M.C.P.J. Knippels

Coping with the abstract and complex nature of genetics in biology education

The yo-yo learning and teaching strategy

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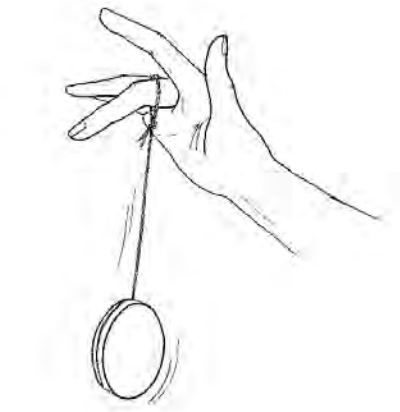

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Coping with the abstract and complex nature of genetics in biology education

The yo-yo learning and teaching strategy

Hantering van de abstracte en complexe aard van genetica in het biologieonderwijs

De jojo-onderwijsleerstrategie

(met een samenvatting in het Nederlands)

Proefschrift

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aan de Universiteit van Utrecht
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Marie-Christine Paulina Josephina Knippels

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Voor mijn ouders

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Chapter 1

Introduction

1.1 Scope of the research project

Nowadays, genetics is not only considered an important topic in biology education, but it has also become very relevant in everyday life. Genetic science is rapidly evolving, and the media inform us almost on a daily basis of new ideas and results in biological research with respect to genetics, for instance of the Human Genome project. In our knowledge-based society, it is important that the majority of people have at least some knowledge and understanding of genetics. First and foremost it is up to scientists themselves to inform society in a clear and understandable way about the state of affairs in genetics research. Besides, schools play an important role in educating society (Waarlo, 1994).
In science education, one of the objectives is that students develop a discerning mind and corresponding skills to be able to assess the reliability and validity of scientific information. Moreover, it is relevant that students learn to apply these skills in all kinds of real life situations (e.g. reading a newspaper article, testing the family for hereditary diseases). Thus, students need to have some basic knowledge and understanding of heredity in order to be able to make informed decisions (e.g. Waarlo, 1998; 1999).
At the same time, however, genetics is also known to be one of the most difficult topics in secondary biology education, for both students and their teachers (Stewart, 1982; Finley *et al.*, 1982; Bahar *et al.*, 1999). Even at university level, undergraduate biology students perform poorly on their propaedeutic classical genetics exams. At Utrecht University the pass rate was 38% in 1996 (resit 55%) and 53% in 1997 (resit 34%) (Faculty of Biology). The lecturer pointed out the following problems in his educational practice (Scheres, 1995 and 1998, personal communication):
1- The (extensive) terminology is mastered insufficiently;
2- Genetics problems are often solved by trial and error; quite often students do not fully understand what the problem is and they have trouble relating the problem to concrete biological phenomena;
3- Some students have insufficient probabilistic reasoning skills.

The problems in this propaedeutic genetics course are not mere incidents. Numerous studies concerning secondary school and university students have reported difficulties students encounter in understanding the concept of inheritance (Smith & Simmons, 1992; Stewart & Hafner, 1994).

Collectively, these three findings: 1) the importance of students acquiring an adequate basic knowledge and understanding of genetics, 2) the problems experienced in genetics education at the Utrecht University, and 3) the difficulties in genetics education that have been reported in educational literature, were the reason for initiating the study at the Department of Biological Education this thesis will report on.
These three motives confirm the need to investigate the difficulties in learning and teaching genetics in more detail. The *aim* of this study is to develop a learning and teaching strategy for genetics in upper secondary biology education to cope with

these difficulties. This strategy should be based on theoretical notions and on empirical testing.
The central research question in this thesis is:

> *What is an adequate learning and teaching strategy for genetics in upper secondary biology education in order to cope with the main difficulties in learning and teaching genetics, and to promote the acquisition of a meaningful and coherent understanding of hereditary phenomena?*

In order to be able to answer this central research question we should firstly determine what exactly the main difficulties in learning and teaching genetics are. Moreover, it would be helpful to look for previously documented and validated solutions to these difficulties. A problem diagnosis and inventory of solutions could serve as a basis for defining criteria which an adequate learning and teaching strategy for genetics should meet. In addition, we should determine and define what we consider a meaningful understanding of genetics. Consequently, a domain-specific philosophy of learning and teaching genetics should be formulated.
Thus, the specific research questions to start with are:

- What are the main difficulties in learning and teaching genetics?
- What solutions are suggested in literature and/or have proven effective in practice?
- What are criteria for an adequate learning and teaching strategy?
- What does a meaningful and coherent understanding of genetics include?

1.2 Context of the research project

The aim of this section is to outline recent developments and the current state of affairs in biological research (science) and biological education at universities and secondary schools. This will yield relevant elements for a philosophy of learning and teaching genetics and it will help us to determine our position in the research field.

Biological science

Although the roots of biology lie in antiquity, biology as a modern science dates from the middle of the nineteenth century. The term 'biology' was coined in 1802, but modern biology started between 1828 and 1866, with landmarks such as Darwin's *On the origin of species*, Schwann and Schleiden's cell theory and Bear's embryology. Because at that time biology was mainly known as natural history, the corresponding school subject was called 'natural history' as well. It kept this name until the 1950s (Mayr, 1997; Hoekstra, 2000).
Today biology is an extremely diversified science. It deals with varied organisms (bacteria, plants and animals), as well as with various hierarchical levels of biological organisation (molecules, cells, tissues, organs, organisms, populations, and ecosystems). These levels correspond with areas of specialisation with their own names, e.g. anatomy, genetics, cytology, ecology, cell biology, and population biology. Biology has a wide range of practical applications, for instance agriculture

and animal breeding (Mayr, 1997). Until the 1970s, the levels of biological organisation (molecule, cell, organism, population, and ecosystems) were also more or less separated research areas, or sub-disciplines. In the 1970s biological research at universities was still divided largely according to traditional organismic disciplines like zoology, botany and microbiology, while by then it became clear that the fundamental biological processes are in fact general and species independent. In the early 1980s a more integrative approach of the research areas in biology emerged. Concepts and methods of biological research on the molecular level were integrated and used in biological research on 'higher' levels.

Over the last decades important new insights into the field of biology have been gained and life sciences are flourishing at this moment. Structural and functional research in living organisms has been made possible by technical breakthroughs, e.g. molecular biological techniques, progress in advanced microscopy and biophysics, and the availability of powerful computers (Biologische Raad , 2001). As a result, the knowledge of fundamental biological processes has increased, e.g. insights into complex biological systems as neural pathways and ecosystems, possibilities to modify the genome of plants, animals and micro-organisms. The progress of bio-informatics in order to process the input of the human genome project has given rise to new opportunities in solving fundamental biological questions. Due to these new insights and developments the nature of biological research has changed. For instance, focus is now on '*functional genomics*', i.e. the study of the functions of genes in relationship to phenotype, physiology and behaviour of organisms (Biologische Raad, 2001). In addition, the functions of individual genes and their products are studied on both the cellular and organismic level. In this way this research area directly connects the molecular level with both the cellular and organismic level, which illustrates the transect character of genetics. These advances in the field of biology have resulted in a stronger integration of research areas on the different levels of biological organisation.

Not only in biology research itself is there more focus on interdisciplinary research, but interdisciplinarity has also increased within the natural sciences as a group. In physics, techniques have been developed that enable researchers to investigate signalling in living systems. Currently, biology is gaining a key position in the natural sciences, partly due to the societal impact of biological research and technologies.

Biological research is no longer merely reductionistic; instead it transects disciplines and levels of biological organisation. There is a new emphasis on the interrelationships and coherence between the levels of biological organisation.

Biological education

The new developments in biology have increasingly societal implications. It is up to biologists to inform and educate the public about these new findings. School biology in particular plays an important role in educating citizens.

