992) first noted the remarkable *discrepancy* between students' perception of the taught curriculum of Salters' Science in terms of enjoyment and usefulness, and their expectation of a traditional school science curriculum, usually perceived as abstract and irrelevant, while lacking the former qualities.

Visionary, written, interpreted, taught and learned curriculum

It can be seen that Figure 4.4 shows that the CTS/PC ratio is steadily decreasing for the different operationalizations of the visionary curriculum of the Salters' Chemistry course as a whole. In Figure 5.5 the CTS/PC ratio is steadily decreasing for the different curriculum levels of the unit Metals (1987). The latter unit became part of the Salters' Science course as Metals (1989), was interpreted by teachers as Metals (1992), and was subsequently interpreted and taught by a teacher, and experienced and learned by students in the classroom.

As explained in section 5.1.4, this decrease in the CTS/PC ratio can be taken as a measure of the *degree of escape* of the visionary curriculum of Salters' Chemistry from NCE, as embodied by the O-level school chemistry curriculum in England in the 1980s, when it is realized by developers in the designer's room and teachers in the classroom. It shows how the differences between dominant school chemistry and Salters' Chemistry at the level of the visionary curriculum gradually diminish at the consecutive curriculum levels: formal, visionary/written, taught, and experienced levels.

5.5.2 Curriculum findings and relationships

Visionary and written curriculum

The findings summarized above raise the following question: Why have the developers of Metals (1989) not been able to adhere more consistently to the central design criteria of the Salters' approach, *relevance* and *context-led development of concepts*? As argued above, they have increasingly been held back by external constraints, and were probably also influenced by an internal constraint, which derives, as the developers say, from "the structure of school chemistry as we all perceive it" (L92). A specific description of this internal constraint, called *dominant school chemistry,* has been given in Chapter 2, which as I argued there, is a form of Normal Science Education. The external constraints operative on the developers stem mostly from the different versions of the National Curriculum (1989, 1992).

Written and taught curriculum

The findings summarized above raise also another question, namely, why has the teacher of Metals (1992) not been able to adhere more consistently to the central design criteria of the Salters' approach, *relevance* and *context-led development of concepts*? Teachers have, of course, a strong obligation to teach the chemical content required by the syllabus, whether it is taught by way of a traditional textbook or by way of innovative CTS units such as Metals (1989). Teachers often consider as their overriding aim the preparation of their students for tests and examinations which in England must follow, up to Year Eleven (16 year olds), the requirements of the National Curriculum. Thus, bound by these external constraints and, as I argued, also by an internal constraint, teachers can be led to introduce more PC content and less CTS content than consistent with the central design criteria. Both Salters' developers and teachers had to work within the same set of external and internal constraints, but for teachers the pressure to comply with them is greater. After all, teachers are much more directly involved in, and responsible for, a proper preparation of their students for examinations and the stress on PC content and skills that this implies.

Furthermore, teachers may find themselves constrained by the course units they use in their teaching, which for them might contain unexpected tensions between curriculum emphases. The point is, that the interpreted and taught curricula are partly a function of the *written* curriculum. That is, teachers have to interpret and teach the written units *including* any tensions, intended or not, built into their design, in this case the tension between CTS content and PC content.

It appears difficult for a Salters' teacher to deal with this tension between PC content and CTS content. Having chosen to trial or teach units of the Salters' Science course, a Salters' teacher will probably not expect this tension. Because the first design criterion, *no preconceptions*, is not explicitly stated in the units, it will be very difficult for a teacher to be conscious of the role that the preconceptions of developers might have played in the design process or to stay alert to the role the teacher's own preconceptions play in the interpretation and teaching of the written unit to his or her students. Thus, the effects of the tension between CTS content and PC content built into a unit such as Metals (1989) will be felt by the teacher, if at all, only during the actual teaching of the lessons of the unit.

The internal constraint, that is, "the structure of school chemistry as we all perceive it" (L92) can pull teachers away from the new CTS emphasis of the course. This can happen implicitly as in the case of the teacher described above (5.3.3), or sometimes explicitly, as in the case of the science course called the 'Circus' (5.3.2), where teachers gave explicit emphasis to scientific processes, and also added some PC content.

Finally, the actual teaching had to conform increasingly, from 1989 onwards, to the demanding external constraints of the National Curriculum, which gave much more emphasis to PC content than to CTS content. Thus, a teacher's preference for an STS curriculum must be very strong indeed to go against the external *push* of the requirements of the National Curriculum, the *pull* of teacher's own internal constraints, and the *tension* in the composition of the unit as designed by the Salters' developers.

Taught and learned curriculum

Although offered to them with a relatively low CTS/PC content, students (13-14 year olds) are able to perceive the new CTS emphasis of Foundation units such as Metals (1989), and to some extent, too, the tension between this new CTS emphasis and the traditional PC emphasis.

Their perception of this tension could be paraphrased for school science as follows: 'If this is science, then we want it, since it is relevant and useful for us.' However, when students later follow the Salters' Science GCSE exam course and approach their examination, their perception might change as a result of having to study relatively more PS content, while the STS content they favored comes to play a minor role. The examined curriculum, represented by examination papers, might differ from the Salters' Science curriculum as perceived or experienced by pupils in their first encounter of Salters' Science in the transitional Year Three (Nine). Indeed, it will probably be closer to the initial expectation students had of traditional school science.

Visionary, written, taught and learned curriculum

Regarding the written curriculum, the lessons of the unit Metals (1989) treat more PC content than needed for the CTS theme *corrosion*, and seem thereby to address the needs of potential chemists more than the needs of actual citizens. The unit Metals, taken as representative of the Salters' approach, has a dual emphasis, both in content and aim, which as we saw above is not removed during teaching. The greater emphasis put on PC content [Sub], which goes to some extent against the central Salters' design criteria, is related to the greater emphasis on preparing future science students, and future scientists [Ped/A], which is in line with the overall emphasis of the National Curriculum.

As argued in Chapter 2, the currently dominant school chemistry curriculum has to be taken as a rigid combination of a specific substantive structure based on corpuscular theory, a specific philosophical structure called educational positivism, and a specific pedagogical structure involving initiatory and preparatory training of future chemists. This applies not only to the levels of the designed, written, and formal curricula, but also to the level of the visionary, interpreted and taught curricula. The rigid relationship between the substantive structure [Sub], philosophical structure [Phil], and the pedagogical structure [Ped] of school chemistry manifests itself here *at the level of the taught curriculum*, that is, in the teaching approach used [Ped/TA] by deleting some CTS contexts and adding some PC concepts. It also reduces to some extent the variety of teaching methods and activities of students [Ped], and it changes thereby the original STS-oriented substantive and philosophical structures.[60]

Thus, the tension between PC content and CTS content appears related to, and probably stems from, the dual aim of the Salters' Science course, which is to prepare students for future study in chemistry *and* to make chemistry accessible and relevant to all students, the sum of whom are viewed as future citizens.

It is important to realize that these curricular findings must be attributed to three main causes:

- A *compositional* constraint set by the written units, in this case, a dual emphasis both in content and aim, from which emerges a tension between PC content and CTS context;
- An *internal* constraint of teachers, that is, the preconceptions of teachers with regard to school chemistry as internalized through education, training, and previous teaching practice;
- The *external* constraints of the educational system, here the National Curriculum of England and Wales as operative on teachers during the period in question.

Together these constraints make it very hard for teachers to choose and adhere consistently to a preferred, strong interpretation of the central design criteria of the Salters' approach, certainly when internal and external constraints pull them in the opposite direction.

Developers are caught up in constraints, too. Not only did the developers described in this research have to work under increasingly stricter external constraints in England in the 1990s, they were also influenced by an internal constraint. The latter, the conceptual structure of school chemistry as most of them perceived it, exercises an important but largely implicit influence on developers. The consistency analysis of the unit Metals

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[60] Generally speaking teachers operate, in these cases, under a rigid combination of specific substantive, philosophical and pedagogical structures. If compared with the concept of pedagogical content knowledge (PCK) as developed by Shulman (1986,1987), one could speak of a combination of pedagogical, philosophical, and substantive knowledge, or more in line with PCK of rigid *pedagogical, philosophical content knowledge* or PPCK. Interestingly, in developing the PCK concept Shulman builds on the work of Schwab (1978).

(1989) in section 5.2 has made this clearly visible. (See also the comparison of the content of the successive units of Metals (1984, 1987, 1989) in relation to the strength of the external constraints as given in Figure 5.14.) Thus, the rigid relationship between the substantive structure [Sub], philosophical structure [Phil], and the pedagogical structure [Ped] of school chemistry manifests itself here at the level of the *designed, written, and formal* curricula, as we have seen in Figures 4.3, 4.7 and 5.7.

Obviously, developers *must* 'match' their visionary or ideal curriculum to the realities of educational practice, but to some extent they end up matching their vision *internally* to the current structure of school chemistry, not withstanding their explicit intention and sincere attempts to get rid of preconceptions with regard to what school chemistry should provide traditionally. We are now in a better position to understand what *matching* a vision or ideal to the realities of educational practice entails for developers and teachers, formulated in terms of the *external, internal, and compositional* constraints.

First of all, it is obvious that both developers and teachers have to 'match' their ideal to the constraints operative in a particular education system, if and when they want to realize and implement the units, produced as visionary/written forms and trialled on a larger scale, and gain the whole acceptance as a national examination course.

Secondly, and less obvious, developers as well as teachers appear to match the envisioned and written curriculum, in their *practice* of developing and/or their *practice* of teaching, to an internal constraint, which I have described (Chapter 2) as *dominant school chemistry*, or the conceptual structure of chemistry as most developers or teachers perceive it.

Thirdly, for teachers working with the 'finished' products of the developmental process – the units of the course, matching also means interpreting and adapting the visionary/written teaching materials, such as the unit Metals, to the realities of their classroom and school, including any *compositional* constraints with regard to a dual emphasis on aims and tensions in the kind of content (PC or CTS) to be taught.

Fourthly, it probably takes several trials and revisions before the set of design criteria are sufficiently articulated to make it possible to claim validly that the units are developed according to the thus 'discovered' and articulated design criteria, while having collected enough classroom-based evidence to back up this claim. So, finally, for developers working with a set of design criteria – the point of which is that they must be articulated and operationalized in the process of development – matching becomes an *inherent* part of the design process.

6 Beyond current school chemistry: Perspectives on chemistry at school

In this chapter, I will summarize the answers with regard to the research questions formulated in Chapter 1 of this thesis, as listed in Figure 6.1 (reproduced from Figure 1.5). First, I summarize and discuss the answers to the first three research questions, which are related to the structure of the current school chemistry curriculum (6.1). Second, I summarize and discuss the answers to research questions five and six, which are related to attempts to escape from the structure of the current school chemistry curriculum (6.2). Third, based on my research findings, its implications, and my explanations of them, I will formulate a number of recommendations for reforming the currently dominant school chemistry curriculum, thereby answering research questions four and seven on the conditions of escape (6.3). While discussing the answers given to my research questions in previous chapters, I will point to the most important implications of the research findings, and give functional explanations of the curriculum phenomena found. Finally, I will give some suggestions for further research by looking back and reflecting on the research reported in this thesis (6.4).

Figure 6.1 Research questions

1. What is the structure of the current school chemistry curriculum?
2. Why is this structure the way it is?
3. Is this structure a desirable structure?
4. What are conditions for escape?
5. To what extent does the Salters' Chemistry curriculum escape from this structure?
6. Why is it so hard to escape from this structure?
7. How can attempts to escape from this structure be more successful?

6.1 Curriculum analysis of current school chemistry

In this first section, I summarize and discuss the answers reached in this thesis for the first three research questions (Figure 6.1) that are related to the structure of the currently dominant school chemistry curriculum. Thus, I will give the main characteristics of what I called Dominant School Chemistry (6.1.1), explain its properties and relationships in terms of Kuhn's functional theory of scientific education (6.1.2), and discuss the appropriateness of the current function of Dominant School Chemistry (6.1.3).

6.1.1 Dominant School Chemistry

We started (De Vos et al., 1991; De Vos, 1992) by answering the question: What is the hidden structure of school chemistry? The initial answer was a hypothesis on the *Coherent Conceptual Structure of School Chemistry Curriculum* (De Vos et al., 1994), which was tested in the form of *Ten Statements* (Figure 1.4) by way of a semi-structured survey of an International Forum of twenty-eight researchers and developers in chemical education, and of a Dutch Forum of twenty-two researchers and developers in chemical education (see sections 1.2.2 and 1.2.3).

The *problem of structure* was initially taken by us as a problem of the hidden *conceptual* structure as present in school chemistry curricula, and described in terms of chemical concepts and their structural relationships. In the course of the analysis of the International Forum responses, the problem was reformulated in terms of three substructures: the substantive, philosophical, and pedagogical structures of the school chemistry curriculum (see Figure 1.1). The problem thus became one of characterizing the three specific substructures composing *the currently dominant school chemistry curriculum*, and of characterizing their specific relationship.

For the sake of analysis and discussion in this Chapter, I will first give a summary of the most important characteristics found for the substantive, philosophical, and pedagogical structure of the currently dominant school chemistry curriculum. Second, I will discuss the relationships of the school chemistry curriculum as a whole. Together, this will constitute my answer to the first research question: *What is the structure of the current school chemistry curriculum?*

Substantive structure of current school chemistry

The currently dominant substantive structure of the school chemistry curriculum is not only built around, but also often starts from, corpuscular concepts. Compared to Coherent School Chemistry (see section 1.2.2), the *structural* relationships of Dominant School Chemistry are partly implicit, incomplete, and incoherent, as I have analyzed in Chapter 2 and summarized in Figure 6.2 below. It is important to note that the choice for a substantive structure of school chemistry in terms of corpuscular theory has implications for the nature, scope, and sequence of related concepts developed in the curriculum, choices which also reflect views on the philosophy and pedagogy of chemistry.

Figure 6.2 Substantive Structure of Dominant School Chemistry

CATEGORIES	SPECIFICATIONS BASED ON INTERNATIONAL FORUM RESPONSES
Chemical concepts	– chemical (pure) substances and their properties, elements, simple reactions – stoichiometry, balanced equation, formulae – taxonomy of substances and reactions – periodic system – atoms, valence and bonds
Chemical relations	- demarcation, mostly implicit, from: common sense, everyday life and society, technology, history/philosophy of science, physics, and research – implicit (partly incomplete) relations among chemical reaction, chemical substance, and chemical element – reaction conditions often implicit, incoherent, and partly incomplete – conditions for existence of substances are presented only as fragments – the relationship of descriptive/systematic chemistry with theoretical/physical chemistry often lacks coherence – corpuscular theory dominates: symbolic notation, balancing equations (number of atoms/charges/electrons)
Chemical techniques	– school laboratory: use of simple reactions, separation techniques

Philosophical structure of current school chemistry

The currently dominant philosophical structure of the school chemistry curriculum, based on my analysis of the IF response (section 2.2.2), consists of the following foundations of science: *scientism*, *positivism*, *reductionism*, and *predictability and control*. Figure 6.3 lists these foundations together with views on the methodology of science. Further listed foundations of chemistry: primacy of chemical theories/concepts, dominance of physics, and a corpuscular curriculum emphasis and views on the methodology of chemistry as present in Dominant School Chemistry.

Figure 6.3 Philosophical Structure of Dominant School Chemistry

Categories	Specifications based ON INTERNATIONAL Forum responses
Foundations of science	• scientism (pure, certain, neutral) • positivism • reductionism • predictability and control
Methodology of science	• no uncertainty of conclusions: interpretation always correct, reified account, models as facts • positivism of physics
Foundations of chemistry	• primacy of chemical theories/concepts • emphasis on physical chemistry and physics • corpuscular orientation: atoms/molecules/atomic structure as basis for stoichiometry, formulae, and equations
Methodology of chemistry	• systematization of substances and reactions • description of patterns in properties of substances and reactions (periodic table)

Pedagogical structure of current school chemistry

The currently dominant pedagogical structure of the school chemistry curriculum, based on my analysis of the IF response (section 2.2.2), has as its main characteristics the teaching and learning of science as a series of propositions and algorithms, and the initiation and preparation of future chemists (see further Figure 6.4).

Figure 6.4 Pedagogical Structure of Dominant School Chemistry

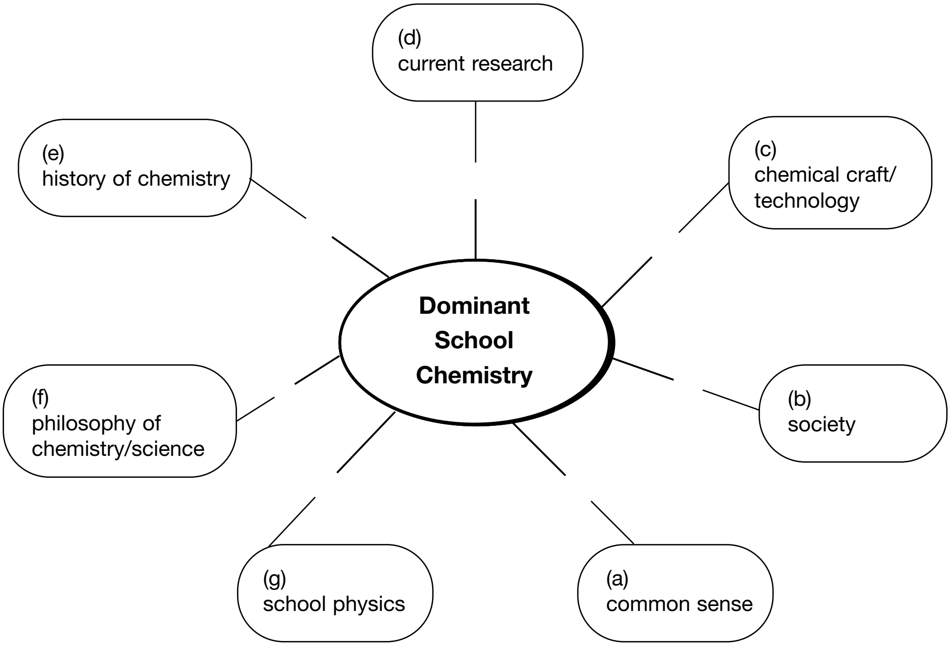
Categories	Specifications based on International Forum responses
Aim	• initiation and preparation for university chemistry/future chemist • learn systematization of chemical information: learn explanation/prediction of properties, formulae, valency, and bonding by applying simplified corpuscular rules
Teaching Approach	• established standard items of dogma: theoretical propositions and algorithms are conveniently reproduced within the limitations of school role play illustrating what professional chemists do
Learning Approach	• rote learning of propositions and algorithms (distinctions, facts, definitions, theories, techniques)

Curriculum structure as a whole

The specification of the separate substructures of Dominant School Chemistry leads to the question of the *relationship* between the specific substantive, philosophical, and pedagogical substructure that together were found to comprise currently dominant school chemistry curricula.

As argued in Chapter 2, Dominant School Chemistry must be taken as a *rigid* combination of a specific substantive structure based on *corpuscular theory*, a specific philosophical structure, which I called *educational positivism*, and a specific pedagogical structure involving *initiatory and preparatory training* of future chemists. This first general feature, its *rigidity*, characterizes the *internal* structure of dominant school chemistry. We also found (section 2.4.1) a second general feature of Dominant School Chemistry, namely its *isolation*, which characterizes its external relations, or rather, the lack of them, with the environment (see Figure 6.5).

Figure 6.5 Sevenfold Isolation of Dominant School Chemistry



The International Forum response to our probe (*Ten Statements*) gave credence to our idea about the resistance to reform of the currently dominant curriculum structure. As we saw in section 2.2.2, IF respondents mentioned some alternative school chemistry curricula, such as Nuffield or Salters' Chemistry, as having been proposed, trialled, and to some extent implemented. The structure of these curricula can be taken as a combination of a different conceptual or substantive structure, of certain views on teaching and learning (pedagogical structure), and of certain views on chemistry and/or science (philosophical structure). According to International Forum respondents, the alternative school chemistry courses usually have only a marginal impact on the currently dominant school chemistry curriculum. The reforms of Dominant School Chemistry appear to be neither systemic nor sustained, and the traditional structure of school chemistry is therefore largely retained, i.e., it resists reform. The so-called ‘consistency’ analysis (section 4.1.3) of the Salters’ Chemistry curriculum based on interview and document analysis and my classroom based research and subsequent consistency analysis (section 5.1.4) of the unit Metals amply confirmed this, as I have described in Chapters 4 and 5.

Whereas we recognized both variations in the pedagogical structure, such as different approaches to teaching and learning, and variations in philosophical structure, such as different views on chemistry and/or science, IF members made the valuable additional point that *variations in the substantive* structure of school chemistry have been proposed and tried as well. At least three such substantive structures have been incorporated in school chemistry curricula: one centered on substances, one centered on corpuscula, and one around chemical reactions (section 2.2.2).

We found that the *prevailing* substantive structure of school chemistry is a structure based on corpuscular theory. Thus, contrary to our initial hypothesis, *all* three substructures of school chemistry curricula must be considered as *variable*. This increases, of course, the number of curriculum structures, taken as combinations of chosen substructures, that are possible for a secondary chemistry curriculum. It appears that one of these structures, the currently dominant curriculum for school chemistry, a rigid combination of substructures, has had extensive implementation (Figures 6.1, 6.2 and 6.3). Other curriculum structures with an emphasis on processes/skills or society/technology have been given, at most, a small niche in the curriculum landscape (see section 3.2).

Schwab (1978, p. 229) poses an important prior question that should be posed before asking any question about the structures peculiar to specific disciplines which might be employed in science curricula.

> What relevance may the structure of the disciplines have for the purposes of education? Why should the curriculum maker or the teacher be concerned with the structure of the disciplines with which he or she works?

The answer to these questions will further increase the number of curriculum structures that are possible, and relevant for a secondary chemistry curriculum, taken as combinations of chosen substructures. Depending on the chosen pedagogical and philosophical structure, the substantive structure needs to undergo a fundamental change in content as well (Van Aalsvoort, 2000, p. 60).

The curriculum structure represented by our initial hypothesis on Coherent School Chemistry contains a *substantive* structure built around the chemical reaction concept (see Figure 1.3). Its most important structural feature consists of three reaction conditions which must be fulfilled in order for a chemical reaction to take place, namely (i) conservation of chemical elements; (ii) decrease of chemical or Gibbs energy, and (iii) kinetic instability (De Vos et al., 1991, 1994).

As became clear from the International Forum response, our hypothesis on Coherent School Chemistry, in particular its reaction-chemical emphases must be regarded as an *idealization* of school chemistry. In other words, our hypothesis has to be seen as a *construction* on the basis of our content analysis of a number of representative textbooks and syllabi *in the light of* our views on chemistry, philosophy of science, and pedagogy (section 1.2.2). This means that the *reaction-chemical* substantive structure contained in Coherent School Chemistry is neither realized nor probably intended in the current school chemistry curriculum.

The corpuscular substantive structure, on the other hand, is often part of the intended curriculum, but is as a rule only incompletely realized in the currently dominant school chemistry curriculum at the level of the formal, the taught, and the learned curricula.

Comments and criticisms of the members of the International Forum on the *Ten Statements* amounted to a refutation of the core statements of our initial hypothesis on Coherent School Chemistry (section 2.2.2). This led to a thorough revision in the light of these criticisms, and to a detailed description in terms of my curriculum categories of the currently dominant curriculum for school chemistry, briefly called Dominant School Chemistry.[1] The revised formulation of the central claims of the core statements taken together constitutes the central core of the currently *dominant* structure of the school chemistry curriculum (Figure 6.6).