Current formal biology curricula reflect these developments in biological research and they try to provide for an integrative, coherent, and competence-based biological education. These current formal curricula focus on active learning and on acquiring meta-cognitive skills, i.e. 'learning to learn'. This should enable students to acquire

relevant biological knowledge in the future and to apply this knowledge in various everyday life settings. In our present knowledge-based society this 'learning to learn' is of vital importance, because it is the only way to stay informed when knowledge is expanding as fast as it is today. In addition, today's knowledge becomes outdated rather quickly. Consequently, it is impossible for students to learn in school all the knowledge and skills they need during their lifetime.

Up to the 1970s biological subject matter in secondary school was mostly an extract of the academic biological knowledge and structure. The focus was mainly on reproducing factual knowledge. In the 1960s the Biological Sciences Curriculum Study project (BSCS) in the United States of America tried to come to a more coherent structure in biology education by identifying unifying themes and levels of biological organisation. In addition, emphasis was on how the inquiry skills of the scientific method could serve as a learning strategy for acquiring knowledge and information (cf. learning to learn).
Jerome Bruner, an educational psychologist, and Joseph Schwab, a biologist and educational philosopher, elaborated on these general ideas on learning to learn and the way they relate to valuable domain-specific knowledge (Janssen, 2001). Bruner (1960; 1962) emphasised that learning general ideas (e.g. biological principles) supports the structuring of more specific knowledge in a domain. Specific knowledge that is embedded in a general structure is easier to recall and if forgotten, easier to reconstruct. Moreover, it enables the learner to learn in the future, because new problems and phenomena can be recognised as specific examples of the general ideas. Schwab (1962; 1964) recognised the structuring function of general ideas, but emphasised the *strategic* function of general ideas. He demonstrated that general ideas are essential in directing the kind of questions a learner should ask about biological phenomena. Without general notions it would be impossible for learners to formulate useful questions, or to know what kind of data should be gathered in order to answer the questions. Schwab (1963) converted some of these general ideas, such as causality, functionality and regulation, into strategies students can use in developing biological knowledge, by specifying the kind of questions to ask and data to gather in order to answer these questions, i.e. the 'invitations to enquiry'.

The most recent Dutch national educational reform has focused on 'learning to learn' and on improved tuning of the different disciplines. The latter resulted in a) assignments in which students have to integrate two subjects (e.g. mathematics and biology), b) an interdisciplinary approach of research methods, and c) new fixed combinations of examination subjects in upper secondary education. The national examination syllabus was extended with additional required skills that would contribute to a more coherent learning approach. For biology this resulted in attainment targets such as: '*students should be able to indicate that the whole is more than the sum of its parts: systems thinking'* and '*students should be able to relate biological phenomena on various levels of biological organisation to each other'* (National Examination Syllabus, 1998, attainment target 48 and 49). Thus, it is stressed that biological phenomena cannot be fully explained and taught in a reductionistic way. Focus should be on the relationships between the processes and

structures on various levels of biological organisation, and on the influence of the environment on biological systems.
It seems like the most recent educational reform stressed the importance of coherent knowledge and skills to promote scientific literacy (De Jong *et al*., 2001). In current educational practice, however, the attainment targets still include extensive and detailed prescriptions of biological facts and concepts students should know. An unpublished analysis (Mathijsen, personal communication) of the different verbs used in defining these attainment targets, showed that when compared to those of chemistry and physics, the biology attainment targets contained the most factual statements. Moreover, in the Dutch examination syllabuses of 1999 and 2000 biology had the highest number of attainment targets (216 versus 74 for physics), and consequently the least available time per attainment target (Morelis, 2001). These findings are supported by the Inspectorate (Inspectie van het Onderwijs, 1999) and by Kamp (2000), who have both reported on the cognitive overload of the current biology curriculum. What is more, biology schoolbooks have hardly been updated and if so, they tend to keep their traditional subject matter selection and sequence. Most schoolbook chapters have still been designed as separate units and most books lack integrating activities and cross-references among chapters. As a result, students often have fragmentary knowledge and lack a coherent picture of biology (Roebertsen, 1996; Boersma, 1997; 2000b).
Due to the rapidly evolving insights and techniques in the life sciences, schoolbooks seem to have become outdated or incomplete at a faster rate. Most schoolbook authors have 'solved' this problem by adding more information (that is, detailed descriptions on particular subjects). This solution has only made the cognitive overload worse, as most teachers strictly follow the structure and contents of the textbook (Boersma & Peters-Sips, 2000; Boersma, 2001). However, the central ideas and themes in (school) biology are still valid. Unifying themes have not been changed, but deeper understanding of these themes and their relationships has been obtained.
We may conclude that the new educational reform, which has emphasised the importance of coherent knowledge and a 'learning to learn' approach, has not been adequately implemented into schoolbooks yet.

How should we deal with the problems in present biological education? Kamp & Boersma (2001) have postulated the idea of defining key concepts, according to which the biological curriculum in secondary education can be structured. Moreover, it has been argued that the focus in the learning process should be on acquiring *competencies*. A competence is defined as a repertoire of specific knowledge, skills, values, attitudes and the like, that is meaningful and functional in one or more real life activities (or settings) (Boersma & Kamp, 2001; Boersma & Schermer, 2001).
It was mentioned before that the central (or general) ideas of a discipline could have a structuring function in knowledge development. The cognitive overload of the present biology curriculum, as indicated by a large amount of factual statements in the attainment targets of the examination syllabus, could be tackled by focusing on key concepts and their relationships. When students have an understanding of these key concepts and their relationships, it is easier for them to retrieve information, to

embed new information, and to see where the knowledge can be applied. These ideas are more or less in accordance with the ideas of Bruner and Schwab that were discussed above. Schwab (1963) defined seven key themes for biology: metabolism, homeostasis, growth and development, behaviour, reproduction, genetics, and evolution. These key themes, however, reflect a division according to biological experts and not so much to the appropriateness for students, nor relevance in school practice (Kamp, 2000). The National Research Council of the United States of America (1996) recently published a list of key themes for biology and they are: basics of heredity, the cell and molecular biological evolution, interdependence of organisms, matter, energy, and organisation in living systems, and behaviour of organisms. Note that the Council added the various levels of biological organisation in its theme definitions.
In our view it is important to emphasise key concepts and their relationships in biological education because it helps students to get a coherent picture and understanding of biology. This implies that when developing an adequate learning and teaching strategy for genetics, the key concepts and main lines in hereditary should be emphasised, and the overall learning goal should be considered a competence.

Conclusions

Outlining the developments in biological science and education underlines the importance of acquiring a coherent and integrative view on biology. It was mentioned that the latest developments and insights in science have given rise to an increased attention for genetics. The new DNA-techniques and possibilities in biological research, however, have also raised multiple (ethical) questions and have led to confusion among the public (Hoekstra, 2000). This stresses the importance of adequate information about and education in genetics.
The developments in the field of education aim at acquiring a 'learning to learn' competence that has become essential in our knowledge-based society. Although, it seems that this approach has still not been adequately implemented in school practice, the focus should be on learning general biological insights and key concepts that help to structure more specific knowledge in a domain.
An adequate learning and teaching strategy for genetics in secondary school should therefore allow students to acquire basic knowledge and understanding of inheritance. This enables students to make informed and reasoned decisions in new situations. This basic knowledge should be structured by emphasising the key concepts and interrelations in genetics.
The developments in biological science showed that an increasing integration of research and knowledge on the different levels of biological organisation is taking place. In fact, researching biological problems and questions is researching problems of biological systems.

1.3 View on learning and teaching

In this section we will outline our view on learning and teaching in science education by discussing some aspects of the current main views on learning and teaching.

Constructivism

Nowadays the dominant paradigm in theory on learning and teaching in science education is the constructivistic perspective (Mintzes *et al*., 1998). Constructivists consider learning an active construction of knowledge, based on what the learner already knows (Driver *et al.*, 1994; Duit, 1994). Consequently, education should be designed in such a way that students are invited to extend their knowledge towards the accepted scientific knowledge that has to be acquired. Constructivism can be seen as a reaction to the traditional transmission paradigm on learning and teaching, which has been severely criticised. In the transmission paradigm on learning and teaching, students are more or less seen as passive receivers of knowledge or information. The teacher transmits information, and the students receive and 'absorb' the new information exactly as it has been presented to them. From the constructivistic perspective, students interpret new information in the light of their own framework of preconceptions. They do not simply receive and integrate the new information as presented to them by the teacher, but they reconstruct it. This process of reconstruction can be seen as a process of making meaning. Therefore, transfer of information can induce misconceptions, i.e. knowledge that differs from the accepted scientific knowledge, and fragmentary knowledge (Duit, 1994; Eylon & Linn, 1988).
In the last few decades a large number of studies in science education have been conducted from the constructivistic paradigm on learning and teaching. Review of this research literature has shown that several movements in constructivism can be distinguished (Boersma, 1995). Firstly a distinction can be made between radical constructivism that does not accept the a priori existence of an objective reality (Von Glasersfeld, 1988; 1989), and moderate constructivism that does recognise the existence of an objective reality (Driver & Oldham, 1986). Moreover, a distinction can be made between individual and social constructivism; the latter emphasises that the act of learning is embedded in a social context (Cobb *et al*., 1992; Driver *et al*., 1994). The critical role of social and physical circumstances in which the activities are situated is stressed in the situated cognition perspective (Hennessy, 1993). In this social constructivistic view, learning is seen as a process that is part of a culturally organised activity which is carried out within a community of practitioners; i.e. in a process of enculturation.
Many of the constructivistic studies deal with how knowledge development in science education occurs in general. Although constructivism has given rise to valuable guidelines for science education and is useful in interpreting educational problems, it lacks concrete guidelines on what science education on a specific topic should look like in practice, or on how we should incorporate such guidelines into an adequate design for learning and teaching. Nevertheless, the basic idea has been recognised as valuable, i.e. that students already have their own ideas or preconceptions on a certain subject before it is taught. These preconceptions originate from society, personal experiences, upbringing, media, etc., and may differ

from the accepted and intended scientific concepts. Students are constructing new knowledge by interpreting new information within their framework of preconceptions.
The question remains: What is meant by actively constructing new knowledge, and how can it be done?

Active learning

The question of what is meant by actively constructing knowledge and how this process of learning and teaching should be designed, has also been addressed by Vollebregt (1998) and Kortland (2001). They expounded their view on learning and teaching from the educational constructivistic perspective of Ogborn (1997), and defined educational constructivism as 'a process in which the learner is *actively involved* in the integration of new experiences and information into what he already knows'.
Subsequently, our next question is how we can get students to be actively involved in the integration of new information and the construction of new knowledge? This problem has engaged many people over the last years, considering the increased attention for *active learning*, which could be one of the ways to address this problem. In fact, there is a widespread agreement on the desirability of active learning (self-directed and independent) amongst educational researchers (Van Hout-Wolters, 2000), policy makers, and the society in general.
Active learning is a way of actively involving learners in their learning process. Van Hout-Wolters *et al*., (2000) have made a distinction between self-directed learning and independent work in active learning. The difference lies in whether the focus of activity is on learning or on action. In independent work the task performance itself is active and the learner is challenged to use his or her mental abilities in the learning process (mental activity). When students figure things out on their own, work together in a group or work without direct supervision, sometimes co-operative learning is involved and at other times it is just individual work. However, in all cases the teacher controls and guides the feedback, learning goals and nature of activities. By contrast, in self-directed active learning it is the learner who controls the learning process by an active execution of the whole range of learning functions. This means that students make their own work schedule, choose their own learning goals and activities to reach these goals, reflect on the activities, etc. In this type of learning the learners have to take care of the learning functions of their own learning process.
For learners active and co-operative learning (Van der Linden *et al.*, 2000) may be more attractive than more passive forms. Learners may be more motivated and interested because they are involved in decisions related to their own learning and because they can find out things independently. Despite consensus on the desirability of active learning by society, the government, and the educationalists, many learners are still not 'active learners'. In teaching practice 'learning to learn' activities have often failed or teachers have been disappointed by the results (Van Hout-Wolters *et al.*, 2000). There are several factors that contribute to the difficulties in implementation of active forms of learning. Firstly, students are not always willing to spend time and energy on gaining new learning skills. Secondly, teachers do not

always see the benefits, they may feel it is time-consuming, or they may find it hard to coordinate and/or difficult to loose their autonomy. In addition, teachers often think that active learning is not appropriate for their subject matter. Finally, school management and organisation are not always equipped for active learning forms as self-study hours, etc.
The independent and self-directed variants of active learning hold important promises for learning, but they have shown to be not so easy to implement. To our mind it is important that students are actively involved in their learning process, but at the same time students should have some guidance so that they do not have to reinvent everything on their own. Simons (1992) already postulated that learning should not be restricted to discovery learning alone, because it is too time-consuming and inefficient. The role of the teacher is important in guiding the learning process and offering new information. The teacher should help students to perform tasks and activities that they are not able to carry out independently, yet. The more difficult activities should be performed under the guidance of the teacher until students are able to perform them on their own. The idea is that students' development can be stimulated by engaging them in activities that they are not able to perform by themselves yet. Since they are able to do so with the help and guidance of the teacher, this gives them the opportunity to work in Vygoyski's zone of proximal development (Hodson & Hodson, 1998).
Learning takes place in a social environment, including other students and teachers. Interaction with other students is important for students, to share their prior knowledge and to become motivated to extend their knowledge. The learning process should be guided by the teacher and the learning activities. This guidance by the teacher and active learning by the students also implies a tension that is well described by Lijnse (1995) as searching for a balance between 'guidance from above' and 'freedom from below'. The guidance from above is provided by the teacher and the sequence of learning activities; the freedom from below is guaranteed by adequately designed tasks, such as group work, in which students can express and develop 'in (limited) freedom' those very ideas that we want them to learn. To adequately tune these two aspects in a learning and teaching strategy, Lijnse (1995) has argued that this balance can only be carefully regulated empirically.

In conclusion, it is important *firstly*, that students are actively involved in their learning process, by learning activities that require active (mental) involvement and that take into account students' prior knowledge. *Secondly*, the learning process should be guided by the teacher and/or learning activities towards the intended learning outcome, i.e. shared scientific knowledge. *Thirdly*, learning activities should be designed in such a way that there is room for interaction with other students (and the teacher). *Finally*, students should be *willing and able* to extend their knowledge in the direction of knowledge accepted in the scientific community.