Figure 6. 6 The Core of Dominant School Chemistry

Statement 1	All current school chemistry curricula belonging to the dominant version are being taught and learned as propositions and algorithms to students seen as future chemists.
Statement 2	All current school chemistry curricula belonging to the dominant version have a corpuscular theoretical focus on chemical substances and their properties.
Statement 3	All current school chemistry curricula belonging to the dominant version deal with the explanation and systematization of chemical information largely in terms of corpuscular theory.
Statement 8	All current school chemistry curricula belonging to the dominant version make a distinction between a level of phenomena and a level of corpuscula. The introduction of corpuscular theory in books and classroom is neither consistent nor accurate, and hence not effective.
Statement 9	All current school chemistry curricula have a dominant substantive structure, based on corpuscular theory, which is rigidly combined with a specific philosophical structure, that is, educational positivism, and a specific pedagogical structure, that is, initiatory and preparatory training of future chemists.

To sum up, the answer to the first, empirical research question, *What is the structure of the current school chemistry curriculum?*, is given by the description of the substantive, philosophical, and pedagogical structure of Dominant School Chemistry, as summarized in Figures 6.3, 6.4 and 6.5, and by the relationships of the school chemistry curriculum as a whole, summarized in Figures 6.5 and 6.6.

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[1] The response of a Dutch Forum (DF) of twenty-two researchers and developers in chemical education led to a similar result (see Chapter 2, notes 3 and 6).

6.1.2 Functional explanation of structure of Dominant School Chemistry

The main properties of the separate substructures: corpuscular theoretical basis, educational positivism, and preparatory training, and of their relationships: rigidity and isolation, raise the question of *why* these properties and relationships hold for the structure of the dominant school chemistry curriculum. This leads to the second, theoretical research question: *Why is this structure the way it is?*

In section 2.4 we established the remarkable similarity of these properties and relationships of Dominant School Chemistry to those of Normal Science Education, a concept based on Kuhn's theory of scientific education. The latter concept led us to the concept of Normal Chemistry Education, which is applicable to both the tertiary and secondary curriculum levels. The basic function of Dominant School Chemistry is, therefore, to prepare students for further study along normal scientific lines and to start initiating them into the current paradigm of chemistry already at the secondary level.

Kuhn's functional theory of scientific education

It is clear from Kuhn's writings that the pedagogy of training normal scientists has an overriding influence on the form and content of the pre-professional curriculum (section 2.3). Historical research of science curricula, too, has shown that from the close of the 19th century, the secondary science curriculum has emulated the same 'academic' model which the university curricula of the natural sciences has followed, according to Kuhn, at least since the beginning of the 19th century.[2]

Kuhn (1970c, p. 237) underpins his theory of the dynamics of science, which includes the process of scientific education, by a rather abstract *functional* argument. I will presently substantiate his argument for the process of scientific education at the secondary school level, but first I give Kuhn's general argument for his theory of the dynamics of science:

> If I have a theory of how and why science works, it must necessarily have implications for the way scientists should behave if their enterprise is to flourish. The structure of my argument is simple and, I think, unexceptionable: scientists behave in the following ways; those modes of behavior have (here theory enters) the following essential functions; in the absence of an alternate mode *that would serve similar functions*, scientists should behave essentially as they do if their concern is to improve scientific knowledge (italics Kuhn).

Let me now apply this reasoning to Kuhn's theory of the dynamics of science education. Kuhn *describes* in his work the "modes of behavior" that scientists have institutionalized to train or teach their students. As we saw in Chapter 2, Kuhn describes these "modes of behavior" in terms of teaching through textbooks and exemplars ("behave in the following ways"). The exemplars are described "as problems *closely* modeled in method and substance upon those through which the *text* has led" (Kuhn, 1977a, p. 229) students

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[2] This educational model for academic science education was first institutionalized in 19th century Germany (Fuller, 2000). After this, it found its way to other European countries and the United States. At the turn of the nineteenth century the academic model was extended, one could also say exported, to secondary schools by university professors and academically oriented school teachers (Schwab, 1942; Layton, 1973; Just, 1989; Homburg, 1993).

in the first place. Those "modes of behavior" – "here theory enters" – have the *function* to develop students' puzzle-solving competence needed in order to function later as normal scientists. Since scientists' "concern is to improve scientific knowledge" as related to their paradigm, scientists should continue to train their students this way "in the absence of an alternate mode *that should serve similar functions*" (Kuhn, 1970c).

Assuming for the moment, with Kuhn, that this argument applies to normal science education at the tertiary level, the question is now whether it also applies to science education at the secondary level: should secondary science education *serve similar functions*? First of all, it must be noted that the function of science education at the secondary level is not, and has not been, as clear-cut as that for the tertiary level (see section 3.2). Science educators all over the world, including many IF and DF members (2.2), have come to regard the function of science education at the secondary level as more and more being *different* from that at the tertiary level. Thus, a first initiation and preparation of students as researchers in normal science is certainly not regarded as the only function, or even as the most important one at the secondary level. In terms of Roberts (1988), there is more that *counts as science education* at the secondary level than just the traditional emphases on Solid Foundations and Correct Explanations. A number of curriculum emphases other than the traditional ones have been, and are currently, explored in the secondary science curriculum (see Fig. 3.5 & 3.6).

For example, what is more and more considered by many science educators as the most important aim is *the initiation and preparation of students into a science and technology based society and culture* (see also section 3.2.4). Students in secondary education are not to be seen primarily as producers of science ("to improve scientific knowledge"), but rather as consumers of science (Schwab, 1962; Millar, 2002). These kinds of aims should therefore define the nature and form of a more general, citizen-oriented science education at the secondary level to a much greater extent than that for which the extrapolation of Kuhn's theory of scientific training to the secondary level seems to allow.

Reversing this reasoning about the function of the school science curriculum leads to the conclusion that a different function of science education at the secondary level requires, in Kuhn's terms, a different "mode of behavior", that is, a different institutional organization of science education, not specialist but general science education. This implies that a new science curriculum structure must be devised, explored, and tested in the design room and the classroom in order to fulfill this new function. It implies a different role for science teachers in providing such a general education, a role for which they must be prepared in pre-service and / or in-service teacher training. While Kuhn's analysis is focused on the practice of the community of normal science researchers, a similar analysis of community practices could also be performed on other science practices. Different chemical practices demand that different roles be taken by practitioners, and appeal to different kinds of knowledge and procedures (see also subsection 6.4.4 below).

Functional explanations

The curriculum phenomena summarized in section 6.1.1 above, that is, the properties and relationships of Dominant School Chemistry, can be explained in terms of Kuhn's theory about the function of scientific education. A choice for a specific pedagogical structure determines to a great extent the choice for a specific substantive structure and entails as well a choice for a specific philosophical structure. In line with Kuhn's reasoning these relationships have a *functional* nature. The pedagogical *aim* of any chemistry curriculum in the end determines the form and content chosen for the course. Conversely, a specific substantive structure often implies a choice for a specific pedagogical structure and for a specific philosophical structure. In brief, a change in function implies a change in structure, and vice versa.

Let me begin with the aim and the teaching and learning approaches of the *pedagogical structure* of Dominant School Chemistry (Figure 6.3). Its aim, initiation, and preparation for university chemistry and/or the future chemist, is in the end influenced by the need to sustain and strengthen the current paradigm of chemistry. A tradition of normal science creates the need and provides the *means*, namely a disciplinary matrix or substantive structure, to train future normal scientists. It is this need that determines the aim, which in turn determines the form and substance of the science curriculum that novices will have to undergo at the university. The pre-professional curriculum entails a clear and coherent message for university teachers and students alike, namely, that the received curriculum is about training to solve conceptual and instrumental *normal science problems* by way of exemplars in textbooks and laboratory books derived from the current paradigm. In Chapter 2, I argued that Dominant School Chemistry must be regarded as a form of Normal Chemistry Education, since the former has almost all its characteristics in common with the latter. Students at school are taught established or standard items of dogma and learn to reproduce, often by rote, propositions and algorithms on the basis of textbooks and exemplars. The puzzle solving abilities they acquire will set a number them, i.e. those who will in the future form the professional community, on their way as scientists in the paradigm of normal science. In brief, Dominant School Chemistry must be regarded as the first stage of this pre-professional curriculum.

The *substantive* structure of Dominant School Chemistry based on corpuscular theory reflects, albeit incompletely, the first stage of the current paradigm of chemistry into which secondary chemistry students are initiated. Even more so than for university students, the research front remains invisible for them until the last stages of their graduate training, that is, if students choose to study chemistry at the university (cp. section 1.1.3).

Our initial hypothesis was that the *hidden structure* of the current school chemistry curriculum was captured by the properties and relationships of Coherent School Chemistry (section 1.1.2 and Figure 1.3). Instead, the International Forum survey showed that the structure of the currently dominant school chemistry curriculum had to be characterized by the properties and relationships of what I have called Dominant School Chemistry. The IF responses revealed most clearly the components of the pedagogical and substantive structures of Dominant School Chemistry, while the components of the philosophical structure remained partly implicit (Figure 6.2).

It is not only the nature of this *philosophical structure* (educational positivism), but also its *function, which* remains partly *implicit*. In that respect, it is very interesting that Kuhn describes both the philosophical assumptions underlying Normal Science Education and the *implicit* function of these assumptions. Students, Kuhn says, receive a steady picture of science as being one of progressively accumulating results arrived at by time-honored methods (textbook image of science). However, both the genesis and conceptual change, which lead to these results, are made invisible by the textbooks used. The function of the image of science as presented by the textbook, Kuhn stresses repeatedly, is to enlist and sustain the motivation of students aspiring to become scientists, and to build up the confidence they need to solve successfully the often difficult puzzles of normal science. Kuhn frankly admits that the textbook image of science is a highly *misleading* picture, but as we have seen in Chapter 2, he defends and explains this distortion of the nature of science by appealing to its pedagogic function. Likewise, the function of the philosophical structure of Dominant School Chemistry, that is, to induce students into a form of paradigm-led puzzle-solving, is served by its implicit or hidden character.

It is clear that any major reform of school chemistry should involve the analysis and criticism not only of the incorrect philosophical assumptions entailed by educational positivism, but also of its *hidden function* which is related to the pedagogic aim of training future chemists or scientists.

Rigidity and isolation of Dominant School Chemistry

The currently dominant school chemistry curriculum has been characterized, in Chapter 2, by a *rigid* relationship of a specific substantive structure based on *corpuscular theory*, a specific philosophical structure called *educational positivism*, and a specific pedagogical structure involving *initiatory and preparatory training* of future chemists.

It might be objected that rigidity, to a certain extent, is not necessarily a negative property because it could also give stability and perhaps even coherence to a curriculum. As noted in section 1.2.1, one of the defining characteristics of a structure is that it persists during change and that it is stable and retained in time and place. Thus, the remarks from IF members to the effect that the traditional school chemistry curriculum has implied a certain conceptual structure combined with a certain pedagogical and an (often) implicit philosophical structure, in a combination retained during change, can also be interpreted in a positive way.

The question is when does stability turn into rigidity in the sense of becoming an obstacle to a necessary reform of a curriculum? In order to prevent this from occurring, or if necessary, to counter it, the reasons for stability of the existing curriculum structure of school chemistry must first be explicated and analyzed. If unwittingly or uncritically accepted as *given*, a stable structure is in danger of becoming a rigid structure, that is, a structure dogmatically adhered to by those who use it. Rigidity formed in this way tends to hinder or exclude reforms. That becomes a problem when the situation changes, that is, with regard to new functions which science education at the secondary level agrees to fulfill, and also often with regard to its current function. Functional stability can thus turn into dysfunctional stability, that is, rigidity.

The rigidity of Dominant School Chemistry manifests itself most clearly in situations of change, namely, as a *resistance* to radical reforms attempted in school chemistry. Thus, after the process-oriented curriculum waves of the 1960s and 1970s had passed, many evaluations concluded that a traditional, academically oriented curriculum structure had largely been retained, although change had seemed necessary. More recent reforms, but now along STS lines, have led in some cases to similar sobering evaluations, for example, Joling et al. (1988) and Van Aalsvoort (2000) for the Netherlands, and Millar and Osborne (1998) for the UK.

A structure, to properly fulfill its function, is to a certain extent *per definition* demarcated or insulated from its environment, and for that reason severs at least some of its relationships with the environment (section 2.4.1). Insulation is thus a useful property as long as it is demonstrably functional or effective. However, the property of insulation can have a negative connotation. The analysis of the IF responses showed that the currently dominant school chemistry curriculum is isolated from seven dimensions: common sense and everyday life, and from society, history and philosophy of science, technology, school physics, and current chemical research (Figure 6.4). As a result chemical education at the secondary level is not open to reforms, that is, to the fulfillment of other functions, which require different combinations of substructures. If it were, it could lead to different modes of teaching and learning chemistry, for example to a citizenship-oriented curriculum. Because of its external isolation, the current structure of school chemistry to a large extent does not even fulfill its own set function. In brief, functional insulation has turned into dysfunctional insulation, that is, to the isolation of school chemistry.

The second general feature of dominant school chemistry, isolation, is therefore the opposite side of the coin, the face of which is rigidity. Thus, looking at current school chemistry from the inside reveals a rigid structure, while looking at it from the outside reveals an isolated structure. The narrow and dogmatic focus of current school chemistry excludes a number of other dimensions, which would be worthwhile to pursue in chemistry teaching, certainly for student-citizens and possibly also for student-scientists.

Resistance to reform

The rigid relationship in the currently dominant school chemistry curriculum explains to a large extent why throughout most of the 20th century school chemistry books from different countries look so remarkably *similar*. Because of that rigid internal structure, the dominant school chemistry curriculum has been found to be very *resistant* to change. To save the traditional structure from major reforms, a number of immunizing strategies have, often unintentionally, been used.

- *Optional* topics or units, either society or process oriented, which are not examined are, consequently, most easily evaded by students and teachers.
- STS issues and/or applications of science added *at the end* of chapters of traditional conceptual textbooks are easily skipped by the teacher, certainly when this added content does not form a substantial part of the examined material.
- A more subtle strategy is the addition of contexts or layers, which can extend either to the traditional curriculum as a whole or a major part thereof, leaving the skeleton intact.

Regarding the latter strategy, De Vos and Pilot (2000) have analyzed the acid-base theories present in the currently dominant school chemistry curriculum. In their paper they point out the several theoretical layers, various acid-base theories, which have been added to the initial oxygen-based theory of Lavoisier. The problem is that such a ‘layered’ text often fails to make clear to students which acid-base theory is needed to explain a type of phenomena in a particular context: chemical research, daily life, or historical. As a result, the distinctions and relationships between these various theories are difficult for students to follow. The new layer has as a rule only an incomplete, incoherent, or implicit relation with what went before. A complete, coherent, and explicit addition of a new layer, on the other hand, would not only require changing a major part of the substantive structure, but also the philosophical and pedagogical structures of dominant school chemistry. Such a coordinated replacement is not usually attempted, and consequently the rigid internal structure of dominant school chemistry is largely maintained.

The relationship between resistance to reform and the rigidity of Dominant School Chemistry is that often unintentionally or unwittingly the protection of the rigid combination of substructures in the current school chemistry curriculum, by way of immunizing strategies, results in additions and/or additional layers in the core curriculum of dominant school chemistry.

6.1.3 Beyond Normal Chemistry Education

This brings us to the third research question: *Is this structure a desirable structure?* As we saw in Chapter 2, the current form of Normal Science Education at the secondary level, Dominant School Chemistry, does not properly fulfill its set function, which is to prepare students for future study of chemistry as a science. The reproduction of chemical facts and algorithms replaces the understanding, explanation, and prediction of chemical phenomena. Improving this ‘parody’ of Normal Chemistry Education so that it would fulfill its function might be possible, but it would still not make Normal Chemistry Education an *appropriate* curriculum for the majority of students who do not aim to pursue their chemical studies further. The point is, that a *new* function – initiating and preparing students for a culture and society in which chemical materials and processes play an important part – requires a new structure for its realization.

Not only does the old structure fail to motivate the majority of students at the secondary level, it also instills in them a dogmatic attitude to science by giving them an incorrect picture of science as one of a steady accumulation of results acquired by a standard method. Further, the addition of a new curriculum emphasis often results in adding a new layer on top of the old structure, which can lead to incoherence and confusion for teachers and students. Clear indications of the latter were seen in the detailed analysis of the written, interpreted, taught, and experienced curriculum of the Salters’ Science unit, Metals in Chapter 5. While in the case of student-scientists, these dangers may be alleviated by the latter’s experiences in their future ‘normal’ science practice, in the case of student-citizens these dangers usually persist and can lead to skeptical, relativistic, or even cynical attitudes to science (cp. section 2.4).

The *domain-specific* character of Normal Chemistry Education (NCE), being in essence a training of specialists, appears not very conducive to fulfilling the purpose of a general chemistry education at the secondary level. As argued in Chapter 2, Dominant School Chemistry does not appear to contribute greatly to the development of students’ general investigative and critical skills. On the contrary, the practice of the currently dominant school chemistry curriculum, rigid and isolated as it is, leads to verbalism and dogmatism.

The science education community must, therefore, provide an appropriate science education for the 80% or more students who do not intend to pursue their science studies at a higher level, i.e., those who do not want or need to become scientists. An initiation and preparation for culture (HPS) combined with an initiation and preparation for society (STS) seems to be a much more appropriate science education model for the majority of students. Science education at schools exclusively modeled on the initiation and preparation for normal science is not.

Thus, a new function requires a new curriculum structure. It is important that the new curriculum instill in students a critical attitude toward the results and methods of science (HPS), and that it enable them to critically appraise scientific and technological information in connection with social issues (STS). Curriculum units developed along these lines should be trialled and tested for their effectiveness in learning and for their contribution to the motivation of students.

6.2 The Problem of escape

I first summarize the curriculum findings that constitute an answer to empirical research question 5: *To what extent does the Salters' Chemistry curriculum escape from this structure*? This question concerns the extent to which an STS oriented project such as Salters' Chemistry manages to escape from the structure of the currently dominant school chemistry curriculum. This has been done by looking at the Salters' Chemistry course as a whole (section 6.2.1) and by looking at the level of the lessons of one chemical unit of the Salters' Science course, Metals (section 6.2.2).

Second, I analyze these curriculum findings in relation to Dominant School Chemistry, its properties, and its relationships, and give an explanation of the curriculum findings in terms of Kuhn's functional theory of scientific education, thereby answering the theoretical research question 6: *Why is it so hard to escape from this structure*? (section 6.2.3).

6.2.1 Curriculum findings on the Salters' Chemistry Course

The curriculum reform intended by the developers of the Salters' Chemistry course is taken here as an attempt to escape from Dominant School Chemistry. Put in terms of Schwab's curriculum substructures, the developers tried to realize this by devising a series of units of an STS course, which would constitute a radical new combination of a pedagogical, philosophical, and substantive substructure, and replace the current rigid combination of substructures summarized above.

Visionary curriculum compared with designed curriculum of the Year Three course

Having decided to develop a radically new school chemistry course, a major concern of the developers was whether the context-based Year Three course would show what they called a recognizable sequential order. This concern was reinforced by the existence of the external constraints embodied in the "Common 16+" examination system. The Year Three course was positioned in this exam system as a transitional, but also as a foundational course (Figure 4.1).

This meant that the developers felt they had to take into account not only the needs of the majority of average students, as originally intended, but also the needs of the minority of students who were about to take O-level examinations. However, in the trial phase the Year Three course was still focussed mainly on the needs of average students.

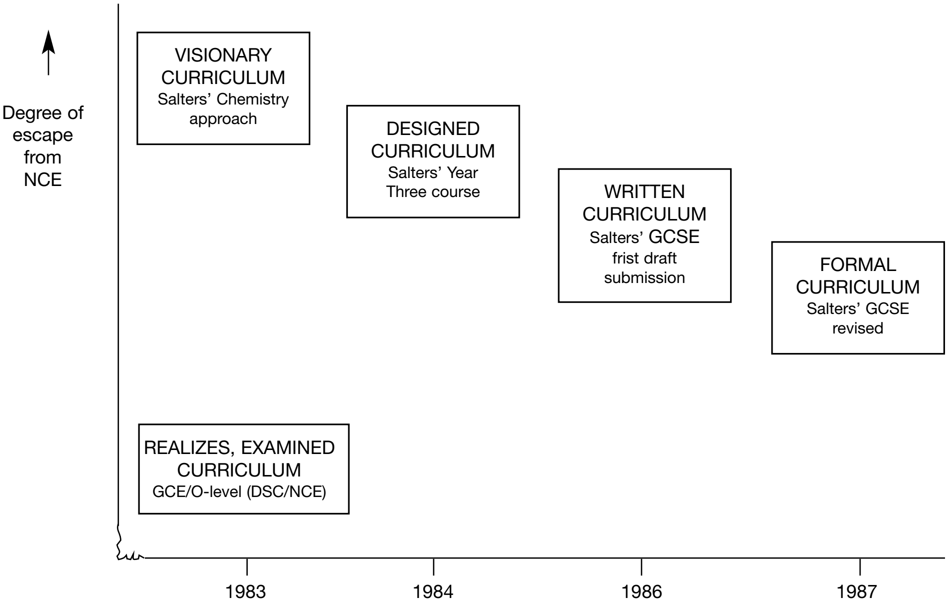
The units of the course were developed using a view on school chemistry, which centered on the ideas of relevance and use, and by starting the lessons with daily life contexts. The developed units contained what they called an agreed-on selection of chemical concepts organized, as they said, on a fairly logical basis as in the units Metals and Transporting Chemicals.

Thus, while designing the units of the Year Three course, the developers *matched* their vision to the realities of external constraints as well as to their perceived concerns, to what I have called internal constraints. This resulted in a designed curriculum, which differed in some respects from the original visionary curriculum (Figure 4.3). The added focus on the needs of future O-level students, a change in pedagogical structure, led to a greater emphasis on explanations and chemical concepts, a change in philosophical structure. The idea of *no preconceptions* as a first design criterion gave way to the selection of a logically organized sequence of chemical concepts, that is, a change in substantive structure. The realized curriculum of the Salters' Chemistry Year Three course, therefore, did not escape as fully from the structure of the dominant school chemistry curriculum as envisioned by the visionary curriculum (see Figure 6.7, reproduced from Figure 4.4).

As we saw in Chapter 4, this was a first manifestation of the important relationship that governs the transformation of the several curriculum levels in the process of development of the Salters' Chemistry course, and which (Goodlad (1979) called:

> … the *slippage* from any ideal formulation to what reaches the student, or of working backwards from what the student perceives to what the formal curriculum intended for him or her (Goodlad (1979, p. 64; italics mine).

Figure 6.7 Process of development of the Salters' Chemistry course (same as Figure 4.4)



Year Three course compared with the first draft of the GCSE exam course

The Salters' Chemistry GCSE examination course, the first draft of which was submitted to the Schools Examination and Assessment Council (SEAC) in 1986, had to conform to the constraints set by the GCSE examination system (section 4.5.2). This meant that the developers had to take into account not only the needs of average students, but also those of future A-level chemistry students. These external constraints reinforced the role of the internal constraint operative during the process of development. At this stage, this internal constraint took the form of what the developers called "the structure of chemistry as we all perceive it" (L92). This constraint was used to organize, in a logical order, the chemical concepts developed from the chosen contexts and applications.