Problem posing approach

The question that remains is how to motivate students and how to keep them motivated for learning? As mentioned before, active and co-operative learning may be more attractive and motivating for students. At the same time Van Hout-Wolters

et al. (2000) have shown that until now many 'learning to learn' activities have failed in teaching practice.
Nevertheless, at the Centre for Science and Mathematics Education at Utrecht University learning and teaching strategies have been developed in which students become actively involved and motivated in the learning process. A general didactical strategy, the *problem posing approach,* developed by Klaassen (1995) at this centre, aims to involve students more actively in their learning process, starting from the *content*. Actively involving students should motivate them to develop their knowledge into the direction of the desired accepted scientific knowledge. Klaassen (1995) developed the problem posing approach for the topic of radioactivity. Since then the approach has also been applied to the particle model (Vollebregt, 1998) and to decision making concerning the waste issue (Kortland, 2001). Janssen (1999) used the problem posing approach in his strategy of *learning by designing*, in which students learn to generate knowledge about biological systems by 'redesigning' them. This learning by designing strategy has been developed for the subject of immunology and was based on a constructivistic view on science education and a view on organisms as optimal designs.
The problem posing approach to teaching and learning aims to provide students with both local and global motives for learning. It has been based on the idea that students should be aware of what they are doing and of why they are doing what they are doing at any time during their learning process. Global motivation is necessary to give students a sense of direction as to where the whole learning and teaching process will take them (Klaassen, 1995). The local motivation should be evoked by learning activities that have been designed in such a way that they raise questions students cannot fully solve yet, but that can be answered by carrying out the subsequent learning activity. The solution of a partial problem gives rise to the next partial problem in the sequence that will be answered or solved in the next learning activity. The learning activities should be chosen in such a manner that working on these partial problems will help students to solve the main problem, and to acquire the desired scientific knowledge.
Klaassen (1995) emphasised that it cannot be expected that all students are always able to raise the intended and adequate questions at every point in the learning and teaching sequence, or to solve these problems all by themselves. It will suffice if a few students raise these questions. However, it is important that all students experience these problems as their own problem (Vollebregt, 1998), although this may not at all be easy to realise in science education. While designing a problem posing learning and teaching sequence, we should take students' prior knowledge into account and consider how the designed learning activities could lead to the anticipated questions and solutions. In other words, we should be able to predict students' actions, by imagining our own actions and ways of thinking when starting from the same prior knowledge as the students.

Conclusions

The problem posing approach seems a fruitful and an adequate way of motivating and actively involving students in content specific learning processes. Therefore, the idea of the problem posing approach will be used in designing a learning and

teaching strategy for genetics. This means that the learning activities of the learning and teaching strategy will be designed in such a way that students first are invited to activate and share their prior knowledge on a specific genetics concept, i.e. by discussing a problem with other students in small groups (the co-operative learning approach). By sharing their ideas and clarifying their prior knowledge in their own words, they will experience that they lack information and knowledge. In addition, by collaboration students will be able to solve a problem or task better than on their own, and they will get stuck on the problem less quickly. The questions that rise should motivate them to obtain more knowledge and insight into the genetics concepts, and to move forward to the next learning activity (local motivation).

1.4 Thesis outline

Chapter 2 will discuss the design of this study according to the developmental research approach. It will explain the characteristic cyclic research process in developmental research, which is preceded by an explorative (orientation) phase. In this explorative phase, partly discussed already in the two previous sections, the domain-specific philosophy of learning and teaching genetics is elaborated upon. The main difficulties in learning and teaching genetics that were identified by means of a literature review and additional focus group interviews with Dutch biology teachers, are outlined in chapter 3. The key difficulties in genetics education are studied in more detail. More in-depth data are gathered in a case study, by observing a traditional genetics course in practice and interviewing students. The explorative phase finally results in defining of four design criteria for a preliminary learning and teaching strategy for genetics.
Chapter 4 will discuss the cyclic empirical research phase of this study. Based on the four design criteria a first outline of a learning and teaching strategy is developed and converted into a context-specific scenario. The scenario is field-tested in a first case study to probe the adequacy of the learning and teaching process. The qualitative data that were derived from various sources are analysed in order to evaluate the scenario and to reflect on the adequacy of the learning and teaching strategy. Based on these outcomes the learning and teaching (LT) strategy is revised and tried out in a second and third case study. The last cyclic process of designing and evaluating resulted in the third and final LT strategy for genetics, i.e. the 'yo-yo' learning and teaching strategy, which is reflected on in chapter 5. Chapter 5 will discuss the didactical structure as well as the wider applications of the yo-yo learning and teaching strategy and anticipate on future research. The central research question of this thesis will be answered in this final chapter.

Chapter 2

Design of the study

2.1 Introduction

Chapter 1 outlined and provided a context for the central problem that is addressed in this thesis. The developments in biological science and education, as well as notions on learning and teaching served as a basis for a domain-specific philosophy of learning and teaching. The aim of this study is to develop an adequate and research-based learning and teaching (LT) strategy for genetics in upper secondary biology education. The interpretative research approach applied to accomplish this aim can be characterised as 'developmental research' (Lijnse, 1995).
A general description of developmental research approach will be given in section 2.2. The various phases, products and activities that are part of this approach will be discussed. Section 2.3 focuses on how *this* study has been designed according to the developmental research approach.

2.2 Developmental research

Situating the approach

Developmental research is based on the assumption that both theory and practice play an important role in developing and testing adequate solutions to learning and teaching problems. Educational researchers and teachers co-operate in defining and developing learning activities and in testing these activities in classroom settings. Several cycles of empirical testing are necessary to optimise the LT strategy.
Developmental research helps to improve the science education practice and at the same time yields scientific output, i.e. a domain-specific learning and teaching theory. Objects of study are the domain specific learning processes and learning outcomes of students, and the impact of teaching on these learning processes and outcomes (Boersma, 1998).
Developmental research shares certain characteristics with action research and with interactive curriculum development, but these three approaches all have distinct characteristics. Developmental research resembles action research in that both the design is tested and the data are collected in a classroom setting instead of a laboratory setting. Furthermore, in both types of research teachers participate to some extent in the research process. Teachers give feedback on the learning activities that have been designed, they carry out the LT strategy in practice and they participate in evaluation activities. However, in action research the main focus is on the social context and idiosyncratic situation. Research problems are selected by the participants, that is, the teachers, who also act as co-researchers. The main goal of action research is to generate new knowledge, new skills and social change that can serve as the basis for emancipatory processes of the group members (Greenwood, 1998). Scientific output is not its first concern; solutions to the problems of the participants are.
Developmental research and interactive curriculum development both have in common that the curriculum is developed in interaction with the target group, i.e. teachers and students (Boersma, 1998). The two approaches differ on the fact that in

curriculum development the objective is only to develop educational materials, not to build a justified theory as well (Gravemeijer, 1994). In developmental research the learning and teaching materials are in fact the vehicle to test the adequacy of the LT strategy (theory).

General design of developmental research

The following description of the design of the developmental research approach has partly been reconstructed in retrospect. Developmental research is a kind of learning process in itself; consequently the characterisation of the phases, objectives and activities could be gradually defined and distinguished more adequately.
The developmental research approach consists of roughly two phases: 1) the explorative (or orientation) phase, and 2) the cyclic research phase. The latter should result in a theoretically founded and empirically tested LT strategy (figure 2.1). Each phase can be characterised by its own products, activities and goals.

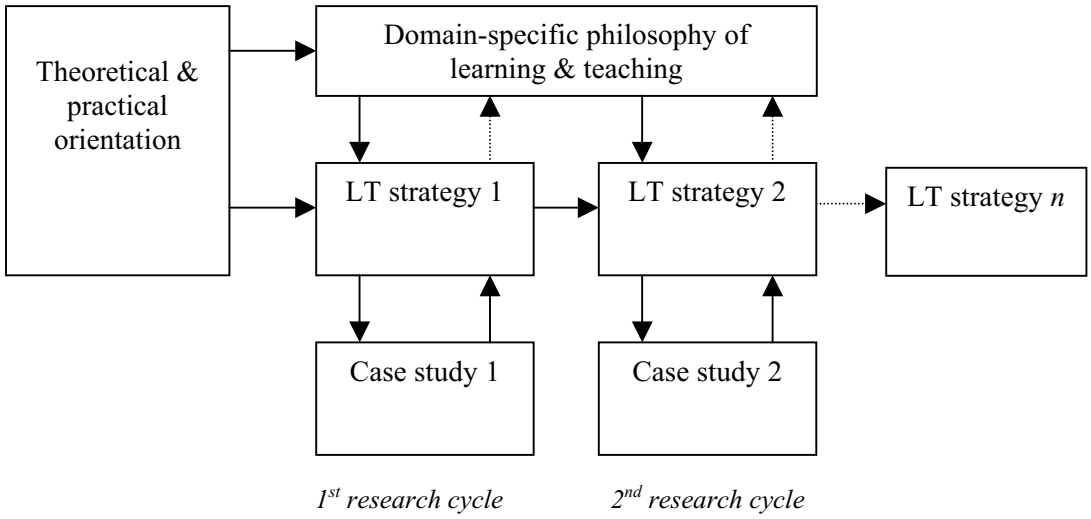


Figure 2.1 ***Design of developmental research***. *Consisting of an explorative phase, construction of a learning and teaching (LT) strategy which is tested in successive case studies in the cyclic research phase, finally resulting in a domain specific theory (n).*

Explorative phase

The explorative phase is meant to explore and define the research field, to determine the learning and teaching problems in the domain and to build ideas to deal with these difficulties. Two components can be distinguished in the explorative phase: a theoretical and a practical exploration. The theoretical component includes an orientation on a) general learning theories, b) the domain-specific subject matter, its contents and conceptual structure, and c) the domain-specific educational literature. The practical component consists of the exploration of educational practice through

observations of genetics lessons and by interviewing students and teachers. Combined, the theoretical and practical exploration should result in a philosophy of learning and teaching genetics and in the definition of design criteria for a preliminary LT strategy.