The examination course, first trialled with students of average ability, was later also trialled with students of high ability. It was found to be suitable for the full ability range. The chosen emphasis on relevance and use had to concur for the examination course with the external demands formulated in the National Criteria for Chemistry. The resulting first draft of the exam course did contain a *slightly reduced* selection of chemical content, concepts, and relationships, which were needed for the chemical explanations of the chosen contexts in the lessons of the units of the course. This was in accordance with design criterion three, *context-led development of concepts*. As with the Year Three course, the selected laboratory techniques were applied as much as possible to relevant, familiar materials, in accordance with design criterion two, *relevance*.

Again, there were some changes accompanying the transformation of the curriculum levels involved (Figure 6.7), There was an added focus on the needs of future A-level students, a change in the pedagogical structure; more emphasis on explanations using chemical concepts, a change in philosophical structure; while the substantive structure was to a large extent now based on "the structure of chemistry as we all perceive it" (see also Figure 4.7). Thus, a comparison of the first draft of the Salters' Chemistry GCSE examination course, with the designed curriculum in the form of the Year Three course, leads to the conclusion that the former course escapes to a somewhat lesser degree from the currently dominant school chemistry curriculum than the latter. In brief, the process of slippage continued during the development of the Salters' Chemistry course.

First draft of the exam course compared with the formal GCSE curriculum

The official constraints of the examination GCSE system, as set by SEAC, forced the developers to add some *abstract* chemical content to the course. Some chemical concepts, such as the Periodic Table and atomic structure, had initially been left out as a consequence of upholding design criterion three, *context-led development of concepts* (Figure 4.5).

It was also clear that a GCSE examination course had to provide education in chemistry both to future citizens and to future A-level science students. The latter students require a sound foundation in theory and processes of enquiry, such as explanation, hypothesizing, and experimenting. Thus, a comparison of the formal curriculum of the Salters' Chemistry course (see Figure 4.7) to the First draft of the Salters' Chemistry GCSE exam course submitted for approval to SEAC shows that this formal curriculum does escape from Dominant School Chemistry to a somewhat lesser degree than the latter curriculum (Figure 6.7).

Comparison of formal and visionary Curricula of the Salters' Chemistry course

Inspection of Figure 6.7 shows that there is a *decreasing degree of escape* going from the visionary to the formal curriculum of Salters' Chemistry. Or, on Goodlad's terms, there is a continuous process of slippage governing the transformation of curriculum levels involved. The increasingly strict external constraints of the educational systems, which the Salters' developers had to meet, combined with the increasingly explicit role of the internal constraints they used in the developmental process, form the mechanism causing the decreasing degree of escape.

As we saw in Chapter 4, the developers initially attached much importance to design criterion one, *no preconceptions*, in guiding the selection of traditional content to be put into a new relevant chemistry course for 13 -16 year olds. For the Year Three course, this meant:

> You must *not* be influenced by your thoughts of what we always do with the third year or your thoughts of what we have covered before we arrive in the fourth year. (G92a:15)

Analysis of the interviews of developers and the documents produced show that it is very difficult for developers to adhere consistently to this first design criterion, during the development of actual curriculum units in a given educational system. Notwithstanding their strongly avowed intention not to use any preconceptions, their internal constraints – a recognizable sequential order, a fairly logical basis, the structure of chemistry as we all perceive it – came to function as successive preconceptions used by them to structure logically the units of the Salters' Chemistry course. By relying on these internal constraints, the developers fell back on their traditional or practical knowledge regarding the selection of chemical content, the ordering of this content and the contexts and activities which would work to put the selected content across to students (pedagogical content knowledge, see section 5.5.2).

To a large extent this probably happened unintentionally or unwittingly. One could therefore say that during the actual developmental practice, developers tended to show what I call a Normal Chemical Education reflex, the effect of which is the often implicit use of the structure of the currently dominant school chemistry curriculum. It is important that this point is recognized, because it should lead to the realization that a new *societal function* of school chemistry requires an explicit and coordinated replacement of the current rigid combination of substructures by a radical new combination of a pedagogical, philosophical, and substantive substructures.

Judging from what developers say in interviews, and from what is stated in formal documents such as the *Salters' Chemistry Syllabus* (1992) and the *Salters' Chemistry course: An overall guide for teachers* (1988), design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, are maintained as design criteria throughout the development of the course. As we saw in Chapter 5, the developers did not manage to apply design criterion two and three consistently throughout a unit (see further in section 6.2.2). The reemergence of the 'structure of chemistry as we all perceive it', as a preconception followed by developers, partly accounts for this.

However, these two central design criteria did play an important role in practice. For example, design criterion three, *context-led development of concepts*, was effective as is shown by the reduced conceptual loading of the draft GCSE course submitted to SEAC. The latter criterion was also articulated in the process of development as the 'need-to-know' principle, that is, the idea of developing only those chemical concepts needed to make sense of chosen contexts. At a later stage the developers referred also to what they called the "drip-feed" approach, that is drip-feeding chemical concepts into the course, for example, by spirally revisiting of qualitatively introduced concepts in different contexts (see also section 4.6.2).

As we noted above in section 5.4.4, this process of drip-feeding chemical concepts was guided more and more by the required concepts, and less by the chosen contexts.

External constraints like the National Curriculum dominated the process to an increasing extent. During the development of the units, another criterion was explicated and articulated, namely, design criterion four, *variety-cum-activity*. The wider use of laboratory techniques, not just with pure chemicals but also with familiar materials, was complemented by several other kinds of activities, such as group work, discussions, and role-play. The increased variety of activities appears to be called forth by the new, relevant emphasis of the chemistry course on coping with everyday materials, applications, and STS issues.

6.2.2 Curriculum findings on the unit Metals (1989)

I will now summarize the findings of the consistency analysis of the application of design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, as used by the developers in the design of the lessons of a unit of the Salters' Chemistry course, Metals (1989).

This consistency analysis has been performed on the eight *lessons* of the unit Metals at the level of the interpreted, taught, and experienced curriculum (sections 5.2, 5.3 and 5.4). The findings give us a detailed picture of the changes in degree of escape from Dominant School Chemistry at the several curriculum levels involved in the process of realizing the unit Metals in the classroom.

In the consistency analysis of the lessons of the unit Metals, I used the ratio between CTS content and PC content as a (relative) measure of the degree of escape from Dominant School Chemistry (section 5.1.4). This made it possible to follow in some detail the transformations of the formal, written, interpreted, and taught curriculum levels of the unit Metals in order to compare these with the PC content of the currently dominant school chemistry curriculum. This ordering allows us to determine the changes in degree of escape at these levels. There appeared to be a substantial decrease in degree of escape moving from the formal to the taught curriculum level of the unit Metals (See Figure 6.8, reproduced from Figure 5.5).

Comparison of formal with written curriculum

The consistency analysis of the lessons of the unit Metals (1989) showed, firstly, that more PC content and less CTS content was developed than was needed, that is, than was consistent with design criteria two and three (Figure 5.13). The CTS/PC ratio, taken as a measure of the degree of escape, decreased substantially in moving from the formal to the written curriculum. The analysis showed, therefore, that the developers did not consistently adhere to design criterion two, *relevance*, and design criterion three, *context-led development of concepts*. In so doing, they went against design criterion one, *no preconceptions*, making it thereby very difficult to uphold central design criteria two and three. While designing the lessons of the unit Metals, the developers *retained* a number of PC concepts traditionally part of dominant school chemistry, that is, concepts developed though not needed to make sense of the selected contexts (see further Figure 5.13).

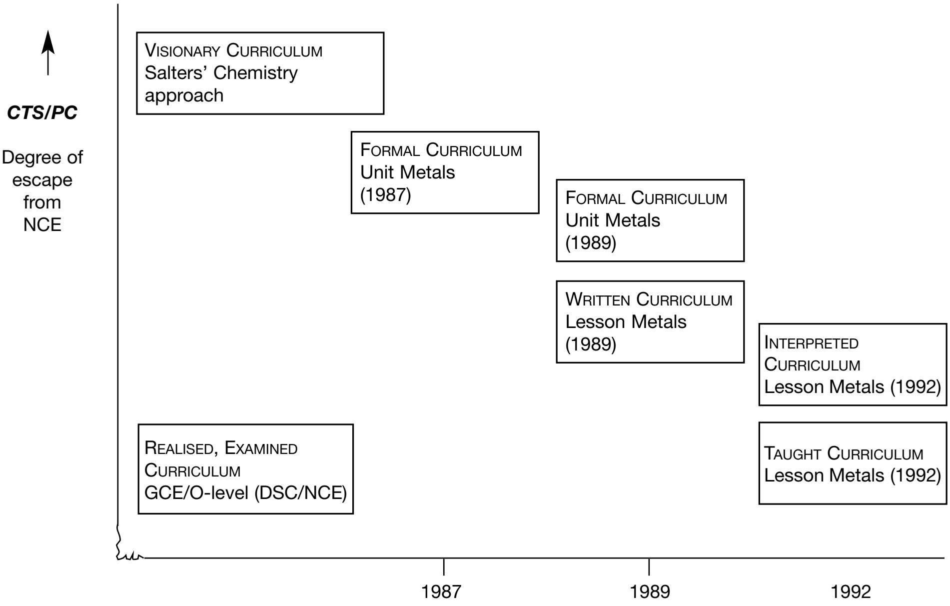
As a result, some lessons of Metals (1989) suffer from a tension between the PC content developed and the CTS content needed. This leads to an important point. The PC-CTS tension present in the substantive structure of the curriculum is connected with a corresponding tension in the philosophical structure, between the cognitive process of explanation on the one hand and the process of application on the other. Further, the PC-CTS tension is also related to a tension in the pedagogical structure, between the aim to train future A-level chemistry students and the aim to educate future citizens in chemical literacy. Such connections can be expected from Schwab's curriculum framework (section 1.3.2).

The concept of normal chemistry education based on Kuhn's functional theory leads to the following explanation. It is predominantly the tension, or dual emphasis in the pedagogical structure, which determines the dual emphasis in the philosophical structure and the PC-CTS tension in the content of the substantive structure. In brief, the change in function determines the change in structure of the curriculum.

As noted above, a combination of increasingly strict external constraints and the increasingly explicit role of internal constraints used by the Salters' developers prevented them from escaping Dominant School Chemistry. In this respect the analysis of the content of the successive formal curriculum units of Metals (1984, 1987, 1989) in section 5.2.8 (Fig. 5.14) is interesting, since it shows the great influence of the traditional structure of school chemistry even in a period *relatively free* from strict external constraints.[3]

Thus, the Normal Chemistry Education reflex manifests itself in all three coordinated curriculum substructures of school chemistry, even under conditions of relatively weak external constraints.

Figure 6.8 Process of development and teaching lessons Metals (same as Figure 5.5)



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[3] A detailed analysis such as the consistency analysis in chapter 5 of the lessons of Metals (1989), but now of the content of the lessons of previous versions, i.e. Metals (1987) and/or Metals (1984), would confirm, I think, the extent of this influence.

Comparison of designed with interpreted curriculum

As we saw in Figure 5.15 summarizing the interpreted curriculum, PC content was added, though it was not needed, and CTS content was deleted, though it was needed to make sense of the contexts selected. In this process the CTS/PC ratio decreased again. Thus, design criterion two, *relevance*, and design criterion three, *context-led development of concepts*, were not consistently upheld.

Science teachers of the Department of Science of the school where I performed my research, adhered to design criterion five, *flexibility*, by interpreting the curriculum unit Metals (1989) and using an emphasis on teaching scientific processes. Students were thus stimulated to work “as real scientists” in the so-called Circus approach these teachers developed. Design criterion four, *variety-cum-activity*, was correspondingly interpreted by them to give an emphasis to student activities that addressed processes and skills more than relevant contexts. Design criterion one, *no preconceptions*, was in this case replaced by a clear preference for a scientific process approach, a choice probably related to the background of the group of teachers involved and to the impending external changes such as the National Curriculum (section 5.3.2). Thus, internal constraints influenced the interpretation and the subsequent implementation of the curriculum unit Metals (1989), again in combination with external constraints.

Comparison of interpreted with taught curriculum

As we saw in Figure 5.16, the chemistry teacher who taught the unit Metals (1989) added some PC content not needed, and did not teach some CTS content that was needed, to make sense of relevant contexts. This is inconsistent with design criteria two and three, and the CTS/PC ratio therefore decreases further. Within the constraints of the National Curriculum, teaching Metals (1992) to a group of students of low to middle ability led to a teacher-directed approach in which there was little room for discussion of either relevant contexts or for process activities (design criterion four). In this case, the external constraints acting on the teacher clearly prevailed over internal constraints or any preconceptions the teacher had with regard to the teaching of chemistry at this level.

Experienced curriculum

Up to this point I have discussed what at various subsequent levels – visionary, designed, interpreted, taught – is offered to students in terms of changes in the CTS/PC ratio. Students have no prior knowledge of the content or structure of the lessons they are about to receive, let alone of the changes in the CTS/PC ratio. However, depending on the probe or method used we can find out to what extent the relevant CTS emphasis is appreciated or learned by students (sections 5.4.1 – 5.4.4), or alternatively the extent to which the PC content is learned by students through a context- and activity-led approach (Ramsden, 1994; 1997).

All studies reviewed in section 5.4.4 show an overall *positive effect* of the context- and activity-based Salters’ Science course on students’ motivation, which has been attributed by Ramsden (1992) to an improvement of the *general* classroom atmosphere (see Figure 5.17). More specifically, as I found out in my case-study on Metals (1989), this positive effect on students’ motivation can be attributed to some *specific* CTS contexts motivating and enabling students to learn some relevant and useful concepts. Students learn through the CTS contexts of the lessons of Metals (1992 the related CTS concepts such as the relationships and causes of rusting/corrosion and its prevention. That is, they acquire in this way some CTS concepts and transfer them to similar CTS contexts (local transfer).

These findings, as may be expected from a case study, add some interesting detail to the general conclusion above.

Secondly, many of the difficulties students have with understanding PC concepts that were found in the case study on Metals (1992), are also found in other studies. More specifically, the average students' conceptual understanding of CTS concepts introduced in the unit Metals (1992) appears to be better than that for PC concepts.

Finally, none of the studies reviewed, mention *specific* examples of PC concepts which, although introduced in the Salters' Science units, students do not really need to make sense of the CTS contexts as I found in my case study on Metals (1989, 1992), namely chemical concepts such as oxidation, reactivity series, compound and formulae (see Figure 5.13)

6.2.3 Discussion and implications

Students are not only motivated by *specific* CTS contexts, they also learn, through these contexts, the related CTS concepts (such as the relationships and causes of rusting/corrosion and its prevention). This leads to the *prima facie* paradoxical result that students do *perceive* an increased relevance in lessons of the unit Metals (1992), although from the point of view of my research, the CTS/PC ratio steadily decreases from the visionary to the taught curriculum.

This surprising perception of students can be explained by taking into account that students do not compare the lessons they experience with the formal or visionary curriculum, which after all is unknown to them, but instead compare it to what they are accustomed to, or what they expect from previous science lessons at school. Had they been given a unit with more lessons with a clear CTS emphasis and a greater CTS/PC ratio, it seems likely that they might have appreciated such a unit even more.

One could argue that, just as students are led by their prior expectations or preconceptions of school science, to some extent so are teachers and developers. Conversely, one could say that developers, teachers, and students show a certain NCE reflex. Thus, teachers, especially those who have no intimate knowledge of the visionary curriculum as embodied in the five design criteria, might feel they have increased the relevance of their teaching compared to what they did in previous years. However, from the point of view of the results of the analysis, the CTS/PC ratio decreased in the case of teaching the unit Metals. Similarly, those developers who take a weak interpretation of the design criteria, instead of the strong interpretation, as discussed in section 5.1.3, might not feel that they have decreased the CTS/PC ratio in some lessons or units. Instead, they might feel that, compared to the lessons they used to develop, they have increased the relevance of the newly developed lessons or units, which is correct in the light of their interpretation of the design criteria.

In a slightly different way this might even apply to those developers who favored a strong interpretation of the design criteria. Since design criteria are being articulated and operationalized *during* the process of development, at the start they are partially *unknown* to the actors involved.

This also explains why it is so difficult for teachers to implement lessons in accordance with the design criteria. After all, they must necessarily rely to a varying extent on their practical knowledge with regard to school chemistry teaching and on the preconceptions entailed by this. The same applies, as we saw, to the developers of the original units. The latter's practical or implicit knowledge[4] with regard to the development of new materials, and their preconceptions about school chemistry entailed by this implicit knowledge, influences their articulation and operationalization of the partially unknown design criteria.

To some extent this is *inherent* in the design criteria approach to development. In this way preconceptions of developers can hold back the implementation of the visionary curriculum, as well as influence the perception of teachers executing the operationalized lessons. Both developers, in their practice of designing new curriculum materials, and teachers, in their practice of teaching those are led by certain preconceptions. In brief, both tend to show a NCE reflex.

It may seem that the degree of escape, as measured by the changes in the CTS/PC ratio, is largely relative to the observer. This can be counteracted, I think, by linking a research project to a development project in order to make explicit in a systematic way all that is involved in the design criteria approach. This would make it less relative and more objective. The purpose of such a developmental research project is thus to explicate, articulate, and if needed, to revise the initially chosen design criteria during the process of development by obtaining during the project at all curriculum levels – visionary, designed, interpreted, and taught – the necessary feedback from the actors involved: developers, teachers, and students.

The case study of the unit Metals, derived from the Salters' Chemistry course, clearly shows the resistance of Dominant School Chemistry, indicated in section 6.1.2 above, to a radical, societally oriented curriculum reform. More specifically, in all three coordinated substructures, and at all curriculum levels of the unit Metals, a *NCE-reflex* manifests itself. The external as well as internal constraints, which are operative during the designing, writing, and teaching of a CTS unit, lead to a NCE reflex, that is, to a *mechanism* which prevents the agents of reform from escaping NCE in the way in which they are intended. This resulted, in the case of the unit Metals, in a PC-CTS tension in the substantive structure of the curriculum unit which, as can be expected, is associated with a tension between the cognitive processes of explanation and application in the philosophical structure, and with a tension between the aims to train future A-level chemistry students and to educate future citizens in chemical literacy in the pedagogical structure.

6.3 A Strategy to escape from Dominant School Chemistry

In this section, I will come back to the three conditions of escape discussed in Chapter 3. Together, these conditions constitute a proposal for a strategy to escape from Dominant School Chemistry (6.3.1). Secondly, I will briefly summarize the curriculum theoretical framework I have developed in this thesis on which the three conditions of escape are based (6.3.2).

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[4] Campbell at al (1994, p. 425) remarks, “We built in, to a significant degree, teachers craft knowledge about teaching and learning. See also section 5.5.2, note 60 on pedagogical content knowledge.

Thirdly, I will outline how the developed curriculum framework can be used, in condition one, for the *analysis* of traditional and innovative school chemistry curricula (6.3.3), in condition two, for the *development* of vision and design of innovative school chemistry curricula (6.3.4), and in condition three, for *developmental research* accompanying the process of large scale development of innovative school chemistry curricula (6.3.5).

Thus, in this section I come back to research question 4, *What are the conditions for escape?*, and I will try to answer research question 7: *How can attempts to escape from this structure be more successful?*

6.3.1 Three conditions for escape

The research findings on the structure of current school chemistry, summarized in section 6.1 gave rise to the formulation of the first condition for escape which has to do with the analysis of the structure of the dominant school chemistry curriculum. The discussion of Roberts' concept of curriculum emphasis lead in Chapter 3 to the formulation of two other conditions for escape. The second condition concerns the development of a vision on new school chemistry curricula, while the third condition has to do with the method to escape from Dominant School Chemistry.

The three conditions are not strictly separable, and have to be applied together. The domain specific analysis of the structure of current school chemistry is performed to initiate a systematic reform, which in its turn has to take fully account of the results of the analysis. The three conditions are summarized in Figure 6.9, which is based on Figure 3.10, but for the points on vision and design derived from the analysis of the Salters' design criteria approach.

The research findings on Salters' Chemistry, summarized in section 6.2, show the usefulness of my curriculum theoretical framework in analyzing an innovative school chemistry curriculum by uncovering the phenomenon of *slippage* during the process of development of the Salters' Chemistry course as well as during the process of teaching of the unit Metals. The findings give us a detailed picture of the changes in degree of escape from Dominant School Chemistry at the various curriculum levels involved (Figures 6.7 & 6.8). As argued in Chapters 4 & 5, the developers of the Salters' Chemistry course can be seen as following to some extent condition one and three, and to a larger extent condition two.

As I will discuss below, attempts to escape could be more successful, if large-scale development projects were to adopt and implement these three conditions of escape together. That is, to articulate a new vision while preventing the importation of the old one, and to plan, realize, and test the new vision by developmental research while using the curriculum framework described in section 6.3.2.

Figure 6.9 Three conditions to escape from Dominant School Chemistry

Condition one: *In order to escape, we have to know what to escape from.*

- Perform a domain specific analysis of the nature and structure of the dominant school chemistry curriculum in terms of the framework developed in this thesis, that is, in terms of a combination of the dominant substantive, philosophical, and pedagogical structure.

Condition two: *In order to escape, we have to know what to escape to.*

- Aim towards a coordinated replacement of the currently dominant (rigid) combination of substantive, philosophical, and pedagogical structure of school chemistry.
- Develop and legitimize a new curriculum emphasis for school chemistry, in terms of a new coherent combination of a substantive, philosophical, and pedagogical structure.
- Use the concepts of curriculum emphases and Normal Chemistry Education (NCE) of the framework as instruments to articulate the visionary curriculum in terms of design criteria, that is, a new conjectural vision to be operationalized by the design of prototypes of the teaching material in the designed curriculum.

Condition three: *In order to escape, we have to know how to escape.*

- Be aware of, anticipate and avoid the NCE reflex, or at least deal in time with any difficulties related to the dominant school chemistry curriculum at all curriculum levels, starting at the visionary and designed curriculum.
- Collect evaluation data at all curriculum levels to safeguard the adopted vision, in moving from the visionary, designed, written, formal up to the interpreted, taught, and experienced curriculum levels.
- Check the newly chosen curriculum emphasis, articulated in the visionary curriculum in terms of design criteria, for consistency at all curriculum levels.

6.3.2 Curriculum theoretical framework

The theoretical framework presented in Chapter 1 consists of the substantive, philosophical and pedagogical structure (based on Schwab) which in a coherent combination makes up a curriculum structure, and which pertains to a number of curriculum levels (based on Goodlad). These substructures and levels apply to the curricula of any discipline not just to the curricula of the natural sciences. They form the *formal* part of the theoretical framework (Fig. 6.10).

Both the concept of curriculum emphasis, as elaborated by Roberts and the concept of Normal Science Education as developed in this thesis (based on Kuhn) are specific to the domain of the natural sciences. They form the *material* part of the framework (Fig. 6.12).

Formal part of the framework

If the formal framework is applied to the domain of the natural sciences it is the use of the material part of the framework which guides the researcher, in an iterative process applied to educational documents such as textbooks or syllabi, transcripts of interviews or relevant publications (see 6.3.3), to fill out the categories and subcategories of a curriculum structure at a curriculum level.

Figure 6.10 Formal part of the curriculum theoretical framework

Curriculum levels	**Substantive structure**	**Philosophical structure**	**Pedagogical structure**
Visionary curriculum Designed curriculum Written curriculum Formal curriculum Interpreted curriculum Taught curriculum Experienced curriculum			

In the case of the development of the vision of the Salters' Chemistry curriculum the application of the formal framework guided by the material part of the framework leads to Figure 6.11. The substantive, philosophical, and pedagogical structure are characterized by the headings used in Figures 4.3, 4.5, and 4.7, which give details in terms of the subcategories I used throughout this thesis (Figure 2.2). Based on the curriculum data collected in Chapter 5, the process of teaching of the unit Metals could be represented in a similar figure. These figures offer another, complementary way to represent the processes of development and teaching of innovative school science curricula than the pictures deployed so far, such as Figures 6.6 and 6.7.

Figure 6.11 Formal part of the curriculum theoretical framework applied to Salters' Chemistry

Curriculum levels	**Substantive structure**	**Philosophical structure**	**Pedagogical structure**
Visionary curriculum (Fig. 4.3 gives details)	Familiar materials approach	Relevance and use	Essential chemistry for living; focus on needs less and moderately able students
Designed curriculum (Fig. 4.5 gives details)	A recognizable sequential order	Relevance and use	Essential chemistry for living; future citizens
Written curriculum (Fig. 4.5 gives details)	Structure of chemistry as we perceive it	Relevance and use	Chemical awareness and basis for further study chemistry; Full ability range, including most able
Formal curriculum (Fig. 4.7 gives details)	Logical development of chemical concepts and principles	Relevance, chemistry for industry and everyday life; sources, manufacture and use	Worthwhile, practical, and relevant chemistry Accessible to full ability range of students

In the process of development moving from the visionary to the formal curriculum, the original curriculum emphasis of the Salters' Chemistry course taken as a combination a substantive, philosophical and pedagogical structure is shifting. As shown in detail in Chapter 4 there is, consequently also a shift in the combination of a substantive, philosophical and pedagogical structure comprising the Salters' Chemistry curriculum.

As for the unit Metals, it is shown in Chapter 5, that the CTS curriculum emphasis of the unit is shifting from a Chemistry along with CTS Content (which might contain about 50% STS content and about 50% pure science content) to a Science through STS Content (which might contain about 30% STS content and about 70% pure science content). Although it is to some extent arbitrary, as explained in section 5.1.4, to put exact percentages to the curriculum levels traversed here, there is at least a substantial relative shift in the original curriculum emphasis of the Salters' Chemistry course, and therefore also in the combination of a substantive, philosophical and pedagogical structure which comprises a curriculum. In brief, in my terms Salters' escape from NCE was much less successful than envisioned.

In Roberts terms, the developers started out with a mix of "Everyday Coping, Science Skill Development, and Science, Technology, and Decisions" curriculum emphases and ended with, as Borgford (1992, p. 28) put it: "A unique hybrid of "Everyday Coping, *Solid Foundation*, Science Skill Development, and Science, Technology, and Decisions" curriculum emphases (my italics).

Material part of the framework

Roberts' concept of curriculum emphasis, enables us to characterize science curricula in terms of seven curriculum emphasis, which can be analyzed ("unpacked" as Roberts called it) in terms of the components: view of science, view of society, view the learner, and view of the teacher (see section 3.2.3; Figure 3.6). Or, alternatively, as I have done in this thesis, specific curricula with various emphases pertaining to secondary chemistry education can be analyzed in terms of the substantive, philosophical and pedagogical structure and their subcategories.

The IF research described in chapter 2 shows that the seven curriculum emphasis identified and characterized by Roberts are not equally strongly represented in school chemistry courses. The currently dominant chemistry curricula have what I called a NSE orientation, whereas STS and HPS orientations on school chemistry must be considered as alternative courses having less representation. The dominant NSE orientation of science curricula consists in its purest form of the curriculum emphases *Solid Foundations* and *Correct Explanations*, and in a somewhat weaker form of the curriculum emphases *Structure of Science* and *Scientific Skill Development,* emphases that emerged in the 60s as a result of the curriculum wave (see section 3.4.2). The curriculum emphasis Personal Explanation is HPS oriented whereas the curriculum emphases Everyday Applications and Science/Technology Decisions are STS oriented. The latter three curriculum emphases are still struggling to get a fair place in the curriculum landscape. I have adapted, therefore, Figure 3. 6 *Seven curriculum emphases for science education in terms of four commonplaces* taken from Roberts (1988, p. 45) in the following way. I have put the most dominant NSE type curricula on top and the STS and HPS curricula at the bottom. In these terms the curriculum emphases *Structure of Science* and *Scientific Skill Development* could be considered as a mixture of NSE and some HPS education (see Figure 6.12).

There is considerable overlap between the curriculum components Roberts uses to

Figure 6.12 Curriculum emphases analyzed in components framework (adapted from Roberts, 1988)

Component **Curriculum emphasis**	**Philosophical structure** **View of Science**	**Philosophical structure** **View of Society**	**Pedagogical structure** **View of the learner**	**Pedagogical structure** ***View of the teacher***
NSE				
SOLID FOUNDATION	A vast and complex meaning system which takes many years to master.	Society needs scientists.	An individual who wants and needs the whole of a science, eventually.	One who is responsible to winnow out the most capable potential scientists.
CORRECT EXPLANATIONS	The best meaning system ever developed for getting at the truth about natural objects and events.	Society needs true believers in the meaning system most appropriate for natural objects and events.	Someone whose preconceptions need to be replaced and corrected.	One responsible for identifying and correcting the errors in student thinking.
STRUCTURE OF SCIENCE	A conceptual system for explaining naturally occurring objects and events, which is cumulative and self-correcting.	Society needs elite, philosophically informed scientists who really understand how that conceptual system works.	One who needs an accurate understanding of how this powerful conceptual system works.	Comfortably analyzes the subject matter as a conceptual system, understands it as such, and sees the viewpoint as important.
SCIENTIFIC SKILL DEVELOPMENT	Consists of the outcome of correct usage of certain physical end conceptual processes.	Society needs people who approach problems with a successful arsenal of scientific tool skills.	An increasingly competent performer with the processes.	One who encourages learners to practice at the processes in many different contexts of science subject matter.
HPS				
PERSONAL EXPLANATION	A conceptual system whose development is influenced by the ideas of the times, the conceptual principles used, and the personal intent to explain.	Society needs members who have a liberal education – that is, who know where knowledge comes from.	One who needs the intellectual freedom gained by knowing as many of the influences on scientific thought as possible.	Someone deeply committed to the concept of liberal education exposing the grounds of what we know.
STS				
EVERYDAY COPING STS	A meaning system necessary for understanding and therefore controlling everyday objects and events.	Autonomous, knowledgeable individuals who can do mechanical things well, who are entrepreneurial, and who look after them, are highly valued members of the social order.	Needs to master the best explanations available for comfortable, competent explanation of natural events, and control of mechanical objects and personal affairs.	Someone who regularly explains natural and man made objects and events by appropriate scientific principles.
SCIENCE/ TECHNOLOGY/ DECISIONS	An expression of the wish to control the environment and ourselves, intimately related to technology and increasingly related to very significant societal issues.	Society needs to keep from destroying itself by developing in the general public (and the scientists as well) a sophisticated, operational view of the way decisions are made about science-based societal problems.	Needs to become an intelligent, willing decision maker, who understands the scientific basis for technology, and the practical basis for defensible decisions.	One who develops both knowledge of and commitment to the complex interrelationships among science, technology, and decisions.

analyze science curricula and the curriculum components I use in this thesis (see also section 3.3). Roberts' view of science and view of society correspond to the philosophical structure, whereas Roberts' view of the learner and view of the teacher correspond to the pedagogical structure (cp. Fig.1.1). The science concepts selected in the light of the view of science and society (philosophical structure), and in the light of the view of the learner and teacher (pedagogical structure) will result in the corresponding substantive structure.

6.3.3 Condition one: using the curriculum framework for analysis

The following chemistry and science curricula (processes) have been analyzed and categorized in terms of the curriculum framework developed in this thesis (Figure 6.13).

Figure 6.13 Science curricula analyzed in terms of curriculum theoretical framework

Chemistry and science curricula	**Analysis based on specifications from:**	**This thesis**
Coherent School Chemistry	• publications De Vos & Verdonk	Figure 1.3
Dominant School Chemistry	• IF and DF responses	Figures 2.3 – 2.5
Normal Science Education	• publications Kuhn	Figures 2.3 – 2.5
O-level chemistry curriculum (England)	• transcripts interviews developers	Figure 4.2
Developmental process of Salters Chemistry	• educational documents • relevant publications • transcripts interviews developers	Figures 4.4 & 6.11 Section 5.4.4 Chapter 4
Teaching process of the units Metals	• classroom based research • transcripts interviews teacher • student questionnaire	Figures 5.5 & 5.13 Section 5.3 Section 5.4.1

In the process of development of my research framework I used an empirical method for the analysis and categorizations of the specifications taken from the relevant documents or transcripts. Together with two other researchers I analyzed, in the steps described in section 2.1.2, these specifications in an iterative way using labeled, but further undefined categories and subcategories (see Figure 2.2). After having filled out, defined as it were or 'inductively', all the categories and subcategories of the curriculum in question, I arrived at a characterization of the curriculum emphasis, which subsumes the combination of substantive, philosophical and pedagogical structure. In contrast with the inductive method I have used, Roberts (1988) uses what one could call a more 'deductive' method using labeled as well as defined categories: view of science, society, of the learner and of the teacher (see further Figure 6.12). This method of analysis was used by Roberts and Orpwood (1978) with teachers in trying to discern the curriculum emphases of textbooks.[5]

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[5] Based on Roberts (1988) and Van Berkel (2000), Westbroek et al. (2000) devised a curriculum framework, which they adapted to Dutch school chemistry education. This framework was used with Dutch teachers in order to clarify and make explicit the curriculum emphasis teachers saw as dominant in the current school chemistry curriculum, and the kind of curriculum emphases they would prefer instead.

The use of the curriculum framework as an instrument of analysis enables us to see differences or similarities between curricula of secondary chemical education. In the case of the IF research, this led to the finding that the currently dominant school chemistry curriculum must be considered as a form of Normal Chemistry Education in the sense of a first initiation and preparation. Furthermore, the finding that Normal Chemistry Education is the dominant emphasis of the current school chemistry curriculum enables us to take Dominant School Chemistry as the *baseline* for comparison with the successive curriculum levels in an innovative developmental and teaching process. The curriculum framework applied to a specific curriculum, such as Salters Chemistry, results in a detailed picture of the transformation of the curriculum structure along the curriculum levels in a developmental process (Fig. 6.6). And, the curriculum framework applied to a specific curriculum unit, such as the unit Metals, results in a detailed picture of the transformation of the curriculum structure along the curriculum levels in a teaching process (Figure 6.7).

In both cases there is visible a steady decrease in the degree of escape from Dominant School Chemistry as a form of NCE (see also Figure 6.11). This pattern of slippage appears to be quite common, especially in large-scale developmental projects (Goodlad, 1979; Van den Akker 1988). In other developmental projects the decrease in the degree of escape from NCE might be much less, though. There could also be a temporary or local increase in going from one level to another. In the transformation from the visionary to the designed curriculum, a group of developers might improve on the explicitness and coherency of the adopted vision by designing a good prototype. Or, in the transformation from the formal to the taught curriculum, a group of teachers could interpret and teach an adopted unit in an improved way by redesigning the unit more in accordance with the design criteria, which articulate of the vision.

In any case, it is the application of the curriculum framework to a specific science curriculum, which will reveal the pattern, which exits in the transformation of the curriculum levels moving from the visionary to the taught curriculum. Performing this analysis in conjunction with the process of development would lead to results, which would enhance the consistency between the products developed at the various curriculum levels. In brief, it would reduce in a systematic way the slippage, and in a more successful escape from NCE. Thus, the curriculum framework can be regarded as a useful instrument which enables the researcher to compare secondary chemistry curricula from different countries at a particular level e.g. at the formal or realized curriculum, and to compare a particular innovative school chemistry curriculum as it is transformed along the different curriculum levels concerned.

6.3.4 Condition two: use of curriculum framework for development

The findings of the analysis of current school chemistry curricula reported in this thesis have implications for the reform of school chemistry (Figure 6.9). The analysis in terms of the curriculum framework makes the structure of *school chemistry* curricula both explicit and specific. This is an important difference with Roberts' framework, which gives general characterizations of *science* curricula in terms of curriculum emphasis 'unpacked' in views of science, society, of the learner and of the teacher.

For example, the characterization of the structure of current school chemistry as a rigid combination of a specific pedagogical structure, a specific philosophical structure, and a specific substantive structure helps to further explicate and specify the analysis or diagnosis performed by Garforth for the O-level chemistry curriculum in use in England in the 1970s. The O-level chemistry curriculum could be identified as a form of Dominant School Chemistry (Figure 4.2).

The analysis of a particular school chemistry curriculum should entail, besides the analysis in terms of the curriculum framework developed here, a supplementary analysis adapted to the local or national situation in terms of the relationships and tensions within and between the pedagogical, philosophical, and substantive substructures of the school chemistry curriculum in question. In this way the analysis will lead to an explicit, specific, and detailed knowledge of school chemistry in a particular educational jurisdiction. The analysis will give developers a list of things that they do want to escape from, and therefore do not want to incorporate in the design of new teaching materials. In brief, it gives developers a specific idea what to escape from.

Furthermore, such an explicit and detailed knowledge will facilitate communication, including critiques among the actors involved in a curriculum project, regarding precisely what the project is trying to escape from. This should concern not only the group of developers and teachers involved but should have already begun in the visionary group. Communication among all these groups must then be facilitated in order to preserve as much consistency as possible. The actors involved in the design and teaching of units incorporating the chosen vision should have, on the one hand, an explicit and specific knowledge of their conceptions with regard to the substructures in current school chemistry, and on the other hand, they should be fully acquainted with the chosen vision as laid down in a set of design criteria.

Also, the actors' awareness of the rigid and isolated nature of school chemistry across the three substructures and at all curriculum levels will tend to prevent, correct, or (at least) control the NCE-reflex, the tendency of developers and teachers to fall back on their explicit or implicit conceptions with regard to the structure of school chemistry. An excellent formulation of this problem has been given by Garforth (1983), one of the pioneer developers of the Salters' Chemistry course.

> It may well be that there is a corpus of knowledge without which no syllabus could be called chemistry. Equally it may be that by our *schooling, subsequent training* and *teaching* we cannot see anything different adequately filling the space called chemistry at the school level.

This calls for an appropriate pre-service and in-service training for teachers and developers in order to prevent, correct or control the NCE-reflex (section further 6.4). The problem is complicated by the fact that not everyone will see the need for escape. For example, a Faculty of Science ad hoc Committee on a new STS-oriented science curriculum in Canada stated:

> We believe that science curriculum development should be primarily *the responsibility of professional scientists and teachers educated and trained in science and science education.* It must not be unduly influenced by professional educators whose background and interests are frequently secondary (Panwar & Hoddinott, 1995, p. 508).

It could well be that, because almost everyone involved in chemical education, or in science education for that matter, has been trained as a normal scientist, has been taught, has been teaching, is teaching, or is learning in an NSE tradition, it will remain very hard to see or do "anything different". In short, it may be very hard to escape from NSE, even if we see the need for escape. As we have seen, the Salters' developers came to violate, in the process of development, their design criterion one, *no preconceptions*, by invoking the structure of school chemistry as they perceived it. This led to the introduction of chemical concepts not needed to make sense of the chosen curriculum emphasis. Appealing to the implicit or practical knowledge of teachers can lead for example to the uncritical introduction of chemical experiments which are traditionally part of school chemistry courses (see Chapter 5).

In sum, applying the curriculum framework to the analysis of the currently dominant school chemistry curriculum leads to a more explicit and specific characterization of current school chemistry. Paying attention to the mechanism of the NCE reflex, will lead to a more explicit and specific strategy, which includes the necessary preventive and corrective measures (Figure 6.9), to escape from NCE at all curriculum levels and across the three substructures of the curriculum.

Besides having a clear conception of where to escape from, one should also have a strategy that addresses the direction where to escape to, that is, a vision should be developed (Condition two; Figure 6.9). The strategy to escape from NCE implies a strategy to replace the rigid combination of substantive, philosophical, and pedagogical structures of current school chemistry with a new coherent combination of substructures constituting the visionary curriculum. The Salters' development team chooses to articulate and operationalize their visionary curriculum using a coherent set of design criteria (Campbell, 1994).

In their retrospective analysis the Salters' Science developers made an important point, namely, that:

> Curriculum development is the process of *discovering* the detailed aims and objectives rather than starting with them (Campbell et al., 1994, p. 420).

They came to see curriculum development as a kind of technological problem solving addressing the needs of potential users (ibid., 421), and they took therefore as their starting point for their development or design of teaching units a coherent set of design criteria (see Chapter 4).

This has two important consequences. First, the design criteria put forward must be articulated and operationalized during the development by way of units embodying the new proposal, and these design criteria may as a result have to be changed during the process. Secondly, at each level of the curriculum's development, evaluation data must be collected in order to evaluate the effectiveness of the units developed in terms of learning and motivation, and also, if needed, to add to or revise the original set of design criteria. The specific choice made by the Salters' Chemistry Project was to develop an STS-type of curriculum, which focused on relevant materials and processes and aimed at a chemical awareness for all students. This led to their adoption of design criterion two, *relevance,* and design criterion three, *context-led development of concepts*, with design criterion one, *no preconceptions,* intended as a check to introducing no more chemical concepts than would be needed to make sense of the chosen, relevant contexts.

Curriculum diversity

In general, teams of developers can try to make school chemistry *relevant* by using some of the relationships given in Figure 6.4. Thus, strengthening relationships b, c, and d is useful in STS approaches, while relationships d, e, and f are addressed in HPS approaches. On the other hand, relationships a, d, and g have been used in NCE approaches (Chapter 2).

Formulated in Roberts' theory of science curriculum emphases, Dominant School Chemistry consists of a cluster of three or four curriculum emphases: *Solid Foundation, Correct Explanations, Structure of Science* and *Scientific Skills Development,* which together send a coherent message to teachers and students alike that school chemistry is about training of sound scientific knowledge, processes and skills (see Figure 6.11). At the same time, Dominant School Chemistry *prevents* the communication to the student of other curriculum emphases, emphases which are perhaps more worthwhile. The process-oriented curriculum emphases: *Self as Explainer* and to some extent *Structure of Science* and *Scientific Skills Development* contain the message that school science is about learning to argue and experiment (see Figure 6.5 for the process-oriented dimensions: common sense, history and philosophy of science, and current chemical research). Also, the society-oriented curriculum emphases, Everyday Coping and Science, Society, and Decisions, contain the messages that school science is about using and applying scientific knowledge and methods, or about making decisions on issues involving scientific and technological knowledge, such as the relevant emphasis of the Salters' Chemistry course (see Figure 6.5 for society-oriented dimensions such as everyday life and society, and technology).

The seven-fold isolation of Dominant School Chemistry has come about by largely excluding or resisting these HPS and STS curriculum emphases while simultaneously narrowing down the first four academically-oriented emphases to a weak version of NCE that consists of the reproduction or rote learning of facts and theories and of performing experiments mostly by way of recipes. The particular combination of specific substructures found for Dominant School Chemistry thus communicates a very specific message to teachers and students. The analysis in terms of the concept of Normal Science Education gives an edge to the analysis of Roberts in terms of the concept of curriculum emphases in that it singles out a (cluster of) emphases as *dominant* emphases pertaining to school chemistry curricula. This has repercussions for the process of development. After all, a characterization of the currently dominant school chemistry curriculum as rigid and isolated, will point to the NCE-reflex, which can be expected to occur during reform, more specifically during the transformations of the various curriculum levels (see Figure 6.9).

6.3.5 Condition three: use of curriculum framework in developmental research

The recommendations which arise from the application of my curriculum framework to the process development may also contribute to the strategy of developmental research as described by for example Lijnse (1995). As we have seen in Chapter 4, the Salters' Chemistry Project arranged to obtain feedback from students by collecting their opinions on the lessons of new units, at least in the early stage of the development. The Project also collected the opinions of teachers throughout the development. Given the *tentative* character of the design criteria approach, there is a need to increase the severity of the evaluation by collecting data from different kinds of sources and from all curriculum levels involved. For the taught and learned curriculum levels, not only should data consisting of *opinions* of teachers and students be collected, but also data on the *behavior* of teachers and students in the classroom, that is, of the actual teaching and learning activities they exhibit in the classroom.

The latter could be achieved by recording verbal and visual behavior using audio- and videotapes. In short, classroom-based research should complement the evaluation of opinions of the actors involved. The same should be done for the levels of the designed and visionary curricula. It would be most useful to have not only a record of the opinions of the actors involved, that is, of developers of materials and developers of vision, but also to have *a record of their behavior during the processes of designing and deliberation* leading to the developed products (teaching materials and curriculum vision). In this case the study of the behavior would involve: (i) the actual activities exhibited in the "vision-room" such as the deliberations and decisions made that lead to the successive drafts of the vision to be developed and (ii) the actual activities exhibited in the "design-room" such as the design of the first prototypes, their further development and revision, and the deliberations and decisions involved here.

Thus, "vision-room"-based research and "design-room"-based research should complement classroom-based research. The study of the behavior of the actors involved – be it 'vision makers', developers, teachers or students – should complement the analysis of the opinions given in interviews or tests by the actors involved. Finally, as shown in Chapter 5, a consistency analysis should be performed of the adopted design criteria as articulated and operationalized in the developed materials in order to screen or revise the original set of design criteria.[6] In sum, valuable data should be gathered on a newly designed curriculum by performing:

- a *consistency analysis* in order to see whether and to what extent the intended design criteria are consistently realized in the designed curriculum units;

- a *reversed design analysis*, that is, inferring from the actually realized content of the unit (contexts, concepts, and activities) any *tacitly* used design criteria which might have led to unintended, unforeseen, or perhaps unwanted consequences;

- a *redesigned proposal* or scenario for the topic or theme of the unit in light of the performed consistency analysis and reversed design analysis.[7]

Thus, to maximize the necessary feedback and to test the curriculum hypothesis severely, data should be collected from all curriculum levels about the *behavior* of actors during the processes, about the *products* of these processes, and about the *opinions* of the actors involved in these processes and products. In order to be able to use this varied feedback in an optimal way, it is important not to begin the designing of units until *after* the

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[6] See Van Berkel (1999) for a consistency analysis and a reversed design analysis performed on the research-based scenario of "teaching an initial particle model" as designed and tested by Vollebregt (1998).

[7] This focus on design in developmental research raises the question whether it would be fruitful to regard and explicate these research activities as a form of 'design science' (Van Heffen et al., 2002, p. 13).

systematic evaluation of the visionary level, and likewise, it is important not to start the large scale teaching of draft materials in the classroom until *after* the systematic evaluation of the designed curriculum level.

The recommendations about curriculum analysis, development, and research can briefly be put as follows: articulate a new vision, prevent import of the previously analyzed old vision, and test and control both processes – to escape from and to escape to – by systematic developmental research augmented by consistency analysis (Figure 6.9). Support for the curriculum framework developed in this thesis will depend on its usefulness in terms of analysis, development and developmental research.

6.4 Suggestions for further chemical educational research

During my struggle with the problem of the structure of school chemistry and the problem of escape from current school chemistry (section 1.1.1), I was led to various research themes which I decided at the time not to pursue in more detail than seemed relevant for the research questions (Figure 6.1).

However, on the basis of the theoretical curriculum framework developed in this thesis, it now seems worthwhile to explore further some of these research themes. Accordingly, I discuss the following: first, a research theme in the field of the history of school chemistry curricula (section 6.4.1); second, the relevance of the history and philosophy of chemistry for curriculum analysis and design (section 6.4.2); third, the development and research of the training of chemistry teachers as developers (section 6.4.3); and fourth, some ways to address the consistency and coherency problems of a context-led development of concepts (section 6.4.4).