Cyclic research phase

The second phase, the cyclic research phase, is the core of developmental research. It is a cyclic process of constructing the design, field-testing it, reflecting on the design and adjusting it, field-testing the revised design, and so on.

Based on the results of the explorative phase (e.g. design criteria) a preliminary *LT strategy* for the domain will be designed first. The LT strategy embraces two levels: a sequence of problems (presuming a problem posing approach) and a sequence of learning activities (figure 2.2). The structure of the domain-specific content is reflected by the sequence of the successive questions (problems) that will be presented to the students. Of course these problems have been adapted to the students' prior knowledge and their reasoning skills. This sequence of questions is a construction of the learning path with the students in mind, and it will be empirically validated in several consecutive research cycles. Students should answer the successive questions by engaging in the learning activities.

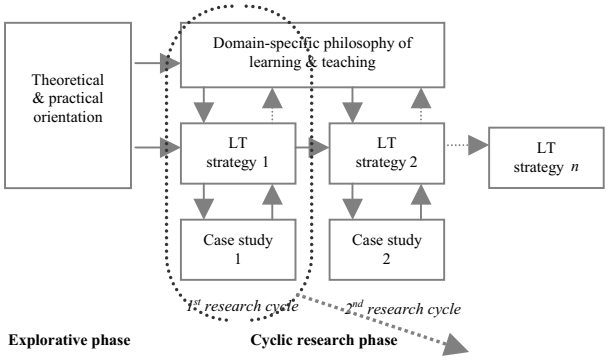
On the basis of the sequence of questions a sequence of learning activities is developed that has been designed from the students' perspective and that has been described on a rather general level. Learning activities include the teaching method; content items to be discussed, explored or investigated; and goal.

Next, this first LT strategy will be elaborated into a *scenario* (figure 2.2). In the scenario, the more global ideas outlined in the learning and teaching strategy are converted into a more explicit and context-specific description of learning and teaching activities, consisting of intended and expected learning and teaching processes, objectives, and teaching methods. 'The scenario describes and justifies in considerable detail the learning tasks and their interrelations, and what actions the students and teacher are supposed and expected to perform' (Lijnse, 1995, p.196). This elaboration process takes place simultaneously and in interaction with the writing of the actual *learning & teaching material.* The practical completion of the scenario and its LT material is guided by the specific case in which it will be tested, i.e. the *case study.*

So the scenario is a context specific, detailed description of the expected teaching and learning processes, including learning and teaching activities and intended learning outcomes. It is a set of 'hypotheses' to test empirically the adequacy of the strategy. The scenario facilitates the intended learning process. In other words, the scenario and LT material are on the one hand the vehicle (research instrument) used to test the adequacy of the LT strategy, and on the other hand serve as a means for the teacher to prepare the actual lessons.

According to Freudenthal (1991) in developmental research the *process* by which the *products* of the activities are created is reported in such a detailed and comprehensible way that it justifies itself. Often researchers publish only the products of their activities, which can be interpreted in many ways, while the knowledge about how to learn and teach a specific topic, has to be justified by the process by which the knowledge was gained.

Figure 2.1 ***Design of developmental research.***



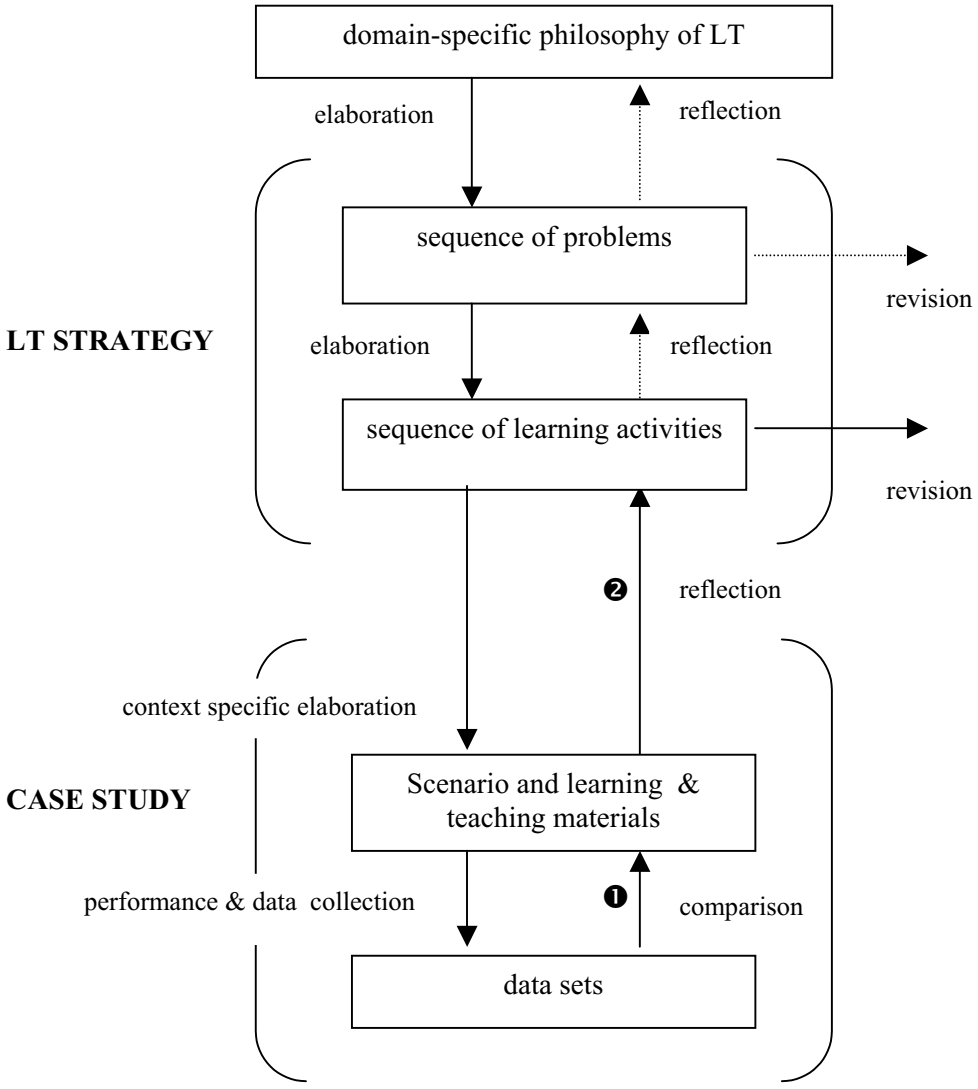


Figure 2.2 ***Research cycle of developmental research.*** *Including sequence of products (boxes) and activities (arrows) involved in one research cycle. The arrows show the sequence in which the multiple levels in*

developing the LT strategy and its scenario are designed and subsequently reflected on. The numbers ❶ and ❷ refer to the research questions. For further explanations the reader is referred to the text.

When the scenario is carried out data are collected and subsequently analysed to compare the executed scenario with the intended scenario. The research question is as follows: *to what extent can the nature and sequence of the learning activities in the scenario be considered adequate?* (see ❶ in figure 2.2). The second step of the analysis is to reflect on the LT strategy and to answer the second research question: *what indications can be extracted from comparison of the observed learning and teaching processes and outcomes with the scenario, for revising the LT strategy?*(see ❷ in figure 2.2). The outcomes provide information necessary for the further improvement of the design. The LT strategy will be revised and subsequently elaborated into a second scenario again to be tested in a second case study, i.e. second research cycle. If these results are not yet satisfying, a further cycle of improvement and testing can be performed (figure 2.1 and 2.2).
Furthermore, *reflection* on the outcomes contributes to the development of theoretical notions concerning the learning and teaching of the specific subject. Reflection activities do not only occur afterwards, but already start during the development and testing of the learning activities, e.g. reflection on learning and teaching activities, experiences in the classroom, and the developmental process itself (Gravemeijer, 1999). In the reflection on the outcomes of a case study different types of reflection activities can be distinguished: 1) weighing the findings of the case study, 2) discriminating between coincidental, crucial and context specific findings, 3) being alert to findings which can lead to adjusting the LT strategy. It is a process of thinking backward-and-forward between the domain-specific philosophy of LT genetics and the scenario (figure 2.2). The reflection activities can be considered as the decontextualisation of the findings of the case study.
In a *case study* a field-test is performed in a naturalistic setting, i.e. one form of one school. It includes a rich, detailed and in-depth description of the observed phenomena in the case. Multiple sources corresponding with different points of view (triangulation) are used for providing evidence (Ghesquière *et al.*, 1999), e.g. classroom observations, audio-taped oral discussions, completed worksheets, written tests, interviews with teachers. In analysing the data sets a comparison is made between the executed scenario and the intended scenario.
So, in the developmental research approach, the domain-specific LT strategy (theory) will evolve in a process of cyclical empirical testing of scenarios, i.e. successive case studies (fig. 2.1 and 2.2). The successive research cycles are a kind of learning and optimisation process itself, rather than a multiple case study (Yin, 1988). Finally, after maturation of the LT strategy, a domain-specific theory for learning and teaching this specific topic is available. This is in contrast to Klaassen (1995) and Vollebregt (1998), who consider the final scenario as the domain-specific theory for learning and teaching the topic. Large-scale implementation of the strategy and scenario is beyond the scope of this thesis.

2.3 Developmental research in this study

Explorative phase

This study has been designed according to the developmental research approach as outlined above. The explorative phase (figure 2.3) resulted in 1) a positioning of this study in the research field and educational theories, discussed in chapter 1, and 2) an identification of the main difficulties in genetics education and more in-depth understanding of these learning and teaching difficulties (chapter 3). Subsequently, the focus was on idea building, trying out promising learning activities, and defining criteria, which an adequate LT strategy should meet. The explorative phase is described in detail in chapter 3. The methods of data collection and analysis (e.g. literature review, focus-group interviews, and students' interviews) will be discussed per research activity in chapter 3.

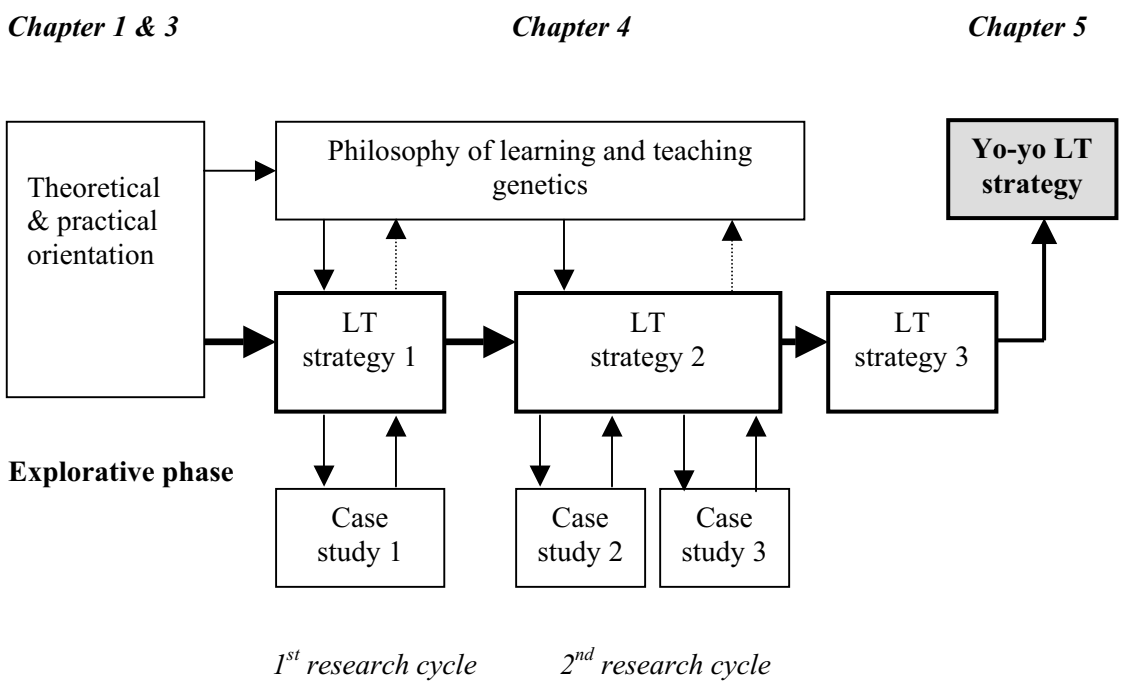


Figure 2.3 ***Design of the study according to the developmental research approach.*** *Three case studies have been carried out in two research cycles, preceded by an explorative phase and resulting in a domain-specific LT strategy. The chapters, in which the phases are outlined, are indicated. Chapter 1 and 3: the explorative phase. Chapter 4: the cyclic research phase. Chapter 5: the yo-yo LT strategy.*

Cyclic research phase

In the cyclic research phase (figure 2.3), to be presented and dealt with in chapter 4, three case studies in different schools and in different forms were planned. Based on

the results of the explorative phase (e.g. design criteria and ideas) a preliminary LT strategy, consisting of a sequence of problems and a sequence of learning activities, was constructed and elaborated into the first scenario, which was then field-tested. The development and results of this cyclic development process will be outlined in detail in chapter 4. Here, the design of the case studies will be described.

The case studies

Three case studies were planned and carried out in the cyclic research phase, taking into account various practical constraints. The topic of genetics in upper-secondary biology classes is generally taught toward the end of, or at the beginning of the calendar year, i.e. before or after the Christmas break. Two out of three biology teachers involved in the case studies also participated in the focus-group interviews of the explorative phase, and were consulted and informed regularly, since.

Upper-secondary education in the Dutch school system comprises two streams (table 2.1).

Starting from three different contexts (different form, students, teacher, school) of upper-secondary education could lead to a more powerful, flexible, and valid LT strategy, than testing three times in one form with one teacher. Therefore, we decided to test the LT strategy, by means of context-specific scenarios, in different forms of upper-secondary biology education (table 2.1). In the step of decontexualising the findings of the scenario in practice, i.e. reflection on the LT strategy, it has to be determined what is crucial in the LT strategy. After a number of research cycles, including data analysis, evaluation and reflection, the core of the LT strategy will mature.