6.4.1 History of school chemistry curricula

In several places (sections 2.3, 3.2 and 3.3.2) in this thesis, I have used international sources from the history of school science/chemistry curricula to support two important claims I make here: first, that the academic orientation of school science, what I called Normal Science Education (NSE), came to dominate at the end of the19th century, and second, that the curriculum orientation called NSE has resisted several curriculum reforms. As I have argued throughout this thesis, this NSE tradition still prevails today as a *rigid* combination of a specific substantive structure, based on *corpuscular theory*, a specific philosophical structure, *educational positivism*, and of a specific pedagogical structure, *initiatory and preparatory training* of future chemists.

As discussed in subsection 1.1.2, I refrained from embarking on an extensive and detailed historical study of school chemistry curricula. Since our ultimate goal was to contribute to reforms of school chemistry, what we needed was a valid description and analysis of the structure of current school chemistry, but only as detailed as required for that purpose. As De Vos (1991, p. 79) remarked:

> We must constantly keep in mind that our motives are educational, not historical, since the history of chemical education turns out to be just as fascinating as its present. Still, in order to understand the present curriculum and explore possibilities for future developments, we must study the past.

In this context of reform, Wobbe de Vos has given in several places an outline of a history of Dutch school chemistry, the last publication being, before he passed away, De Vos (2002). In our joint paper (De Vos et al. 1994, p. 746), written in the context of my research, he stated that:

> In a historical analysis of chemistry curricula in secondary schools it is interesting to see how (and to try to understand why) various aspects of the structure have been emphasized for some time, only to be overshadowed by others in later years. Developments in chemistry as well as in society in general have had their influences.

Therefore, the educational focus of my thesis has been on *phenomena of curriculum continuity*, not on phenomena of curriculum diversity of school chemistry curricula. Looking back, though, I think it would be worthwhile, on the basis of the curriculum framework I developed, to undertake a more detailed history of Dutch school chemistry. Such a curriculum history could describe in more detail for the Netherlands:

- How and why the academic orientation to chemistry prevailed at the end of the 19th century over the, originally intended, vocational orientation to Dutch school chemistry.

- Why curriculum changes resulting from intended reforms of Dutch school chemistry came to overlay the dominant curriculum emphasis.

- How mechanisms impending change, such as the NSE reflex, operate at the different curriculum levels involved.

Such a historical analysis of the Dutch school chemistry curriculum would reveal to what degree the actual curriculum diversity differs from the intended curriculum diversity. It would also show to what extent the actual curriculum emphases used in the Netherlands match the curriculum emphases as described by Roberts for North America (1982).

6.4.2 Relevance of history and philosophy of chemistry for curriculum design

The actual curriculum diversity revealed by curriculum history (Layton, 1973; Just, 1989; DeBoer, 1991) is often smaller than the intended curriculum diversity. The potential curriculum diversity, the possible new visions on science curricula, is even greater, as was argued by Schwab (1978), for example. These new visions, taken here as a coordinated combination of a specific substantive, philosophical, and pedagogical structure, are nowadays based on the work of science educators, developers, and teachers who are assisted at times by reflective scientists. These visions, however, can also by drawn from sources of the history and philosophy of science, especially with regard to the substantive and philosophical structure of potential new curricula.

The history of chemistry, an established discipline since the1950s, has occasionally been a valuable source to inform science curriculum design (Conant, 1948; Matthews, 1994; Holton, 2003), but as one of the respondents of the International Forum remarked:

> I do not know – like Aarons or Hecht in physics – a secondary textbook that shows chemistry as an historical process.

As for the philosophy of chemistry, this field of research has recently (1999) became more firmly established by the publication of its own journal titled, *Foundations of Chemistry*, while an electronic journal, *Hyle* has already been on-line since 1994 (www.hyle.org). Several conferences on the philosophy of chemistry – to which chemical educators attended or were invited – have led to the publication of many papers on important topics in the philosophy of chemistry, while a number of dissertations have appeared and recently a number of books on the philosophy of chemistry have also been published.

With regard to my own research, I used Kuhn's philosophy of science to analyze the currently dominant school chemistry curriculum as it came out of the responses of the International Forum (Chapter 2). I have further characterized, in Schwab's terms, Dominant School Chemistry as a rigid combination of a specific substantive structure, based on *corpuscular theory*, a specific philosophical structure, *educational positivism*, and a specific pedagogical structure, *initiatory and preparatory training* of future chemists. The rigid and isolated nature of Dominant School Chemistry as a form of Normal Chemistry education, has, as I have argued, its origin in the narrow and insulated nature of Normal Science/Chemistry, as described by Kuhn. In brief, the scientific practice of Normal Science is at the origin of the educational practice of Normal Science education.

Both the responses of the International Forum (Chapter 2), and Roberts historically informed educational analysis, have pointed to the existence of (partially realized) alternative science/ chemistry curricula having curriculum emphases differing from the dominant school science/ chemistry curriculum. As noted before, a new curriculum emphasis can be seen as a coordinated combination of a specific substantive, philosophical, and pedagogical structure. It is at this point that sources of the history and philosophy of chemistry can support the educational analysis of specific substantive and philosophical structures as contained in an alternative or new curriculum emphasis. For example, the work of the German chemical philosopher Schummer (1996) on the representation of dynamical relationships in chemistry could be used to elaborate the reaction-chemical emphasis of the "Coherent Conceptual Structure of the Chemistry Curriculum" as proposed by De Vos et al. (1994). The combined efforts of chemical educators and chemical philosophers might thus lead to a further elucidation and elaboration of the reaction-chemical curriculum emphasis, and the subsequent design and trial of such an (advanced) chemistry course. For another example of the relevance of history and philosophy of chemistry for curriculum design, see section 6.4.4.

Members of the International Forum (Chapter 2) made the valuable additional remark that variations in the substantive structure of school chemistry have been proposed and tried. At least three such substantive structures have been incorporated in school chemistry curricula: one centered on substances, one centered on corpuscula, and one around chemical reactions (section 2.2.2). Erduran and Scerri (2002, p. 20) make the same claim, while arguing for "the inclusion of philosophical perspectives in the chemistry curriculum" over and above these three emphases on chemical content. They mention as an example, the "Acids & Bases Curriculum" in which the main emphasis is of a philosophical, or rather epistemological nature, namely: "to engage students in the process of model generation, evaluation and revision" (ibid., p. 21).

Thus, curriculum diversity can be further increased by choosing alternative philosophical structures but also by choosing alternative substantive structures from the wider field of chemistry, taken as a set of chemical practices or activities in society of which the purely scientific research activities form only one subset (Fensham, 1984; Hoffmann (1995). An example of the latter type of curriculum (section 3.2) is the elementary chemistry curriculum of Van Aalsvoort (2000), a curriculum that is oriented in the chemical practice of making chemical products in conformity with chemical, technical, and societal norms. Needless to say, the pedagogical structure has to change as well. Only then can we say that we deal with:

> A fundamental change.. [which].. consists of an alteration of aims, contents and teaching strategies in concert, due to their being founded in a different representation of reality (Van Aalsvoort, 2000, p. 60).

6.4.3 Training chemistry teachers as developers

In Chapter 4, I have shown that the development team of the Salters' Chemistry project did not fully escape from the traditional O-level chemistry curriculum, the embodiment of normal chemistry education (NCE) in England in the 1970s (Figure 4.2). The larger part of the development team consisted of creative chemistry teachers (temporarily seconded to the Salters' Chemistry project as developers), as well as experienced developers and textbook writers, most of them still teaching in the classroom. In addition in Chapter 5, I have shown in detail to what extent a teacher, congenial to the Salters' approach while in the process of interpreting and teaching the unit Metals of the Salters' science course, did not escape from the substantive structure of NCE (Figures 5.5 and 5.16).

Apparently, it is a problem for both developers and teachers to escape from NCE while designing and teaching units of an alternatively conceived chemistry curriculum. The problem of escape, therefore, has to be faced, for both developers and teachers, at the visionary and designed curriculum levels as well as at the levels of interpreted and taught curricula. This is particularly important now, since in new curriculum projects of the 21st century the role of teachers as developers is seen to be of paramount importance for the success of the kind of reform the project sets out to achieve. Examples of such curriculum projects are Millar and Osborne (1998) on projects to be initiated beyond the year 2000 in the UK; Nentweg et al. (2002) on their "Chemie im Kontext" (Chemistry in Context) project in Germany; Driessen and Meinema (2003) on "Chemie tussen context en concept, ontwerpen voor vernieuwing" (Chemistry between context and concept, a design for renewal), the report which forms the basis for the "Nieuwe Scheikunde" Project (New Chemistry Project) in the Netherlands.

This means that we have to provide chemistry teachers with training, in-service as well as pre-service, which aims to enhance teachers' competence to design, develop, and teach new chemistry curricula. During these processes teachers should be aware of the constraints in order not to succumb to the NCE reflex. The three conditions to escape from Dominant School Chemistry, applied to teachers as developers, take the form of the following recommendations for further research (see also Figure 6.9).

Recommendations for further research on teacher training

Condition 1: *In order to escape, teachers have to know what to escape from.*

Develop and research a teacher training course on traditional, alternative and potentially possible chemistry curricula conceived in terms of curriculum levels (Goodlad), curriculum substructures (Schwab), and curriculum emphases (Roberts). Before assuming their role as developers, teachers should be made aware in this training course of their starting position with regard to their knowledge, skills, and attitudes in the curriculum landscape of their country.

Condition 2: *In order to escape, teachers have to know what to escape to.*

Develop and research the content of a teacher training course, including an effective teaching strategy, which aims to empower teachers with competencies to select, envision, design, interpret, and teach newly devised curriculum units.[8] Curriculum units should, after analysis in the design room and trials in the classroom, be revised or redesigned in accordance with the adopted design criteria, which constitute the new curriculum vision.

At a later stage these piloted teacher training courses might lead to a full-blown teacher training course on “Science Curriculum, Design and Development” to be integrated in the regular pre-service training of science teachers.

Condition 3: *In order to escape, teachers have to know how to escape.*

Perform a developmental research project on *Training Teachers as Developers*, which accompanies a large-scale curriculum developmental project such as the “Nieuwe Scheikunde” Project (Driessen & Meinema, 2003).

In the first phase of this project teams of teachers are formed who act as developers and are coached by a chemical educator. The teacher teams will design and develop pilot units on the basis of the context-led approach envisioned by the project. This is an excellent opportunity to perform design-room-based research on the design and development processes. In this way chemistry teachers learn to enhance their competencies to design, develop, and teach new chemistry curricula.

Furthermore, the chemical education researcher participating in this research project will be able to explicate, elucidate, and elaborate the adopted design principles, possibly into a design heuristic or a set of design procedures, needed to realize the envisioned curriculum effectively in the classroom. The results of the developmental research performed in this way might lead the development team to go back to the ‘design room’, or even back to the ‘vision room’, in order to adjust the originally adopted design criteria constituting the new curriculum vision. The findings of the first cycle of the developmental research project on “Training Teachers as Developers” is then used as input for the next cycle. The newly chosen curriculum emphasis is thus checked for consistency at all curriculum levels, from the visionary and designed curriculum up to the taught and experienced curriculum level.

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[8] For research on effective teaching strategies for teacher training courses see Janssen and Verloop (2004) and Stolk et al. (2004).

6.4.4 Problems with context-led development of units of a chemical course

In this final subsection I discuss, first, the *problem of consistency* of a context-led development of a chemical *unit*, and, second, the *problem of coherency* of a context-led development of a chemical *course*. I also outline some practical and theoretical ways to approach the problems of unit consistency and curriculum coherency and suggest some further research.

Problems of consistency of a context-led development of a chemical unit

As we saw in Chapter 4 (and in more detail in Chapter 5) in the analysis of the unit Metals the developers introduced more chemical content (PC content) than needed to make sense of the chosen CTS contexts, which centered around the theme corrosion. As a consequence, the CTS content, as entailed by the CTS contexts, had to give way to traditional PC content. As argued in Chapter 5, these findings are inconsistent with design criterion three, *context-led development of concepts*, which the developers expressed in the Salters Chemistry Syllabus as follows:

> ... chemical generalizations, principles and explanations are only introduced as and when they arise naturally from or when needed in the work on these 'everyday' substances (SLB, p. 1).

In subsections 4.6.2 and 5.2.3, I referred to this problem of unit consistency as the *tension between chemical content and context*, the main problem I discussed in Chapter 5. We also came across a second problem, namely, the *tension between the process of inquiry and the chemical context*, that is, a strong unit emphasis on context development can lead to a certain lack of evidential teaching with regard to the conceptual development. A third tension, *between chemical content and process*, became manifest in the first curriculum wave in the 1960s when many developmental projects tried to address science taken as a process of inquiry, while often holding on to more traditional science content than needed to make sense of the selected context of inquiry and the scientific processes entailed in this (section 3.2).

While developing and teaching any unit with a non-traditional curriculum emphasis, there is a danger that too much traditional content is, explicitly or implicitly, appealed to because of, what I called, the operation of the NSE reflex (section 3.4).

In terms of Roberts' concept of curriculum emphasis we could say in general, that it turns out to be very difficult to develop science units in which two or more curriculum emphases are addressed effectively at the same time. Attempts to do so, be they explicitly or implicitly intended, give rise to the tensions in the curriculum materials mentioned above, and with them to ambiguities and possibly confusion for teachers and students executing them.

In subsection 5.2.8, I suggested that the problem of unit consistency, the *tension between chemical content and context*, could be dealt with in a practical way by attempts to redesign the unit in more strict conformity with the design principles, which articulate the original vision of the developers (see also Van Berkel, 1999).

In brief, based on the consistency analysis performed during and after the development of a unit, there should follow the consistent redesign of the unit, alongside the usual tests for effective teaching and learning of the newly developed unit.

In view of the growing number of context-led developed science courses and projects the problem of unit consistency and the problem of course coherency discussed below deserve theoretical attention as well. The second generation of context-led developed science courses is about to take off (Millar & Osborne, 1998; Nentweg et al., 2002, Driessen & Meinema, 2003). Reflection and research on the first generation of context-led developed science courses such as the MAVO project (Joling at al., 1988), PLON (Wierstra, 1990; Kortland, 2002), Salters Science (Bennett & Holman, 2002) and ChemCom (Sutman et al., 1992) can hopefully lead us to make changes in our development projects, where previously we failed (Aikenhead, 1997). For instance, Bennett and Holman (2002, p. 181) reflect on the Salters Science projects as follows:

> The major challenge still lies ahead: to develop a curriculum for chemical and scientific literacy that meets the needs of all students, *the generalists as well as the future specialists*. The curriculum for chemical and scientific literacy represents the next logical step for context-based movement, yet it requires a fundamentally new approach. It is not a matter of asking what contents can be used to illustrate *a pre-existing body of scientific knowledge*. It is necessary to ask what science explanations and ideas students need to make sense of for their future live in a world dominated by science – *and to exclude rigorously anything that does not meet these selection criteria* (my italics).

In line with the findings of my research, it is my contention that in future context-based development science projects two things are essential to bear in mind (the first of which we have already discussed above). That is, to focus fully consistently on the chosen curriculum emphasis, and beware of developing, explicitly or implicitly, a mix of curriculum emphases Roberts (1988) in which very often the operation of the NSE reflex counteracts the realization of the newly chosen curriculum emphasis. Secondly, to focus in a fully consistent way on the needs of future citizens as generalists, and beware of addressing, explicitly or implicitly, the needs of a mix of future citizens and future science specialists in which, as we saw, the needs of the latter tend to prevail. From now on we should focus on "...learners as future citizens who will be consumers (Millar, 2002. p. 11).

In terms of Schwab, this amounts to the replacement of the prevailing *rigid* combination of a concept-led substantive, philosophical, and pedagogical structure aimed at the preparatory training of future scientists, with a new *coordinated* combination of a consistent, *context-led* substantive, philosophical, and pedagogical structure aimed at the general science education of future citizens.

Furthermore, questions about what we mean in a theoretical sense by the term *chemical context* and the term *chemical concept* need to be addressed as well. In a recent paper Bulte et al. (2004) have discussed a new theoretically based approach to context-led development of chemical units. Following the chemical philosopher Psarros (1998), chemical contexts are taken as what the authors call *authentic chemical practices*. Each chemical practice, they say, embeds a certain kind of question, which is answered by the practitioners of the authentic chemical practice while using appropriate knowledge and procedures contained in that chemical practice.

Different chemical practices embody different issue-knowledge and procedures. Simulating or 'mimicking' those authentic chemical practices for educational purposes leads to the design of educational materials by which students are motivated to explore this type of questions using appropriate knowledge and procedures with regard to the issue involved in the unit. Examples of chemical practices mentioned by Bulte et al. (2004) are: quality control of products, chemical inquiry, chemical modeling, and chemical design. The first two practices have been developed, trialled, and researched (Westbroek et al., 2004; Westbroek, 2005; Van Rens et al., 2003; Van Rens 2005), while using the methodology of developmental research (Lijnse, 1995), the first one in combination with the problem posing teaching approach (Klaassen, 1995).[9]

It is to be hoped that the prototypes of these authentic chemical practical units will inform and influence the large scale developmental project in the Netherlands, *Nieuwe Scheikunde* (Driessen & Meinema, 2003), a project which, as we saw, is also based on a context-led approach to development of a chemical curriculum.

The knowledge and procedures of chemical practices can be researched in an empirical or naturalistic way by observing or interviewing the practitioners of the authentic chemical practice (Prins et al., 2004). Another way to explicate the kind of knowledge and procedures of these authentic chemical practices is by making use of sources of history and philosophy of chemistry (see subsection 6.4.2 above). The expertise from the field of the history and philosophy of chemistry can be used to explicate what could be called *the logic of* these chemical practices, such as the logic of quality control of substances (conform to an international set of quality norms), the logic of chemical inquiry, the logic of chemical modeling, and the logic of chemical technological design.[10] Such logic of chemical practices could inform the consistent development of teaching materials, and thereby underpin the chemical competencies to be taught by chemistry teachers and to be acquired by students. This would constitute a much needed enrichment of the currently taught competencies of explaining and puzzle solving, competencies which have received up to now the most attention from science educators and, to some extent also from philosophers of science, in their explication of the logic of explanation (Hempel, 1965) and the logic of puzzle-solving (Kuhn, 1970). Also the logic of application, and its relation to the logic of explanation, would deserve more attention from science educators. If fully explicated, the logic of application could contribute to the consistent development of applications-led or context-led science courses mentioned above.

Problems of coherency of a context-led development of a chemical curriculum

Having developed chemical units with a consistent chemical context, chemical emphasis, or an authentic chemical practice, the problem arises, regarding the curriculum order or structure in which these various consistent chemical units must or should be put. In other words, we have to face the problem of the coherency of a context-led development of a chemical curriculum composed of different consistent, context-led units without the usual, explicit or implicit, appeal to the traditional conceptual structure of school chemistry. We have seen that the Salters' developers faced this problem in the end by appealing to: "what we perceive, what we all perceive to be *the structure of chemistry*" (L92). This should be avoided. As we have seen, the mechanism of the NCE reflex will lead to *slippage* in the processes, which lead from the visionary curriculum to the

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[9] Another example is Kortland (2001), who uses a *logic of decision* as explicated by philosophers to develop a problem posing approach to teaching decision making about a waste issue.

[10] See Roozenburg & Eekels (1996) for an interesting explication of the logic of technological design, on which the Techniek 15+ Project based its use of the technological design cycle (De Beurs et al., 2003).

realized, taught and learned, curriculum in the classroom and as a result to an inconsistent realized curriculum.[11]

Another, theoretical, solution to the problem of curriculum coherency has been put forward by Roberts (1982) who argued for what he called a *balance* of curriculum emphases in a newly developed curriculum. Such a balance would increase the likelihood of engaging more students in the various activities or practices of science by appealing to a broader array of interests, aptitudes, and abilities of the students involved. A consistent development of a curriculum emphasis would avoid the danger of slippage along the curriculum levels involved.

Another, practical, solution to the problem of curriculum coherency would be to leave it to chemistry teachers to select and compose their own chemistry course. This chemistry course would then be adapted to their own educational situation, school, and classroom while being based on the consistent and effective context-led chemical units provided by a project such as *Nieuwe Scheikunde* (Driessen & Meinema, 2003). It is important to realize that this approach to the problem of curriculum coherency assumes that teachers have been able to enhance their professional expertise in terms of teaching and developing teaching materials conceived along the new curriculum emphases, as I stressed in subsection 6.4.3. For biology education, Janssen (2004) discusses a problem posing approach to teaching eight biological perspectives, while developing at the same time a teacher training course for biology teachers so that they can themselves select, develop, and use these biological perspectives as applied to biological issues chosen by their students. Finally, just as with trialling lessons of a unit for consistency, order, and effectiveness, we can also make an informed guess as to the order for the consistent units making up a course, and then test this hypothesis for consistency and effectiveness.

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[11] A first proposal to address this problem from the perspective of authentic chemical practices has been described by Bulte at al. (2004).

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Appendices

Appendix 1: Illustrations of core statements on Coherent School Chemistry

Statement	*Illustration of Statement*	*Reference*
1	... in this book *we* are concerned with the science of chemistry ... emphasis on understanding ... essential for those pupils for whom the work [leads] to more advanced study.	Clynes and Williams, 1960, p. 14
	Many of you will continue with the subject and possibly add to our store of knowledge.	Mathews, 1964 (Coda, p. 347)
2	[Contrary to] physical change ... chemical change; (1) always produces a new kind of matter; (2) Is generally not reversible; (3) Is usually accompanied by considerable heat change...	Holderness andLambert, 1986, p. 5
3	To sum up: chemical laws .. are true until proved false, the laws can be used to predict the results of future experiments; .. new facts have been studied which this simple theory does not explain.	Mathews, 1964, pp. 27 & 228
	Explanations in terms of a Model.	Nuffield Chemistry, 1966, Ch. 2, p. 7
8	Concepts to which this book gives *prominence* include the electrical and particulate nature of matter ... redox reactions in terms of electron transfer, ionic equations, the chemical bond and crystal structure ...	Mathews, 1964 (Preface, p. 7)
	... chemical change involves the re-arrangement of atoms.	Clynes & Williams, 1960, p. 21
9	... is intended for children of average and above average in the 11-16 age group. Most of these children will not continue to study science ... the course must also serve as an adequate basis for future work [Ped]...	Nuffield Chemistry, 1966, Preface
	...seek to encourage lively enquiry, understanding and an ability to interpret evidence [Phil].	Nuffield Chemistry, Ch. 1, p. 1
	However, the chemistry through which pupils attain this ... will often be that used in older syllabuses [Sub].	Nuffield Chemistry, Ch. 4, p. 18

Appendix 2: List of abbreviations

Abbreviations specific for England and Wales

A-level	Advanced level (16 – 18)
ASE	Association of Science Education
CSE	Certificate of Secondary Education
DES	Department of Education and Science
GCE	General Certificate of Education
GCSE	General Certificate of Secondary Education
HPS	History and Philosophy of Science
HMI	Her Majesty's Inspectorate
INSET	In-service Education and Training of Teachers
ICCE	International Conference for Chemical Education
LAMPP	Less Academic Motivated Pupils Project
LEAs	Local Education Authorities
MEG	Midland Examining Group
NC	National Curriculum
O-level	Ordinary level (14 – 16)
PS	Pure Science
SAT	Standard Assessment Tasks (NC)
SATIS	Science and Technology in Schools
STS	Science, Technology and Society
SEAC	Schools Examination and Assessment Council
UYSEG	University of York Science Education Group

Abbreviations specific to this thesis

CC	Chemical Concepts
CR	Chemical Relationships
CT	Chemical Techniques
CSSC	Conceptual Structure of School Chemistry
CTS	Chemistry, Technology and Society
DF	Dutch Forum
DSC	Dominant School Chemistry
FC	Foundations of Chemistry
FMA	Familiar Materials Approach
FS	Foundations of Science
IF	Internatonal Forum
NCE	Normal Chemistry Education
NSE	Normal Science Education
MC	Methodology of Chemistry
MS	Methodology of Science
OGT	Overall Guide for Teachers (UYSEG, 1988)
PC	Pure Chemistry
Ped	Pedagogical structure
Phil	Philosophical structure
SAG	Student Activity Guide
SIS	Student Information Sheet
SLB	Syllabus Salters’ Chemistry (1992)
Sub	Substantive structure
TA	Teaching Approach

Appendix 3:

International Forum on Structures in School Chemistry

The list of international respondents (28) reads, in alphabetical order:

Dr. Philip Adey (UK);

Dr. Michael F. Akeroyd (UK);

Dr. Vanessa Barker (UK);

Dr. Judith Bennett (UK);

Prof. John D. Bradley (South Africa);

Mr. Neil Braund (UK);

Dr. José A. Chamizo (Mexico);

Dr. Glen Chittleborough (Australia);

Prof. Roger Cross (Australia);

Dr Arthur J. Davies (Australia);

Prof. Peter J. Fensham (Australia);

Prof. Ronald J. Gillespie (Canada);

Prof. Altfrid Gramm (Germany);

Dr. Vadim Grot (USSR);

Prof. Stephen J. Hawkes (USA);

Prof. Edgar W. Jenkins (UK);

Prof. Richard F. Kempa (UK);

Dr. Mary Beth Key (USA);

Dr. Andrea Kisfaludi (Hungary);

Prof. Dr. Peter G. Mahaffy (Canada);

Prof. Dr. Robin Millar (UK)

Dr. Mins Minssen (Germany);

Dr. Brandan Schollum (New Zealand);

Mr. Neil C. Smith (UK);

Prof. Dr. John S. Spencer (USA);

Dr. Paul Strube (Australia);

Prof. Dr. Elke Sumfleth (Germany);

Dr. Clive Sutton (UK).

Appendix 4:

Dutch Forum on Structures in School Chemistry

The list of Dutch respondents (22) reads, in alphabetical order:

Drs. W. Akkermans.

Drs. F. J. C. M. Arnold

Drs S. A. Bakker

Drs A. A. J. van Berkel

Ir. A. Beverloo

Drs. J. Bouma

Drs. F. Brants

Dr. J. van Driel

Ir. A.M. Edelbroek

Prof Dr. M. J. Goedhart

Dr. H. G. de Graaf

Drs A. v.d. Heijden

Drs. J. G.Hondebrink

Dr. C. de Jong

Dr. Ir. G. Laméris

Drs. H. van Lubeck

Prof. Dr. A. Rip

Drs. A. J. Schoneveld

Prof. Dr. H. A. M. Snelders

Dr. P. van der Vet

Dr. M. J. Vogelezang

Dr. H. Zandvoort

Appendix 5: Lesson plans of unit Metals of Salters Science (1989)

LESSON PLAN M1: WHAT ARE METALS?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
Survey	Laboratory survey in which students list things which they think are metals.	Metals are widely-used materials.
Teacher-student discussion 1	Students check their lists against the teacher's list.	Metals have certain properties in common.
Laboratory-based practical work	Comparison of the properties of metals and plastics based on experiments using a metal spoon and a plastic spoon. SAG M1.1.	
Individual student activity (optional)	Students list the metals they know and identify any known properties.	
Teacher-student discussion 2	Discussion to clarify points from the previous activity and from the class practical.	
Teacher-student discussion 3	Introduction to the use of symbols to represent metals.	Metals can be represented by symbols.
Homework suggestion	Completion of a word search for metals. Data analysis and interpretation exercise to explain the reasons for certain uses of metals. SAG M1.2 and SAG M1.3.	The use of a metal is related to its physical properties.

LESSON PLAN M2: WHICH METAL IS USED TO MAKE A DRAWING PIN?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
Teacher-student discussion 1	Discussion to recall that metals have common physical properties and many look alike. Discussion of possible ways of identifying different metals. Introduction to the idea that a more precise identification can be made through study of their chemical reactions.	Metals have certain physical properties in common.
Laboratory-based practical work	Simple qualitative tests on known metals. Identification of the dominant metal in a drawing pin. SAG M2.1	Chemical tests are often better than physical tests at distinguishing between metals.
Teacher-student discussion 2	Brief discussion to reinforce ideas from M1 (homework) looking at the relationship between the properties of metals and their uses.	The use of metals are related to their chemical properties.

LESSON PLAN M3: WHAT HAPPENS WHEN METALS CORRODE?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
Teacher-student discussion 1	Samples of corroded metals are displayed and discussion establishes where these might be found.	Metals often corrode.
Teacher demonstration	Removal of corrosion by rubbing with an emery cloth.	Corrosion occurs at the surface of metals.
Teacher-student discussion 2 Designing an experiment (key activity)	Comparison of corroded and uncorroded metals provokes discussion of the corrosion process. Introduction to the terms element, compound and chemical reaction. Students make suggestions about the conditions needed for corrosion. Class discussion leads to the design of an experiment to investigate air, water, and salt as possible causes of corrosion.	A new substance is formed when metals corrode. Some metal is used up when this new substance forms. An element is the simplest possible substance. A chemical reaction involves the formation of a new substance. A compound is formed when two or more elements combine together.
Laboratory-based practical work	Students set up an investigation into the extent and rate of rusting of iron nails in the presence of combinations of air, water and salt. SAG M3.1.	Rusting is the name given to the corrosion of iron
Talking and listening in small groups or homework suggestion	Students make and record predictions about the results of their investigation. (key activity)	

LESSON PLAN M4: DO ALL METALS CORRODE?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
Teacher-student discussion 1	Examination of rusting experiments and recording of results. Discussion to summarise information collected about rusting at this stage.	Air and water are both needed for rusting. Salt makes rusting happen more quickly. Iron is used up during rusting. A new substance is formed when iron rusts.
Teacher demonstration	i) Burning of a piece of magnesium ribbon in the air. ii) Heating of a piece of magnesium ribbon in a crucible with the lid lifted and replaced at frequent intervals.	Air is needed for magnesium to burn. Magnesium is used up during burning. A new substance is formed when magnesium burns.
Talking and listening in small groups	Students discuss their ideas in small groups in order to agree a theory as to what happens during the processes of rusting and burning.	
Teacher-student discussion 2	Reporting back of the ideas. The teacher might pose the question: * How can we prove that iron and magnesium gain something from the air during rusting and burning?	
Laboratory-based practical work and / or Teacher demonstration	Study of possible changes in mass: i) as magnesium burns, ii) as iron rusts. SAG M4.1.	When a metal corrodes or burns it gains mass. Corrosion and burning involve reaction with oxygen. When elements react with ogygen compounds are formed. Reactions with oxygen are called oxidation reactions.
Teacher-student discussion 3	Discussion should allow the production of word equations to summarise the processes of corrosion and burning and should reinforce ideas about elements and compounds from M3.	Elements can combine to form compounds, but they cannot be made to weigh less.

LESSON PLAN M5: DO ALL METALS CORRODE?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
Datacollection / presenting a report.	Examination of rusting experiments. Recording of results on SAG M3.1. Each group should prepare a written report from their results.	Air and water are both needed for rusting. Salt accelerates rusting.
Teacher-student discussion 1	The display of corroded metals in M3 suggests that there may be an order of ease of corrosion.	
Teacher demonstration	Samples of the five metals are displayed. Demonstration of the rapid tarnishing of freshly-cut sodium. Demonstration of the reaction of sodium with water.	Sodium corrodes quickly in air and reacts violently in cold water.
Laboratory-based practical work	Investigation of the corrodibility of the remaining four metals by observing their action with water. SAG M5.l.	Hydrogen explodes when mixed with air and ignited. A small-scale conversion of this reaction is used to test for hydrogen.
Teacher-student discussion 2	Discussion of the class experiment. Introduction to the term oxidation. Use of word equations to summarise the reactions of metals with oxygen.	The order of decreasing corrodibility and reactivity with water of the metals is sodium, calcium, magnesium, iron and copper. This order forms a reactivity series for the metals.
Homework suggestion	Completion of a question sheet to examine how corrosion can be prevented. SAG M5.2.	A number of methods are available for preventing corrosion.

LESSON M5X1: HOW CAN WE PREVENT RUSTING?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
Teacher-student discussion	Examination of a bicycle to consider how rusting is prevented on various parts of the machine. SAG M5X1.1.	Rusting is prevented by excluding air and / or water.
Laboratory-based practical	Students set up an investigation to answer the question: * Do rust stoppers work? Students prepare their samples and examine them daily to determine the length of time necessary for the cans to rust. The results of this experiment will be discussed in M6. SAG M5X1.2.	

LESSON M5X2: DO OTHER METALS STOP IRON PROM RUSTING?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
Teacher-student discussion	Recall the need to cover iron and steel to prevent rusting (from MS and MSX1).	
Laboratory-based practical work or Teacher demonstration	Students set up an investigation into the effect that other metals have on the rusting of iron. Students investigate the rusting of iron in salt solution in the presence of a second metal. Samples are examined daily. The results of this experiment will be discussed in M6.	(see Lesson M6)

LESSON M6: WHAT ARE METAL ALLOYS?

TYPE OF ACTIVITY	OUTLINE	KEY POINTS
(If M5X1 covered) Teacher-student discussion 1	Discussion of the experimental results from M5X1 and method of rust prevention.	Several methods are available for the prevention of rust.
(If M5X2 covered) Teacher-student discussion 2	Discussion of the experimental results from M5X2 and methods of rust prevention. Explanation of the differences in behaviour of metals in terms of differences in corrodibility.	Metals above iron in the reactivity series slow down rusting; those below iron speed it up.
Teacher-student discussion 3	Introduction to the word alloy. Reference to the fact that steel rusts readily in moist air but steel containing chromium (stainless steel) hardly rusts at all.	An alloy is a mixture if one metal with one or more other elements. Forming an alloy changes the properties of a metal.
Teacher demonstration 1	Comparison of the bendability and brittleness of a paper clip and a darning needle both of which are made from steel.	The composition of an alloy determines its properties.
Teacher demonstration 2	Preparation of solder. Comparison of the melting points of tin, lead and 50% tin / 50% lead alloy.	The melting point of a metal can be lowered by the presence of a second metal.
Homework suggestion	Completion of a question sheet on the use and properties of alloys. SAG M6.1. SIS M6.1.	The use of an alloy depends on its properties.

Appendix 6: List of Figures

Summary

In this thesis I have addressed two main problems of the current school chemistry curriculum. The first problem is the *problem of structure*: What is the structure of the chemical concepts and chemical relationships present in school chemistry textbooks? The second problem is *the problem of escape*: Why do reforms of the current school chemistry curriculum lead to only marginal changes? Attempts to escape are more likely to succeed if one knows what to escape. This raises the question whether the structure of the current school chemistry curriculum is an asset or an obstacle for reforming school chemistry. The solution of the problem of escape thus bears on the solution of the problem of structure.

The first condition for realising a more successful reform in chemistry education is to understand the structure of the current school chemistry curriculum. The second condition concerns the development of a coherent vision on secondary chemistry education, that is, on where to escape to, and the third condition concerns a systematic method about how to escape from the currently dominant school chemistry curriculum. In this thesis I have answered the seven research questions listed below, dealing with the problem of structure (1-3), and the problem of escape (4-7).

1. What is the structure of the current school chemistry curriculum?
2. Why is this structure the way it is?
3. Is this structure a desirable structure?
4. What are conditions for escape?
5. To what extent does the Salters' Chemistry curriculum escape from this structure?
6. Why is it so hard to escape from this structure?
7. How can attempts to escape from this structure be more successful?

In Chapter 1, Problems of current school chemistry, a preliminary answer has been given to the first question in the form of an initial hypothesis on the Coherent Structure of the School Chemistry Curriculum. By analysing school chemistry textbooks and syllabi from the point of view of *learning to explain and predict chemical phenomena* we arrived at a reaction-chemical structure of the current school chemistry curriculum with the following structural features:

- demarcation of everyday life, school physics and chemical technology
- relationships between macroscopic concepts with the concepts of chemical reaction, chemical substance, and chemical element at the heart of this macroscopic substructure

- three conditions for reactions
- – conservation of chemical elements
- – decrease of chemical or Gibbs energy
- – kinetic instability
- theories of structure and bonding.

The reaction-chemical view on Coherent School Chemistry was summarized in Ten Statements and submitted it to an International Forum (IF) and a Dutch Forum (DF) of chemical educators, developers, and researchers, for comments and criticisms.

The curriculum theoretical framework developed in this thesis consists of the substantive, philosophical and pedagogical structure (based on Schwab) which in a coherent combination make up a curriculum structure, which pertains to a number of curriculum levels (based on Goodlad). These substructures and levels apply to the curricula of any discipline not just to the curricula of the natural sciences (formal part of the theoretical framework). Both the concept of curriculum emphasis, as elaborated by Roberts and the concept of Normal Science Education as developed in this thesis (based on Kuhn) do apply to, or are specific to the domain of the natural sciences (material part of the curriculum framework). The curriculum framework appeared to be fruitful for describing, analysing and explaining the curriculum data in this research.

Kuhn's view on scientific training as puzzle-solving within the paradigm of normal science made it possible to single out, characterise, and explain the *dominant* emphasis and structure of the current school chemistry curriculum. This led to the formulation of the concept of Normal Science Education, more particularly for chemical education to Normal Chemistry Education.

Following Goodlad several curriculum *levels* in school chemistry curricula were distinguished:

- *visionary* or *intended curriculum*: the formulation by the developers of a number of design criteria
- *designed curriculum*: the operationalization of the design criteria by the developers in teaching materials
- *formal curriculum*: the official codification of the designed curriculum product in a syllabus by the developers in collaboration with the staff of an exam board
- *interpreted curriculum*: the curriculum (units) as perceived by teachers
- *taught curriculum*: teachers in the classroom executing the curriculum units
- *experienced curriculum*: students in the classroom experiencing the teaching of the curriculum units.

Lastly, Roberts' concept of *curriculum emphasis* is used in order to characterise the school chemistry curricula I am dealing with in this thesis. Roberts distinguished seven types of emphases for science curricula:

- *Solid Foundation*: stresses science as cumulative knowledge
- *Structure of Science*: how science functions as a discipline
- *Science/Technology/Decisions*: the role scientific knowledge plays in decisions which are socially relevant

- *Scientific Skill Development*: the ‘science as process’ approach
- *Correct Explanations*: science as reliable, valid knowledge
- *Personal Explanation*: understanding one’s own way of explaining events in terms of personal and cultural (including scientific) influences
- *Everyday Applications*: using science to understand both technology and everyday occurrences.

In Chapter 2, **Normal Science Education and its dangers: The case of school chemistry,** I describe first the research design and method used in the testing of the hypothesis on Coherent School Chemistry and the theoretical curriculum framework used in the analysis of the research data. The IF and DF responses are analysed in terms of a this framework in which the curriculum structure of science curricula is subdivided in the substantive, philosophical, and pedagogical substructures. The comments and criticisms made by the members of these two forums – experts in chemical education: researchers, developers, teachers – led to a major revision of the initial claims, and to the concept of Dominant School Chemistry. Contrary to what we assumed, current school chemistry is not about learning to explain and predict chemical phenomena in terms of a reaction-chemical approach. Instead, all current school chemistry curricula belonging to the dominant version:

- are being taught and learned as *propositions and algorithms* to students seen as future chemists.
- have a *corpuscular theoretical* focus on chemical substances and their properties.
- deal with explanations and systematisation of chemical information largely in terms of *corpuscular theory*.
- make a distinction between a level of *phenomena* and a level of *corpuscula*. The introduction of corpuscular theory in books and classroom is not consistent nor accurate, and hence not effective.

The first research question was: What is the structure of the current school chemistry curriculum? The IF and DF survey led us to the answer that all current school chemistry curricula have a dominant substantive structure, based on *corpuscular theory*, which is *rigidly* combined with a specific philosophical structure, that is, *educational positivism*, and a specific pedagogical structure, that is, *initiatory and preparatory training* of future chemists.

Further, the structure of Dominant School Chemistry as a whole suffers from a sevenfold *isolation*: from common sense, everyday life and society, history and philosophy of science, technology, school physics, and from chemical research.

The second research question was: Why is this structure the way it is? This question is answered by giving an explanation of the main characteristics of Dominant School Chemistry, rigidity and isolation, in terms of Kuhn’s theory of science and science education. This leads to the concept of Normal Chemistry Education. As I argue in Chapter 2, a radical reform, or an escape from Dominant School Chemistry is only possible through a *co-ordinated replacement* of the currently rigid combination of a substantive, philosophical, and pedagogical structure of school chemistry.

This leads then to a discussion of the third research question, Is this structure a desirable structure?, that is, whether the structure of school chemistry, thus described and explained, is a desirable structure from the point of view of teaching chemistry for understanding chemical phenomena and from the point of view of teaching chemistry to future citizens.

Dominant School Chemistry fails to realise its own set goal, that is, teaching and learning all pupils the understanding, prediction and explanation of chemical phenomena. What it does teach and learn instead is a set of propositions and algorithms. Neither the effectiveness of Dominant School Chemistry nor its superiority over more critical forms of secondary chemistry education has been conclusively demonstrated. The conclusion, therefore, is that it is not possible to justify, *by* argument or experiment, an Normal Chemistry Education based chemistry course that is suitable for all pupils. At most this might be realized for the small minority of students who will study chemistry at a further level, some of whom might become chemists. Normal Chemistry Education cannot be regarded as a form of chemistry education appropriate for all pupils, exactly because it consists of a dogmatic, domain-specific training for future chemists. Therefore, at the secondary level, the initiation into normal chemistry should be largely replaced by an education in or through fluid, critical or creative chemistry, together with an education in or about the relations between chemistry, technology, and society.

In Chapter 3, Conditions to escape from and to escape to, I discuss the conditions for escape from the currently dominant school chemistry curriculum (research question 4).

A brief review of some attempts to reform the dominant school science curriculum, in terms of the concept of Normal Science Education, gives an idea of the many difficulties involved when trying to realise a desirable reform in science education. These manifest themselves at the various curriculum levels involved. For example, researchers have pointed to factors at the level of the:

- *visionary curriculum*: misplaced goals, lack of involvement teachers in policy making, inadequate views of scientific method;
- *designed curriculum*: a lack of consistency between vision project and teaching materials, text do not reflect vision, exercises do not reflect idea of enquiry, lack of involvement of teachers in developing process;
- *formal curriculum*: professionalization of school science;
- *interpreted curriculum*: lack of consistency vision and in-service training, lack of ‘practical on-site experience’ for teachers;
- *taught curriculum*: resistance of teachers and lack of consistency between vision and views of teachers.

Analysing why it is so difficult to escape from Dominant School Chemistry, given its rigid and isolated character, leads to an initial formulation of the *first condition* for escape which has to do with the analysis of the structure of the currently dominant school chemistry curriculum. In Chapter 6, I come back to the first condition of escape, which we have to take into account while planning to reform current school chemistry. In Chapters 4 and 5 I argue, based on the analysis of the process of development of the Salters Chemistry curriculum, that condition one is often neglected.

In Chapter 3, the curriculum framework of Roberts, centered around the conceptual lens of curriculum emphases, is discussed in order to give a first charac*terization of the second condition of escape,* the development of a vision, and the *third condition* of escape, the method of development.

Roberts defined the concept of curriculum emphases as a coherent set of messages to the students about science, answering the students' question: Why he or she had to learn this? The concept of curriculum emphasis can be used for both analytical and developmental purposes:

- as a theoretical instrument to describe, analyze and explain the *vision* and structure of past and current science curricula, documents, and textbooks
- as a practical instrument to deliberate, choose, develop, sustain, and evaluate in a structured way a *vision* on new science curricula.

The discussion of the first, theoretical function, and more in particular of the second, practical function lead to important insights with regard to the second and third condition of escape, the development of a vision and the method of development. These conditions are further discussed and elaborated upon in Chapter 6.

In Chapter 4, Salters' Chemistry: An analysis of its process of development, I focus on research question 5: To what extent does the Salters' Chemistry curriculum escape from Dominant School Chemistry, as it existed in England at the time? I focus on the development of units of the Salters Chemistry course as a whole in Chapter 4, while focus on the lessons of the unit Metals of the Salters' Science course in Chapter 5.

The process of the Salters' Chemistry developmental project is analyzed in terms of the curriculum theoretical framework: the substantive, philosophical, and pedagogical structure as pertaining to the curriculum levels involved, the concept of curriculum emphasis and the concept of Normal Chemistry Education. The Salters' Chemistry course combines a curriculum emphasis on *Everyday Applications*, using chemical knowledge to understand everyday occurrences, a curriculum emphasis on *Science, Technology, Decisions*, stressing the role of chemical knowledge in decisions with social relevance and a curriculum emphasis on *Science Skill Development.* The course is further categorized as a "Science through STS" curriculum (Aikenhead) in terms of the ratio between STS and Pure Science content.

The developers of the Salters' Chemistry course use *a design criteria approach*, that is, general criteria providing direction but not limiting the outcomes at the level of detail. Initially, three design criteria: *no preconceptions*, *relevance* and *context-led development of concept* were formulated, while in the process two other design criteria: *variety-cum-activity* and *flexibility* were added. A consistency analysis on relevant curriculum documents and transcriptions of interviews with developers, is performed in order to see whether and to what extent the design criteria are consistently realized in the development of Salters' Chemistry course. This curriculum analysis concerns the visionary, designed, written, formal and experienced curriculum level. The analysis showed that design criterion 1, *No preconception*s has gradually been replaced by a guiding conception, internally by what the developers perceived to be *the structure of chemistry*, and externally by the GCSE exam demands.

The application of design criterion 2, *Relevance*, in the transformation of the visionary to the formal curriculum led to a choice of relevant contexts but it was constrained more and more, both internally by what the developers perceived to be *the structure of chemistry* and externally by GCSE requirements of content or process. This has given rise to tensions in the course between the original context oriented approach and the traditional emphases on chemical content and skills and science processes.

The application of design criterion 3, *Context-led development of chemical concepts*, led to an increased emphasis on chemical concepts and their sequential and / or logical development. Important too was a greater emphasis on scientific processes over and above the initial emphasis on chemical techniques and associated practical skills.

Further, by categorizing the visionary, designed, written and formal curriculum of the Salters' Chemistry course in terms of the substantive, philosophical, and pedagogical substructures, I identified the changes in the components of these substructures. The main changes in the process of transformation of one curriculum level to another are the following.

The *substantive structure* of the Salters' Chemistry GCSE course initially contained, compared to a traditional O-level course, a somewhat *reduced* load of chemical concepts and relationships, while retaining about the same set of standard chemical techniques. The concepts and relationships were put in a teaching sequence partly informed by, and consistent with, the structure of chemistry as the developers perceived it, not in a top-down hierarchy, but bottom-up led by contexts and activities, and starting at the observational and manipulative level via low-level generalizations moving to more abstract relationships and theories. The developers did not escape *fully* from substantive structure of Dominant School Chemistry, but only to a certain degree. The ruling of an exam committee brought back the chemical concepts initially excluded by the developers.