Table 2.1 ***Upper secondary education in the Dutch school system: two streams.*** *The superscripts 1,2, and 3 refer to the successive case studies. E refers to the explorative case study.*

	Two streams	Dutch equivalent	Grades	Age students in years	Abbreviation
1	General secondary education: highest level	HAVO	4 and 5	grade 4: 15-16 grade 5: 16-17	4 H^3 5 H^E
2	Pre-university education	VWO	4, 5 and 6	grade 4: 15-16 grade 5: 16-17 grade 6: 17-18	4 V^2 5 V 6 V^1

Due to the national innovation of the program in upper-secondary school in 1998/ 1999, there were classes that still followed the old program and classes that just started with the reformed program. Due to this overlap there were no 5V classes that taught the topic of genetics in the research period.

Furthermore, it was decided to include two classes per teacher in the same case study. This gave us an opportunity to make small adjustments before a lesson was carried out

for the second time. And it enabled the teacher to focus on and familiarise her- or himself with the new strategy, resulting in more self-confidence and higher scenario fidelity. In addition, it made the case study less vulnerable for disturbing events like non-attendance or cancelling of lessons. Three case studies were planned and carried out. A schedule of the successive case studies is presented in fig. 2.4. The scenarios of case study two and three were both based on the same (second) LT strategy, and were consequently treated and discussed as one research cycle.

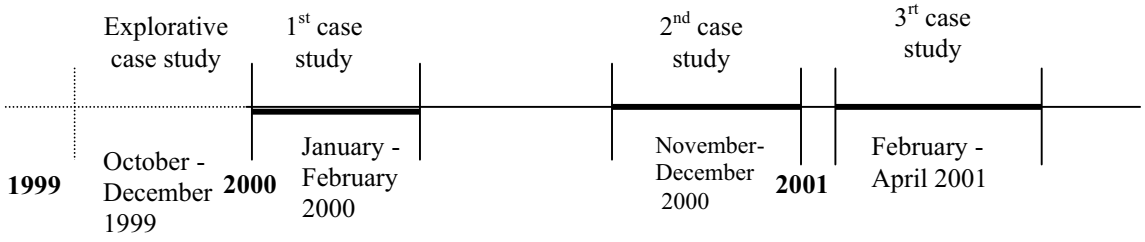


Figure 2.4 ***Schedule of the case studies.***

The research cycles in this study are applied according to the successive steps explicated in section 2.2 and figure 2.2, i.e.:

1. Designing the LT strategy for genetics.
2. Converting LT strategy into a scenario for the specific context (case).
3. Developing accompanying learning and teaching materials.
4. Trying out the scenario and its learning and teaching material in practice.
5. Gathering various qualitative data sets in practice (e.g. audio-taped group and class discussions, worksheets, classroom observations, written tests, and evaluation interviews with teacher).
6. Analysing the various data sets and comparing the executed with the intended scenario.
7. Reflection on the observed learning and teaching processes and outcomes in order to revise the LT strategy.
8. Revision of the LT strategy, i.e. transition to the next research cycle.

The strategy field-tested in the first research cycle was not yet a fully cut-and-dried strategy. The first case study started in January 2000 and involved two classes of the highest levels of pre-university education (6V). The data collected in the case study were analysed in two steps, which corresponded with the first and second research question. According to the evaluation and reflection outcomes of the first research cycle, the LT strategy could be revised and founded in more detail. The research findings gave rise to further reflection on and elaboration of the LT strategy. The resulting second LT strategy was converted into a second and third scenario and tried out in a second and third case study, i.e. November 2000, two classes of pre-university education (4V), February 2001, one class of general secondary education level (4H).
This cyclic research process and the case studies involved will be discussed in more detail in chapter 4. Section 4.2 will specify the various sources used per case study and the method of data collection and analysis.

Chapter 3

Identification and exploration of learning and teaching problems in genetics

3.1 Introduction

In order to identify the main problems in genetics education and to gather more in-depth information about these difficulties, various explorative research activities were planned. The criteria for the development of a preliminary learning and teaching strategy will be a result of interrelating the outcomes of these different research activities. Section 3.2 will report on the educational difficulties identified in the international literature. Section 3.3 is about Dutch biology teachers' perceptions of learning and teaching problems collected by means of focus group interviews, which resulted in the identification of 10 problem categories. Based on the literature review and additional focus group interviews, two key issues were selected to focus further research on. Section 3.4 offers more in-depth data about these key issues gathered in a case study, in which a traditional upper-secondary genetics course was observed and students were interviewed. Content analysis of schoolbook chapters dealing with genetics is reported on in section 3.5. Finally, based on these research activities, the two key difficulties were defined in more detail and criteria for a preliminary educational strategy were extracted (section 3.6).

3.2 Reviewing the literature

The literature review and the focus group interviews (discussed in section 3.3) are the main sources used in the explorative phase of this study to identify the main difficulties in learning and teaching genetics.
In the past two decades, science education research paid relatively much attention to learning and teaching genetics. About 20 years ago, a study concerning difficulties encountered by secondary and university students in learning biology was published (Johnstone & Mahmoud, 1980). To identify topics of high-perceived difficulty in school biology, a list of 36 major topics taken from a Scottish syllabus was administered to 167 first-year undergraduate biology students. The two topic areas that proved to be most troublesome to these students were water transport in plants and genetics. Other authors also highlighted genetics as traditionally one of the most difficult topics in biology courses for both students as well as secondary science teachers (Stewart, 1982; Finley et al., 1982).
Recently, Bahar *et al.* (1999) have updated the Scottish study with 207 first-year university students, to ascertain any changes in students' perceptions after curricular changes had been implemented. The water transport problems were found to have largely disappeared, but the genetics problems were still persisting.
It is at least remarkable that after 20 years of research in genetics education, it is still perceived as one of the most difficult topics in biology education. In order to gain an overview and more in-depth knowledge of the difficulties, the literature over the last two decades has been reviewed.

Different research perspectives

To make the extensive and diverse literature on genetics education manageable, we

tried to categorise the articles. By focusing on review articles and the abstracts of relevant primary articles, a global overview was obtained. Noticeable were the various perspectives and highlights used by the different authors in their research. Due to movements in research interests in time, emphasis shifted from a Piagetian perspective to more constructivistic approaches. The articles on genetics education could roughly be divided into three perspectives used by authors: 1- Piagetian perspective, 2- cognitivistic perspective and 3- constructivistic perspective (although it has to be noticed that no classification is extensive and exclusive). Different perspectives imply different designs of the studies and paying attention to various aspects of the learning and teaching process.

Piagetian perspective

In the Piagetian perspective, researchers focus on levels of formal reasoning and problem solving success (Gipson *et al*.,1989). Studies from this perspective point out the value of relating curricular requirements to the stage of cognitive development of students (Gipson *et al*., 1989). Difficulties that students encounter in solving Mendelian genetics problems may be associated with in the cognitive development levels of students. Studies originating from a Piagetian framework, indicate that secondary school students and undergraduate students are lacking formal reasoning skills, needed to solve genetics problems (Walker *et al*., 1980; Gipson *et al*., 1989). This lack of formal reasoning skills might explain why students find genetics difficult to learn (Walker *et al.,* 1980). They suggest that instructions in genetics emphasising formal reasoning, could be used to increase students' problem-solving performances.

Smith and Good (In: Stewart & Hafner, 1994) reported that formal operational thought is not enough to account for problem solving success. In a literature review, Smith (1992) analysed the research by focusing primarily on Piagetian schemes of combinations, proportions and probability and concluded that formal-operational thought is conducive to successful genetics problem solving, but is not strictly required for solving typical genetics problems.

Over the last decade, the articles on genetics education from a Piagetian perspective seem to decrease and attention is shifting to constructivistic approaches, in terms of identified 'misconceptions' (or alternative conceptions), with emphasis on the importance of prior knowledge as a central variable affecting learning.