The *philosophical structure* of Salters' Chemistry moved away from theoretical chemistry towards applied chemistry emphasizing relevance and use. The developers did not escape *fully* from traditional philosophical structure, but they did use applications of chemical knowledge to familiar phenomena and materials, so not using just 'academic' applications as had been customary in traditional O-level chemistry.

The *pedagogical structure* of the Salters' Chemistry GCSE course initially focused on the needs of the majority of students, the less and moderately able, but at a later stage had to consider the needs of the most able students as well, in particular by incorporating explanation using abstract chemical concepts. And at a later stage the original aim of chemical awareness for the future citizen had to compete with the traditional aim of preparing future A-level candidates, by an exam course for the full range of grades. The context-led teaching approach evolved into, what the developers called, a *context and activity led* teaching approach using a varied set of learning activities including customary laboratory experiments. The developers did escape from the pedagogical structure of Dominant School Chemistry by devising a context-led teaching sequence which differed from the traditional theory-based sequence.

In Chapter 5, Metals: A Chemical unit of the Salters' Science curriculum, I answer research question 5: To what extent does the Salters' Chemistry curriculum escape from Dominant School Chemistry? The analysis concerns the curriculum unit Metals as interpreted and taught by a teacher, and experienced and learned by students in the classroom.

A detailed consistency analysis was performed on a unit of the written curriculum as operationalized in the eight lessons of the unit Metals of the Salters' Science course. Following Aikenhead, the Salters' Science course is categorized as a "Science through STS" curriculum in terms of the ratio between STS and Pure Science content which I use as a measure of the degree of escape of the unit Metals from Dominant School Chemistry. This way we can follow the subsequent transformations of the written, interpreted, and taught curriculum levels, to compare these with the formal curriculum level of the unit Metals, and with the currently dominant school chemistry curriculum. The consistency analysis made it also possible to investigate more precisely to what extent the developers were able to fulfil in a *consistent* way the adopted design criteria. The analysis focused on the two central Salters' design criteria of *relevance* and *context- led development of concepts*, while trying to answer the following two subquestions:

- Does each lesson of the unit Metals have its origin, and hence its *justification* for study, *fundamentally*, in aspects of *everyday life*?
- Are all chemical concepts and explanations, introduced in the lessons of the unit Metals *needed* for the study of these everyday situations?

The consistency analysis of the lessons of the unit Metals showed, firstly, that more Pure Chemistry (PC) content and less Chemistry-Technology-Society (CTS) content was developed than was needed, that is, than was consistent with design criteria 2 and 3. The CTS/PC ratio, taken as a measure of the degree of escape, decreased substantially going from the formal to the written curriculum. In doing so, the developers went against design criterion 1, *no preconceptions*, making it thereby very difficult to uphold the central design criteria 2 and 3. While designing the lessons of the unit Metals, the developers *retained* a number of PC concepts traditionally part of dominant school chemistry, that is, concepts developed though not needed to make sense of the selected contexts. Consequently, some lessons of Metals (1989) suffer from a tension between the PC content developed and the CTS content needed.

In the transformation from the written to the interpreted curriculum, it turned out that the teacher added some PC content although not needed, and deleted some CTS content, although needed to make sense of the contexts selected, decreasing thereby again the CTS/PC ratio. Design criterion two, *relevance*, and design criterion three, *context-led development of concepts* were not consistently upheld. Subsequently, the teacher added during his teaching again some PC content not needed, while he did not teach some CTS content that was needed to make sense of relevant contexts. This is inconsistent with design criteria two and three, and the CTS/PC ratio therefore decreases further in the transformation from the interpreted curriculum to the taught curriculum. Thus, here we have for developers and teachers specific illustrations of what Goodlad called “slippage” from one curriculum level to another.

In this process of *slippage*, the tension between the PC content developed and the CTS content steadily increases in the case of Metals. This tension is connected with a corresponding tension in the philosophical structure: between the cognitive process of explanation on the one hand and the process of application on the other hand. It is also related to a tension in the pedagogical structure: between the aim to train future A-level chemistry students and the aim to educate future citizens in chemical literacy. A successful escape from Dominant School Chemistry requires, therefore, a *co-ordinate replacement* of the currently rigid combination of substantive, philosophical, and pedagogical structure of school chemistry. This appeared to be difficult task to perform. The concept of normal chemistry education based on Kuhn’s functional theory gives another reason why is it so hard to escape. It is predominantly the tension or dual emphasis in the pedagogical structure which determines the dual emphasis in the philosophical structure and the PC-CTS tension in the content of the substantive structure. In brief, function determines structure of the curriculum.

In Chapter 6, Beyond current school chemistry: Perspectives on chemistry at school, the focus is on research question 7, How can attempts to escape from the structure of the currently dominant school chemistry curriculum be improved?

Based on my research findings, its implications and explanations recommendations are formulated in order to reform the currently dominant school chemistry curriculum. This amounts to a strategy to escape from Dominant School Chemistry in terms of a framework for analysis, development, and developmental research. This is a further elaboration of the three conditions for escape as introduced in Chapter 3, thereby answering also research question 4, What are the conditions for escape? I have summarized the three conditions for escape as follows:

Condition one: *In order to escape, we have to know what to escape from.*

- Perform a domain specific analysis of the nature and structure of the dominant school chemistry curriculum in terms of the framework developed in this thesis, that is, in terms of a combination of the dominant substantive, philosophical, and pedagogical structure.

Condition two: *In order to escape, we have to know what to escape to.*

- Aim towards a coordinated replacement of the currently dominant (rigid) combination of substantive, philosophical, and pedagogical structure of school chemistry.
- Develop and legitimize a new curriculum emphasis for school chemistry, in terms of a new coherent combination of a substantive, philosophical, and pedagogical structure.
- Use the concepts of curriculum emphases and Normal Chemistry Education (NCE) of the framework as instruments to articulate the visionary curriculum in terms of design criteria, that is, a new conjectural vision to be operationalized by the design of prototypes of the teaching material in the designed curriculum.

Condition three: *In order to escape, we have to know how to escape.*

- Be aware of, anticipate and avoid the NCE reflex, or at least deal in time with any difficulties related to the dominant school chemistry curriculum at all curriculum levels, starting at the visionary and designed curriculum.
- Collect evaluation data at all curriculum levels to safeguard the adopted vision, in moving from the visionary, designed, written, formal up to the interpreted, taught, and experienced curriculum levels.
- Check the newly chosen curriculum emphasis, articulated in the visionary curriculum in terms of design criteria, for consistency at all curriculum levels.

The recommendations about curriculum analysis, development and research can briefly be put as follows: articulate a new vision, prevent importing the old vision, and test and control the coupled processes of escaping from and escaping to by the methods of developmental research.

Secondly, I gave some suggestions for further educational research in the following areas. The research focus of my thesis being on curriculum continuity and not on curriculum diversity, it would be worthwhile to undertake, on the basis of the curriculum framework I developed, a more detailed history of Dutch school chemistry. Such a curriculum history would describe in more detail origin, curriculum changes and mechanisms of change.

Expertise from the disciplines of the history and philosophy of chemistry could support the chemical educational analysis of specific substantive and philosophical structures as contained in alternative or newly proposed curriculum emphases. For example, to elucidate further the reaction-chemical curriculum emphasis discussed in Chapter 2, or to explicate *the logic of* chemical practices such as quality control, chemical inquiry, chemical modeling and chemical technological design.

While designing and teaching units of a new school chemistry curriculum, it turned out to be difficult for both developers and teachers to escape from Dominant School Chemistry. The three conditions for escape, as applied to teachers as developers, are formulated as follows:

- *Condition 1: In order to escape, teachers have to know what to escape from.*
- *Condition 2: In order to escape, teachers have to know what to escape to.*
- *Condition 3: In order to escape, teachers have to know how to escape.*

Fulfilling these conditions will lead to the following recommendations for further research:

- Develop and research a teacher training course on the curriculum emphases of traditional, alternative and potentially possible school chemistry curricula.
- Develop and research a teacher training course, including an effective teaching strategy, which aims to empower teachers with competencies to select, envision, design, interpret and teach newly devised curriculum units.
- Perform a developmental research project on “Training Teachers as Developers” which accompanies a large scale curriculum developmental project.

Also, I discuss the *problems of consistency* of a context-led development of a chemical *unit* and, the *problems of coherency* of a context-led development of a chemical *course*. I have outlined some practical and theoretical ways to approach these problems of unit consistency and curriculum coherency.

In this thesis I have tried to show the *usefulness* of the curriculum framework as an instrument of analysis in the following ways:

- By uncovering the existence of the currently dominant school chemistry curriculum and its properties of rigidity and isolation.
- By explaining the dominance, rigidity and isolation of Dominant School Chemistry in terms of the concept of Normal Science Education.
- By using Dominant School Chemistry, taken as a form of Normal Chemistry Education, as a baseline for comparison with the curriculum levels of an innovative developmental project.

- By detailing the curriculum phenomenon of slippage, with regard to this baseline, in the developmental and teaching processes of an innovative developmental science project.

Finally, I have tried to argue for the *fruitfulness* of the curriculum framework developed in this thesis as an instrument for development and developmental research in the following ways:

- By formulating three conditions of escape which would, if adopted by a large scale innovative developmental chemistry project, lead to more successful attempts to escape from Dominant School Chemistry, taken as a form of Normal Chemistry Education.
- By applying the three conditions of escape to teachers in order to develop and research a teacher training course which aims to enhance the competence of teachers as developers.
- By pointing to the curriculum problems of consistency of a context-led development of a chemical unit and the problems of coherency of a context-led development of a chemical course.
- By pointing to the relevance of the field of the history and philosophy of chemistry for the analysis of the logic's of authentic chemical practices, other than the logic of puzzle-solving, the traditional practice of Normal Science and Normal Science Education.

Samenvatting

In dit proefschrift worden twee belangrijke problemen van de huidige schoolscheikunde behandeld. Het eerste probleem betreft de structuur van het schoolvak scheikunde: Wat is de samenhang tussen de scheikundige begrippen in schoolboeken? Het tweede probleem betreft het ontsnappen aan de huidige schoolvakstructuur: Waarom leidt hervorming van de schoolscheikunde slechts tot marginale veranderingen? Pogingen tot ontsnapping hebben meer succes als we weten *waaraan* we willen ontsnappen. Is de schoolvakstructuur een steunpilaar of een sta-in-de-weg bij de hervorming van de schoolscheikunde? Het probleem van de structuur van de huidige schoolscheikunde en het probleem van de ontsnapping daaraan zijn op elkaar betrokken.

De eerste voorwaarde voor het realiseren van een geslaagde hervorming van de huidige schoolscheikunde is het verkrijgen van *inzicht* in de begrippenstructuur van het huidige schoolvak *waaraan* we willen ontsnappen. De tweede voorwaarde betreft de ontwikkeling van een coherente visie op voortgezet onderwijs in de chemie: het ontwikkelen van een visie *waarnaar* we willen ontsnappen. De derde voorwaarde betreft het ontwikkelen van een systematische methode om te ontsnappen aan de structuur van het huidige schoolvak scheikunde bij het ontwerpen van nieuw chemieonderwijs.

In dit proefschrift worden onderstaande onderzoeksvragen beantwoord: de vragen 1-3 betreffen het probleem van de structuur en de vragen 4-7 betreffen het probleem van ontsnapping.

1. Wat is de structuur van het huidige schoolvak scheikunde?
2. Waarom heeft het schoolvak scheikunde deze structuur?
3. Is de huidige structuur van het schoolvak scheikunde wenselijk?
4. Wat zijn de voorwaarden voor ontsnapping?
5. In welke mate slaagt het Salters’ Chemistry project erin te ontsnappen?
6. Waarom is het zo moeilijk om te ontsnappen?
7. Hoe kunnen pogingen tot ontsnapping met meer succes worden uitgevoerd?

In Chapter 1, Problems of current school chemistry, wordt een antwoord gegeven op de eerste onderzoeksvraag door een hypothese te formuleren over de structuur van het curriculum van de schoolscheikunde. Op grond van een analyse van schoolboeken en leerplannen, vanuit het gezichtspunt van *het leren verklaren en voorspellen* van chemische verschijnselen, wordt een *reactiechemische* opvatting van de structuur van het huidige schoolvak scheikunde verkregen met de volgende structurele kenmerken:

- afgrenzing van het dagelijks leven, van het schoolvak natuurkunde en van de chemische technologie
- relaties tussen macroscopisch chemische begrippen en de begrippen chemische reactie, chemische stof en chemisch element als kern van deze macroscopisch substructuur

- drie reactie voorwaarden
  - chemisch elementbehoud
  - afname van Gibbs energie
  - kinetische instabiliteit
- theorieën over chemische structuur en binding.

De reactiechemische opvatting van Coherente Schoolscheikunde is samengevat in Tien Stellingen. Deze zijn voorgelegd voor commentaar en kritiek aan een Internationaal Forum (IF) en een Nederlands (Dutch) Forum (DF) van onderzoekers, ontwikkelaars, docenten, en andere betrokkenen en geïnteresseerden uit het voortgezet onderwijs in de chemie.

Het *formele* theoretische kader, dat in dit proefschrift wordt ontwikkeld, bestaat uit het idee dat de structuur van een curriculum bestaat uit drie met elkaar samenhangende substructuren: de substantiële, filosofische en pedagogische structuur (Schwab). Deze substructuren hebben betrekking op een aantal met elkaar gerelateerde curriculumniveaus (Goodlad). Bij het onderzoek naar het Salters' Chemistry curriculum waren de volgende curriculumniveaus van toepassing:

- *visionair of beoogd curriculum:* de formulering door de ontwikkelaars van een aantal ontwerpcriteria.
- *ontworpen curriculum:* de operationalisering van de ontwerpcriteria door de ontwikkelaars in prototypisch lesmateriaal.
- *geschreven curriculum:* de nadere uitwerking en herziening van het prototypisch lesmateriaal na toetsing hiervan in de onderwijsleersituatie in de klas.
- *formeel curriculum*: de officiële vastlegging van het geschreven curriculum in een leerplan in overleg met een examencommissie.
- *geïnterpreteerd curriculum*: het door de docenten geïnterpreteerde curriculum.
- *onderwezen curriculum*: het door de docenten in de klas uitgevoerde curriculum.
- *ervaren curriculum*: het door de leerlingen ervaren curriculum.

Het door Roberts uitgewerkte begrip *curriculum emphasis* (curriculum oriëntatie) en het op Kuhn's werk gebaseerde begrip *Normal Science Education* (Normaal Wetenschappelijk Onderwijs), zoals ontwikkeld in dit proefschrift, zijn begrippen die specifiek zijn voor het natuurwetenschappelijke onderwijsdomein. Deze twee begrippen vormen de kern van het *materiële* curriculum kader. Het gecombineerde formele en materiële curriculumtheoretische kader bleek vruchtbaar voor het beschrijven, analyseren en verklaren van de curriculumverschijnselen die door het onderzoek aan het licht gebracht werden. Kuhn's opvatting van natuurwetenschappelijke training als een vorm van puzzel-oplossen (puzzle-solving) binnen de grenzen van het 'normal science' paradigma heeft geresulteerd in een nadere karakterisering en verklaring van de huidige *dominante* schoolvakstructuur. Dit heeft geleid tot de formulering van het begrip *Normal Science Education*, en meer specifiek voor het chemieonderwijs tot het begrip *Normal Chemistry Education*. Om de verschillende curriculumoriëntaties van het schoolvak scheikunde inhoudelijk te karakteriseren is het begrip curriculum emphasis gebruikt. Roberts onderscheidt voor secundaire natuurwetenschappelijke curricula zeven curriculum emphases:

- Basiskennis (Solid Foundation): wetenschap als een systeem van cumulatieve kennis.
- Structuur van de wetenschap (Structure of Science): het functioneren van wetenschap als discipline.
- Wetenschap, techniek en beslissing (Science/Technology/Decision): de rol van wetenschappelijke kennis bij sociaal relevante beslissingen.
- Ontwikkeling van wetenschappelijke vaardigheden (Scientific Skill Development): de benadering van wetenschap als een onderzoeksproces.
- Juiste verklaringen (Correct Explanations): wetenschap als betrouwbare en valide kennis
- Persoonsgebonden verklaring (Personal Explanation): Persoonsgebonden verklaringen van natuurwetenschappelijke verschijnselen in termen van persoonlijke en culturele, inclusief wetenschappelijke invloeden.
- Alledaagse toepassingen (Everyday Applications): het gebruik van wetenschap om zowel technologische als alledaagse gebeurtenissen te begrijpen.

In Chapter 2, **Normal Science Education and its dangers: the case of school chemistry,** wordt de onderzoeksopzet beschreven: de werkwijze die is gebruikt bij het testen van de hypothese over Coherente Schoolscheikunde en het curriculumkader dat bij de analyse van de uitkomsten wordt gebruikt. De reacties van het internationale en Nederlands forum worden geanalyseerd in termen van de drie met elkaar samenhangende substructuren: de substantiële, filosofische en pedagogische substructuur van het schoolchemische curriculum. Het kritische commentaar van de forumleden (onderzoekers, ontwikkelaars en docenten chemie) heeft geleid tot een ingrijpende revisie van de aan hen voorgelegde claims en tenslotte tot het begrip *Dominante Schoolscheikunde*. De praktijk van de huidige schoolscheikunde is volgens de forumleden niet gericht op het leren verklaren en voorspellen van chemische verschijnselen vanuit reactiechemisch oogpunt. De praktijk is dat in het huidige dominante curriculum van het schoolvak scheikunde:

– feiten en voorschriften worden onderwezen aan leerlingen die gezien worden als toekomstige chemici.
– uitgegaan wordt van een theoretisch, corpusculair perspectief op chemische stoffen en stofeigenschappen.
– de vakinhoud voornamelijk bestaat uit corpusculaire systematiseringen en verklaringen van chemische informatie.
– onderscheid gemaakt wordt tussen chemische verschijnselen en corpusculaire deeltjes, maar dat de introductie van de daarbij horende corpusculaire theorie in het schoolboek en in de klas noch consistent noch zorgvuldig is en daarom niet effectief blijkt te zijn in het leerproces.

De eerste onderzoeksvraag luidde: Wat is de structuur van het huidige schoolvak scheikunde? De uitkomst van dit deel van het onderzoek is, dat de huidige schoolscheikunde bestaat uit een dominante substantiële substructuur, gebaseerd op corpusculaire theorie, die een rigide combinatie vormt met een specifieke filosofische substructuur, bestaande uit op onderwijs toegesneden positivisme (educational positivism) en een specifieke pedagogische substructuur, gericht op inwijding en voorbereiding van toekomstige chemici. Bovendien is de structuur van het dominante curriculum van de schoolscheikunde afgegrensd, en daarmee geïsoleerd, van een zevental gebieden: gezond verstand (common sense), het dagelijks leven en maatschappelijke situaties, het schoolvak natuurkunde, de geschiedenis en filosofie van de wetenschap, de chemische technologie en het chemisch onderzoek. De rigide structuur biedt weerstand tegen hervorming en leidt tot isolatie.

De tweede onderzoeksvraag luidde: Waarom heeft het schoolvak scheikunde deze structuur? Deze vraag wordt beantwoord met behulp van een functionele verklaring van de twee belangrijkste eigenschappen van de structuur van de Dominante Schoolscheikunde, rigiditeit en isolatie, in termen van Kuhn's wetenschapstheorie en opvatting over natuurwetenschappelijke onderwijs. Een radicale hervorming, een ontsnapping uit de Dominante Schoolscheikunde, is gegeven dit resultaat, alleen mogelijk door middel van een goed gecoördineerde vervanging van de huidige rigide combinatie van substantiële, filosofische en pedagogische substructuur.

Hiermee zijn we beland bij de derde onderzoeksvraag: Is de huidige structuur van het schoolvak scheikunde wenselijk, vanuit het oogpunt om chemieonderwijs meer te richten op het begrijpen van chemische verschijnselen en ook veel meer te richten op de behoeften van toekomstige burgers? Dominante Schoolscheikunde slaagt er kennelijk niet in, zo bleek uit het forum onderzoek, zijn eigen doelen te realiseren met name waar het gaat om het leren begrijpen, verklaren en voorspellen, van chemische verschijnselen. In plaats daarvan wordt leerlingen veelal een verzameling feiten en voorschriften aangeleerd. Dit leidt tot de conclusie dat op *Normal Chemistry Education* gebaseerd secundair chemieonderwijs niet te legitimeren is voor *alle* leerlingen. Alleen bij de leerlingen die later chemie gaan studeren kan inzicht in de chemische verschijnselen ontstaan. Voor de meerderheid van de leerlingen bestaat deze mogelijkheid echter niet. Juist omdat *Normal Chemistry Education* bestaat uit een dogmatische en domeinspecifieke training van toekomstige chemici, gericht op inwijding en voorbereiding, moet het vervangen moeten worden door chemieonderwijs dat zich kritisch richt op de processen van ontdekking, ontwikkeling en toetsing van chemische kennis in samenhang met onderwijs dat zich richt op de relaties tussen chemie, technologie en maatschappij. Daarbij gaat het dus om inwijding en voorbereiding van leerlingen op het functioneren als burger in maatschappelijke situaties en praktijken.

In Chapter 3, Conditions to escape from and to escape to, worden de voorwaarden besproken voor het ontsnappen aan de structuur van het dominante curriculum van het schoolvak scheikunde. Een kort overzicht van enkele pogingen om het dominante natuurwetenschappelijke curriculum te hervormen geeft een idee van de vele moeilijkheden die overwonnen moeten worden bij de realisering van een gewenste, radicale hervorming. De moeilijkheden kunnen zich manifesteren op verschillende curriculumniveaus. Door verschillende vakdidactische onderzoekers is gewezen op de volgende factoren voor:

- het *visionaire curriculum*: onduidelijke of misplaatste doelstellingen; docenten niet voldoende betrokken bij het onderwijsbeleid; onjuiste opvattingen over de aard van de natuurwetenschappelijke methode van onderzoek.

- het *ontworpen curriculum*: gebrek aan consistentie tussen de visie van het innovatieproject en het uitgewerkte onderwijsmateriaal, waarbij tekst en opgaven geen juiste afspiegeling vormen van de gekozen visie; docenten niet voldoende betrokken bij het proces van ontwikkelen.
- het *formele curriculum*: sterke gerichtheid van het schoolvak scheikunde op het vervolgonderwijs, universitair- of beroepsgericht.
- het *geïnterpreteerde curriculum*: gebrek aan consistentie tussen visie project en de nascholing aan docenten; gebrek aan praktische ervaring met het onderwijzen van het nieuwe onderwijs.
- het *onderwezen curriculum*: weerstanden bij docenten; gebrek aan consistentie tussen de visie op toekomstig onderwijs en de opvattingen van docenten.

De analyse in Hoofdstuk 2 heeft als uitkomst dat de eerste voorwaarde, waarmee bij de planning van een radicale hervorming van het chemieonderwijs rekening moet worden gehouden, bestaat uit een grondige analyse van de structuur van het dominante curriculum van het schoolvak scheikunde. De analyse van het ontwikkelingsproces van het Salters' Chemistry project, in Hoofdstuk 4 & 5, laat zien op welke momenten niet genoeg met de eerste voorwaarde voor ontsnapping rekening is gehouden. In Hoofdstuk 6 wordt op deze eerste voorwaarde voor ontsnapping teruggekomen.

In Hoofdstuk 3 wordt het curriculumkader van Roberts besproken, met name het begrip curriculum emphasis dat als conceptuele lens wordt gebruikt, teneinde een eerste uitwerking te geven van de tweede voorwaarde voor ontsnapping, het ontwikkelen van een visie, en van de derde voorwaarde voor ontsnapping, het ontwikkelen van een methode voor ontsnapping. In antwoord op de vraag van leerlingen, 'Waarom moet ik dat leren?', omschrijft Roberts het begrip curriculum emphasis als een coherente boodschap over het doel van het secundair natuurwetenschappelijk onderwijs dat verder gaat dat alleen maar het leren van feiten, wetten en theorieën. Het begrip curriculum emphasis kan voor zowel analyse als ontwikkeling gebruikt worden:

- Dat is als theoretisch instrument voor de beschrijving, analyse en verklaring van de visie en structuur van natuurwetenschappelijke curricula, curriculumdocumenten en schoolboeken.
- Dat is als praktisch instrument om te komen tot een gestructureerde werkwijze bij het overleg, de keuze, de ontwikkeling, evaluatie en revisie van nieuwe natuurwetenschappelijke curricula.

De discussie over de theoretische en praktische functie van het begrip curriculum emphasis leidt tot belangrijke inzichten met betrekking tot de tweede en derde voorwaarde voor ontsnapping: het ontwikkelen van een visie en van een methode voor ontsnapping. In hoofdstuk 6 wordt op deze twee voorwaarden voor ontsnapping teruggekomen.

In Hoofdstuk 4, Salters' Chemistry: An analysis of its process of development, wordt onderzoeksvraag 5 behandeld: In welke mate slaagt het Salters' Chemistry project erin te ontsnappen? In dit geval gaat het om het ontsnappen aan de Dominante Schoolscheikunde in de vorm waarin die in de jaren tachtig in Engeland voorkwam. In Hoofdstuk 4 is de aandacht gericht op de ontwikkeling van modulen ('units') van de

Salters' Chemistry cursus, in Hoofdstuk 5 op de ontwikkeling van de lessen van de module Metals van de Salters' Science cursus.

Het proces van het Salters' Chemistry ontwikkelingsproject wordt geanalyseerd in termen van het curriculum kader: de substantiële, filosofische en pedagogische structuur die betrekking hebben op een aantal met elkaar verbonden curriculumniveaus, het begrip curriculum emphasis en het begrip Normal Chemistry Education. De Salters' Chemistry cursus combineert de curriculum emphasis *Everyday Applications*, het gebruik van wetenschap om alledaagse gebeurtenissen te begrijpen, met de curriculum emphasis *Science, Technology, Decisions*, de rol van gemeenschappelijke kennis bij sociaal relevante beslissingen. De cursus wordt nader gekarakteriseerd als een "Science through STS" curriculum (Aikenhead) door middel van de verhouding tussen de science, technology & society (STS) inhoud en de zuiver wetenschappelijke (Pure Science) inhoud.

De ontwikkelaars van de Salters' Chemistry cursus gebruiken een benadering via *ontwerp criteria*, dat wil zeggen dat algemene criteria richting geven aan het ontwikkelen van onderwijsmodulen zonder dat deze ontwerp criteria vooraf in detail de uitkomst bepalen. Aanvankelijk werden drie ontwerpcriteria opgesteld: *Geen vooroordelen, Relevantie en Contextgestuurde ontwikkeling van begrippen*. Tijdens het proces van onderwijsontwikkeling zijn nog twee andere ontwerpcriteria toegevoegd: *Variatie van leeractiviteiten* en *Flexibiliteit* bij de uitvoering door docenten.

In het onderzoek werd een *consistentieanalyse* verricht op relevante curriculumdocumenten en transcripties van interviews met ontwikkelaars om na te gaan of en in welke mate de ontwerpcriteria consistent werden gerealiseerd bij de ontwikkeling van de Salters' Chemistry cursus. De analyse betreft hier het visionaire, ontworpen, geschreven, formele en ervaren curriculum. De analyse wees uit dat ontwerpcriterium1, *Geen vooroordelen*, geleidelijk aan vervangen werd door een sturend principe van interne aard, namelijk door de opvatting van de ontwikkelaars over de structuur van de chemie (vakstructuur), terwijl daarnaast de externe eisen van het Engelse (GCSE) examen een steeds grotere rol gingen spelen. De toepassing van ontwerpcriterium 2, *Relevantie,* leidde bij de transformatie van het visionaire naar het formele curriculum weliswaar tot een keuze voor relevante contexten, maar deze keuze werd meer en meer beperkt, intern door de opvatting van de ontwikkelaars over de structuur van de chemie, en extern door de (GCSE) exameneisen voor inhoud en vaardigheden. Dit leidt tot een spanning in de Salters' Chemistry cursus tussen de originele contextgestuurde benadering en de traditionele nadruk op chemische inhoud en vaardigheden, Daaraan werd de nieuwe (GCSE) nadruk op wetenschappelijke processen toegevoegd. De toepassing van ontwerpcriterium 3, *Contextgestuurde ontwikkeling van begrippen,* leidde in overeenstemming met het bovenstaande tot een grotere nadruk op chemische begrippen en logische begripsvolgorde dan voorzien.

Door het visionaire, ontworpen, geschreven en formele curriculum van de Salters' Chemistry cursus te categoriseren in termen van de substantiële, filosofische en pedagogische structuur wordt het mogelijk om de veranderingen in de componenten van deze substructuren aan te geven. De belangrijkste veranderingen in het transformatieproces van het visionaire naar het formele curriculum worden als volgt beschreven.

De substantiële structuur van de Salters' Chemistry GCSE cursus bevat in het begin een wat kleiner aandeel aan chemische begrippen dan de traditionele Engelse O-level cursus, en ongeveer hetzelfde aandeel aan chemische werkwijzen. De chemische begrippen en chemische relaties zijn geplaatst in een onderwijsvolgorde die *ten dele* is gebaseerd op, of consistent is met, de structuur van de chemie zoals opgevat door de ontwikkelaars. De chemische begrippen en chemische relaties vormen daarom geen strikte 'topdown' hiërarchie, maar hebben een 'bottom-up' structuur die voor een groot deel bepaald wordt door de gekozen contexten en activiteiten. Deze structuur start bij het waarnemings- en handelingsniveau en gaat via eenvoudige generalisaties over naar meer abstracte relaties en theorieën. De ontwikkelaars zijn er dus niet in geslaagd om volledig te ontsnappen aan de substantiële structuur van de Dominante Schoolscheikunde. Het gevolg van de beslissing van de examencommisie was tenslotte dat chemische begrippen, waarvan de ontwikelaars eerder hadden afgezien, weer in het formele curriclum werden opgenomen.

De filosofische structuur van de Salters' Chemistry GCSE cursus was minder gericht op theoretische chemie en meer op toegepaste chemie waarbij relevantie en gebruik van kennis benadrukt werden. De ontwikkelaars zijn er weliswaar niet in geslaagd om volledig te ontsnappen aan de traditional filosofische structuur, maar ze gebruikten wel meer toepassingen van chemische kennis op verschijnselen en materialen uit het dagelijks leven, en minder 'academische' toepassingen zoals te doen gebruikelijk in traditioneel O-level onderwijs.

De pedagogische structuur van de Salters' Chemistry GCSE cursus was aanvankelijk gericht op de behoeften van de meerderheid van zwakke en gemiddelde leerlingen, terwijl in een later stadium ook meer rekening moest worden gehouden met de behoeften van de beste leerlingen. Ze deden dat door met name het verklaren in termen van abstract chemische begrippen meer in het curriculum op te nemen. Ook het oorspronkelijke doel, het nieuwe onderwijs te richten op de toekomstige burger, moest steeds meer concurreren met het traditionele doel om A-level (bovenbouw) kandidaten voor te bereiden door zich te richten op de exameneisen.

De contextgestuurde onderwijsbenadering evolueerde in een context- en activiteiten gestuurde onderwijsbenadering, zoals de ontwikkelaars dat noemen, waarbij een gevarieerde verzameling onderwijsleeractiviteiten wordt gebruikt, inclusief de gebruikelijke laboratoriumexperimenten. De ontwikkelaars zijn er wat de onderwijsbenadering betreft goed in geslaagd om aan de Dominante Schoolscheikunde te ontsnappen door een contextgestuurde onderwijsvolgorde te realiseren die sterk verschilt van de traditionele, op de vakstructuur gebaseerde, onderwijsvolgorde.

In Hoofdstuk 5, Metals: A chemical unit of the Salters' Science curriculum, wordt onderzoeksvraag 5 behandeld: In welke mate slaagt het Salters' Chemistry project erin te ontsnappen aan de Dominante Schoolscheikunde? De analyse betreft nu de *lessen* van de module Metals zoals geïnterpreteerd en onderwezen door een docent in Engeland en zoals ervaren door leerlingen in de klas.

Er wordt een gedetailleerde consistentie analyse verricht op een module van het geschreven curriculum zoals geoperationaliseerd in acht lessen van de module Metals van de Salters' Science cursus. In navolging van Aikenhead wordt de Salters' Science cursus getypeerd als "Science through STS" door middel van de verhouding tussen STS inhoud en Pure Science inhoud. Deze verhouding staat voor de mate van ontsnapping van de module Metals aan Dominante Schoolscheikunde. Op deze manier kunnen de opeenvolgende transformaties van het ontworpen, geïnterpreteerde, onderwezen en ervaren curriculum worden vergeleken met het formele curriculum van Metals, en met het huidige dominante curriculum van de schoolscheikunde. De consistentieanalyse maakt het mogelijk om na te gaan in welke mate de ontwikkelaars erin geslaagd zijn op een *consistent*e manier aan de door hen gekozen ontwerpcriteria te voldoen. De analyse is gericht op de twee centrale ontwerpcriteria 2 en 3 van het Salters' project: *Relevantie* en *Contextgestuurde ontwikkeling van begrippen*. Hierbij worden de volgende twee vragen beantwoord:

- Vormen chemisch relevante alledaagse situaties of contexten het fundamentele uitgangspunt, en daarmee de rechtvaardiging, voor het onderwijs in de lessen van de module Metals.
- Zijn alle chemische begrippen en verklaringen, die worden geïntroduceerd in de lessen van de module Metals, nodig voor het onderwijs dat uitgaat van deze relevante contexten?

De consistentieanalyse van de lessen van de module Metals laat zien dat er meer Pure Chemistry (PC) inhoud wordt ontwikkeld, en minder Chemistry-Technology-Society (CTS), dan nodig is. De CTS/PC verhouding, die staat voor de mate van ontsnapping, blijkt substantieel af te nemen in het proces van transformatie dat loopt van het formele naar het geschreven curriculum. Hiermee voldoen de ontwikkelaars niet aan de centrale ontwerpcriteria 2 en 3: Relevantie en Contextgestuurde ontwikkeling van begrippen. Uit de analyse bleek ook dat niet werd voldaan aan ontwerpcriterium 1, Geen vooroordelen. Bij het ontwikkelen van de lessen van de module Metals werden door de ontwikkelaars enige PC begrippen geïntroduceerd en ontwikkeld die traditioneel deel uitmaken van het dominante curriculum van de schoolscheikunde, maar die niet nodig zijn om inzicht in de gekozen contexten te verkrijgen.

In het transformatieproces dat loopt van het geschreven naar het geïnterpreteerde curriculum, bleek dat de docent enige PC inhoud heeft toegevoegd die niet nodig was, en dat hij enige CTS inhoud heeft verwijderd die wel nodig was voor leerlingen in de gekozen contexten. Hierdoor neemt de CTS/PC verhouding verder af. Er werd niet op een consistente manier voldaan aan ontwerpcriterium 2 en 3. Vervolgens werd tijdens het onderwijsproces door de docent weer wat PC content toegevoegd die niet nodig was, terwijl hij enige CTS inhoud niet behandelde in de klas, die wel nodig was in de gekozen contexten. Dit is inconsistent met ontwerpcriteria 2 en 3. De CTS/PC verhouding neemt daardoor verder af in het transformatieproces dat loopt van het geïnterpreteerde nar het onderwezen curriculum. Het *afglijden (*Goodlad: slippage) van enerzijds ontwikkelaars in het transformatieproces van het formele naar het geschreven curriculum en anderzijds van de docent in het transformatieproces van het geschreven naar het geïnterpreteerde en vervolgens het onderwezen curriculum wordt hier duidelijk geïllustreerd aan de hand van een concreet voorbeeld. In dit afglijdingproces neemt de spanning tussen de ontwikkelde PC inhoud en de benodigde CTS inhoud geleidelijk toe in het geval van Metals. Deze spanning hangt samen met een spanning in de filosofische structuur tussen het cognitieve proces van het verklaren van chemische verschijnselen en het proces van toepassen van chemische kennis. Deze spanning hangt samen met een spanning in de pedagogische structuur: tussen het traditionele doel (in Engeland) om kandidaten voor te bereiden op het A-level examen en het oorspronkelijke doel van het Salters' project om het chemisch onderwijs te richten op de toekomstige burger (chemical literacy).

Deze resultaten van de consistentieanalyse van Salters' Chemistry en de module Metals bevestigen dat de eerste voorwaarde voor een geslaagde ontsnapping aan de Dominante Schoolscheikunde bestaat uit een goed gecoördineerde vervanging van de huidige rigide combinatie van substantiële, filosofische en pedagogische substructuur. Het blijkt dat dit een moeilijke opdracht is. Kuhn’s opvatting over de functie van natuurwetenschappelijk onderwijs verklaart waarom het zo moeilijk is om te ontsnappen (Normal Chemistry Education). Het is met name de bovengenoemde spanning in de pedagogische structuur, die de spanning in de filosofische structuur bepaalt en de CTS/PC spanning in de inhoud van the substantiële structuur. Kort samengevat, de functie bepaalt de structuur en inhoud van het curriculum.

In Hoofdstuk 6, Beyond current school chemistry: Perspectives on chemistry at school, wordt antwoord gegeven op de laatste onderzoeksvraag: Hoe kunnen pogingen tot ontsnapping met meer succes worden uitgevoerd? Uitgaande van de onderzoeksresultaten en de daaruit volgende implicaties worden er een aantal aanbevelingen gedaan teneinde het huidige dominante curriculum van de schoolscheikunde te hervormen. Dit leidt tot een strategie om aan de Dominante Schoolscheikunde te ontsnappen in termen van een curriculumkader met de onderdelen analyse, ontwikkeling en ontwikkelingsonderzoek. Dit curriculumkader is een nadere uitwerking van de drie voorwaarden voor ontsnapping die geïntroduceerd werden in Hoofdstuk 3. Op grond van het hier gerapporteerde onderzoek worden de volgende voorwaarden beschreven.

Eerste voorwaarde: *Teneinde te ontsnappen, moet men weten waaraan te ontsnappen.*

- Voer een domeinspecifieke analyse uit van de aard en structuur van het huidige dominante curriculum van de schoolscheikunde in termen van een combinatie van een substantiële, filosofische en pedagogische substructuur, zoals ontwikkeld in dit proefschrift.

Tweede voorwaarde: *Teneinde te ontsnappen, moet men weten waarnaar te ontsnappen.*

- Beoog een gecoördineerde vervanging van de huidige rigide combinatie van de substantiële, filosofische en pedagogische substructuur van het curriculum van de schoolscheikunde.
- Ontwikkel en legitimeer een nieuwe curriculum emphasis voor het voortgezet onderwijs in de chemie in termen van een nieuwe combinatie van een substantiële, filosofische en pedagogische structuur van het beoogde curriculum.
- Gebruik de begrippen curriculum emphasis en Normal Chemistry Education (NCE) als instrumenten om het visionaire curriculum te articuleren en werk de gekozen visie uit met behulp van een aantal ontwerpcriteria, die geoperationaliseerd worden in prototypes van het onderwijsmateriaal.

Derde voorwaarde: *Teneinde te ontsnappen, moet men weten hoe te ontsnappen.*

- Herken, anticipeer en vermijd de NCE reflex, en los op tijd de problemen op die verband houden met de structuur van het huidige dominante curriculum van de schoolscheikunde; doe dit op alle betreffende curriculumniveaus, te beginnen met het visionaire en ontworpen curriculum.
- Verzamel op alle curriculumniveaus evaluatiegegevens, teneinde de realisatie van de gekozen visie te waarborgen in het transformatieproces dat loopt van het visionaire, ontworpen, geschreven, en formele naar het geïnterpreteerde, onderwezen en ervaren curriculum,

- Controleer gedurende het transformatieproces de consistentie van de gekozen visie zoals gearticuleerd in het visionaire curriculum met behulp van de ontwerpcriteria.

De aanbevelingen met betrekking tot curriculumanalyse, curriculumontwikkeling en ontwikkelingsonderzoek kunnen kortweg omschreven worden als: articuleer een nieuwe visie, voorkom het vasthouden aan de oude visie, en test en controleer de gekoppelde processen van het ontsnappen aan de oude visie en naar de nieuwe visie door middel van ontwikkelingsonderzoek.

Ook worden er in dit proefschrift enkele suggesties gedaan voor verder chemiedidactisch onderzoek. De focus van het hier verrichte onderzoek was niet gericht op curriculum-diversiteit, maar veeleer op curriculum continuïteit. Het zou evenwel de moeite waard zijn om, aan de hand van het in dit proefschrift ontwikkeld curriculumkader, gedetailleerd historisch onderzoek te verrichten aan de Nederlandse schoolscheikunde en zo de curriculumdiversiteit in beeld te brengen.

De chemiedidactische analyse van specifieke substantiële en filosofische substructuren, die deel uitmaken van alternatieve of nieuwe curriculum emphases, zou veel profijt kunnen hebben van de expertise die verworven is op het gebied van de geschiedenis en filosofie van de chemie. Bijvoorbeeld de nadere verheldering van de reactiechemische curriculum emphasis (Hoofdstuk 2) of de explicitering van de logica van authentieke chemische praktijken zoals kwaliteitscontrole, chemische onderzoek, chemische modelvorming en chemisch-technologisch ontwerpen.

De volgende aanbevelingen voor nader onderzoek zijn erop gericht dat aan de beschreven voorwaarden voor ontsnapping beter kan worden voldaan:

- Verricht ontwikkelingsonderzoek aan een te ontwikkelen (na)scholingscursus over traditionele en alternatieve curricula voor voortgezet onderwijs in de chemie.
- Verricht ontwikkelingsonderzoek aan een (na)scholingscursus, die als doel heeft de competenties van docenten te ontwikkelen met betrekking tot het ontwerpen, interpreteren en onderwijzen van nieuwe curriculummodules.
- Verricht ontwikkelingsonderzoek aan de ontwikkeling van de competenties van docenten als ontwikkelaars in het kader van een grootschalig onderwijsontwikkelingsproject.

Voor het probleem van de consistentie van een contextgestuurde ontwikkeling van een chemische module, en voor het probleem van de coherentie van een contextgestuurde ontwikkeling van een chemische curriculum worden enige praktische en theoretische oplossingswegen besproken.

Acknowledgements

But even if you do obtain a solution, you may then discover, to your delight, the existence of a whole family of enchanting though perhaps difficult problem children for whose welfare you may work, with a purpose, to the end of your days.

Karl R. Popper (1983, p. 8)

First of all, I want to thank Albert Pilot, my promoter, for the constructive way he guided me for many years through the difficult process of finishing my thesis. In the same period I had to apply myself to mostly work-related activities. There were times, I realize, when I have tried Albert's patience to its limits, times which we managed to overcome, though, thanks largely to Albert's common sense and bonhomie. Furthermore, Albert had the ungrateful job of catching me in midstream: he was so kind to take over from Adri Verdonk, my former promoter. The latter took early retirement in 1995 in order to be able to take care of his lovely wife, Emy Verdonk. I want to thank you, Adri, for the inspiring way you discussed the topic of my research with me and Wobbe, called by us at the time briefly '*vakstructuur*' (disciplinary structure), and for providing a stimulating atmosphere for research and critical discussion in our group.

Sadly, Wobbe de Vos, my co-promoter passed away in July 2002, after a courageous struggle with the cancer in his body, his mind witty and alert to the very end. It was Wobbe, who helped me on a day-to-day basis with clarifying my ideas and framing my hypothesis on *vakstructuu*r, with the writing of papers, and the analysis of educational materials relating to school chemistry, and the responses of Forum members. In all of this, Wobbe had developed an uncanny sharp intuition about, what he called, the *vakstructurele* reflex. I am very grateful, that I could express my appreciation to him at that time in person, as I am now doing in print.

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Taking longer than usual to finish one's thesis has some disadvantages. But one advantage is to have a chance of meeting a new group of interesting people, in this case my esteemed colleagues at Joh. Enschedé Amsterdam B.V., a printing firm. They were more than willing to help my thesis through the desktop publishing, printing and pre-binding process. Special thanks go out to Chris Broersma, Director, and Michel Vastenhout, Manager of Operations, who reacted very enthusiastically and generously to my request to print my thesis at their firm. Thanks also to Jeroen Hoppenbrouwer who

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Curriculum vitae

Berry van Berkel werd geboren op 20 juni 1948 in Den Haag. Het HBS-B diploma behaalde hij in 1966 aan de Rijks HBS te Utrecht. Na in april 1971 het kandidaatsexamen scheikunde (S2) met succes te hebben afgelegd aan de (Rijks)Universiteit van Utrecht, werd begonnen aan de bovenbouwstudie, filosofie van de exacte natuurwetenschappen aan de Centrale Interfaculteit te Utrecht.

De studie filosofie werd met enige onderbrekingen voortgezet aan Universiteit van Amsterdam. In deze periode ben ik op diverse gebieden werkzaam geweest, onder meer als medewerker van een chemisch technisch bedrijf, als student-assistent en als educatief medewerker van het Utrechts Universiteitsmuseum. In 1986 werd het doctoraaldiploma filosofie behaald aan Universiteit van Amsterdam, met als specialisatie geschiedenis- en filosofie van de natuurwetenschappen.

Vervolgens werd in 1989 aan de Universiteit van Utrecht de Middelbare Onderwijsakte-B voor Scheikunde behaald, en daarmee ook een 1^e graads lesbevoegdheid scheikunde verkregen. In het kader van het daarbij horende bijvak Chemiedidactiek werd onder leiding van Jan van Driel een kleinschalig chemiedidactische onderzoek uitgevoerd naar de opvattingen van leerlingen en een docent over chemisch evenwicht. Het aanstekelijke enthousiasme van Jan voor conceptuele problemen met chemisch evenwicht wekte bij mij grote interesse voor chemiedidactisch onderzoek.

Na enige tijd scheikundeles te hebben gegeven aan RSG Thorbecke (HAVO/VWO) en het Dr. Gijsen Instituut (MBO) kreeg ik in 1990 de kans om als assistent-in-opleiding bij de vakgroep Chemiedidactiek te gaan werken, onderdeel van het Centrum voor Didactiek van Wiskunde en Natuurwetenschappen, Universiteit Utrecht. Wobbe de Vos werd mijn co-promoter en Adri Verdonk mijn promotor. Het onderzoek betrof *Structuren in het Schoolvak Scheikunde* waarvoor het baanbrekende artikel van De Vos en Verdonk, *Een Vakstructuur van het Schoolvak Scheikunde*, in 1990 gepubliceerd, de grondslag had gelegd.

Over het door mij verrichtte onderzoek is gerapporteerd in een aantal publicaties en tenslotte, onder leiding van mijn nieuwe promotor, Albert Pilot, in een vijftal Engelstalige rapporten, voordat het als proefschrift zijn uiteindelijk beslag kreeg.

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