Cognitive perspective

Studies from the second perspective, the cognitive view, put emphasis on the concepts that learners hold and how they process information. The 'expert-novice' approach is characteristic for the cognitive framework in genetics education. By comparing the problem-solving performances of experts and novices (successful vs. unsuccessful), researchers try to characterise cognitive differences between those two groups. The work of Smith *et al*. (1984; 1988; 1992) and Hafner *et al.* (1995; 1996) for instance, focuses on characteristics of successful and unsuccessful problem-solvers in the context of genetics, like identification of heuristics and key issues in experts' reasoning. However, practical applications of expert-novice comparisons are somewhat limited, since experts and novices do not normally share

the same goals or have to carry out similar tasks. Experts have often spent years acquiring specialist knowledge and artificial mental models of their domain (Collins & Genter, 1987). Therefore, the general characteristics of experts in solving a problem are not necessarily an optimal strategy for novices. Hence, most of these kinds of studies are carried out in laboratory settings instead of classroom settings.
The cognitive perspective does not primarily focus on genetics: the context of genetics is used to test general problem-solving skills.

Constructivistic perspective

Studies done from the third perspective, the constructivistic perspective focus on differences in content and structure of personal and scientific knowledge and on bridging the knowledge gap. Scientific knowledge cannot be 'transplanted' unmodified, due to interference with students' prior knowledge. They construct their own knowledge. In this view emphasis is on the importance of prior knowledge as a central variable affecting learning (Ausubel *et al.,* 1978).
There are different sources of misconceptions described in the area of genetics education. Cho (1985) for instance, outlined difficulties students have with genetics due to the biology textbook. Longden (1982) showed that some major students' misconceptions were related to the nature of the concepts used in genetics, such as 'meiosis'. Brown (1990) and Kindfield (1991; 1994) identified students' misunderstandings with the process of meiosis. They suggest a variety of instructional changes that may help students in learning genetics, such as a different conceptual organisation of the biology textbooks, and the type and extent of practical support. Stewart & Van Kirk (1990) suggest the conceptual-change approach for learning and teaching genetics, in an effort to encourage students to give up their alternative conceptions on classical genetics.

The most eminent feature in all investigations carried out from different approaches (Piagetian, cognitivistic, constructivistic) is the focus on *problem solving* research in the context of genetics. Since the eighties of the last century, problem solving research in science education is increasing. In biology, genetics is the area in which most problem solving research has been done (Stewart & Hafner, 1994). Problem solving is the super imposed theme in all these studies and classifications. Whereas the main part of the publications on genetics education focus on 'problem solving' research, it has to be noticed that this term is used in different perspectives. Firstly, problem solving in general is domain-independent and the area of genetics is a rather coincidental context. In this kind of research, emphasis is on general characteristics of successful problem solvers. The context of genetics is used to test general problem-solving skills and strategies. Secondly, problem solving is used as a means of learning and teaching itself (Stewart & Van Kirk, 1990). It is a general educational strategy. Lastly, genetics itself consists of solving problems, such as solving pedigree problems and mono- and dihybrid crosses. This kind of problem solving research emphasises the content and the domain-specific tasks that are an integral part of the (Mendelian) genetics.
In this brief overview of research perspectives concerning genetics education, we have shown that the research orientation can differ largely among the various

authors in this area. In general we can say that over the last 20 years the dominant research paradigm is *problem solving* exemplified for genetics.
From the Piagetian perspective we could learn that it is important to realise that students have to develop an ability to handle abstraction. Studies from the cognitive perspective focus mainly on researching general problem solving skills. Our main interest is not in research dealing with the general problem solving approach, but in learning genetics. Consequently, searching the extensive literature on genetics education in more detail should focus on identifying domain-specific learning and teaching difficulties and proposed solutions to these difficulties.

Main difficulties

The main domain-specific difficulties identified in the literature on genetics education, can be divided into five categories:

1. Domain-specific vocabulary and terminology
2. Mathematical content of Mendelian genetics tasks
3. Cytological processes
4. Abstract nature due to the sequencing of the biology curriculum
5. Complex nature of genetics: a macro-micro problem

It has to be noticed that these problems are not isolated problems, but tied together.

1. Domain specific vocabulary and terminology

One source of confusion and error in genetics education is the extensive and complex technical vocabulary of genetics. Students are often not confident with the definitions of the genetics-related words, and there is confusion because terms look and sound very similar, e.g. homologue, homologous, homozygous and homozygote (Bahar *et al.* 1999).
In school practice, the genetics vocabulary is introduced to students by three sources: the teachers, the textbook and the requirements of examinations (Kinnear, 1992; Pearson & Hughes, 1988). Unfortunately, the vocabulary of genetics is not always used consistently by these three different sources, and therefore a source itself can induce confusion and error. Moreover, the genetics terminology is extensive, so textbooks and teachers need to be selective and specific in their use of genetics terms, and avoid using too many synonyms. Students can be easily overwhelmed by the number of new genetics terms.
Radford's and Baumberg's glossary of terms in teaching genetics (1987) mirrors the need for accurate and consistent terminology for genetics in the educational field. Concerns about the use and misuse of terminology in genetics has been expressed by several authors, e.g. Evans (1974; 1976) and Cho *et al.* (1985). Sikkema (1977; 1978; 1992) discussed the incorrect and ambiguous use of genetics terminology in schoolbooks and examinations in the Netherlands.
Pearson & Hughes (1988a; 1988b) reviewed the literature on problems related to the use of terminology in genetics education. They classified the different types of difficulties as: a) misuse of terms, b) existence of synonyms, and c) occurrence of redundant and obsolete terminology. An example of the misuse of terms is the incorrect use of the terms 'gene' and 'allele' as synonyms, which is persuaded by textbooks and teachers that use these two concepts as interchangeable (Cho *et al.*,

1985; Pearson & Hughes 1988a). Errors arise when these sources use phrases such as 'the gene for red coloured flowers' instead of 'the allele for red coloured flowers', or a 'lethal gene' instead of a 'lethal allele'. Not the gene is lethal, but the expression of a certain allele of a gene can be lethal to an organism. Due to this misuse of these genetics terms as synonyms, the misconception arises that the term gene and allele are interchangeable. Besides, in the molecular biological context the (true) synonym cistron is used for gene. This use of synonyms creates even more confusion for students. Some authors (e.g. Sikkema, 1977; 1978; 1992) propose to remove the term 'allele', because it is used inconsistently and inaccurate by the different sources (textbooks and teachers). In their view the term 'gene' is sufficient for an adequate understanding.

Besides the misuse and use of synonyms by textbooks, teachers, and examinations, students often misassociate terms. The term 'dominant' for instance is confusing for students. They often misinterpret the term 'dominant' as a synonym for frequent (Smith & Good, 1984; Kinnear, 1983), and a common idea is that 'dominant' alleles are 'good' and are needed to mask the effect of 'bad' recessive alleles (Pearson & Hughes, 1988; Mahadeva & Randerson, 1982). Students often conclude that due to its strength the dominant allele should become more common in the course of evolution (Heim, 1991). In their view 'dominant' is frequent and stronger, and 'mutations' are rare and usually recessive.

Terms often have different meanings depending on the context of use. Mutation, for instance is strongly associated with the idea of change and some students consider the term synonymous with biological developmental changes (Albaladejo & Lucas, 1988); they emphasised that the sample in their study consisted of students from a Catalan language school, and that in Catalan the term 'mutation' has a range of meanings in everyday language. But Pearson & Hughes (1988) also reported on the term 'mutation' used for a variety of processes, which produce genetic changes. This concept is usually presented incorrectly in textbooks. Mutations are described as rare, harmful and recessive events. But mutations are changes in the DNA molecule and the expression of mutations may be rare, harmful and recessive dependent on the environment in which the organism lives at a given time (Mahedava & Ranederson, 1982). Likewise, the understanding of the concept 'linkage' is dependent on the ability of students to differentiate the many senses in which the terms 'linkage' and 'linked' are being used in genetics (Kinnear, 1991).

Besides the misuse of terms and misassociation of terms, also obsolete or redundant terms (i.e. terms which no longer have any real meaning) are sources for confusion. For instance, the term 'element' used by Mendel, has been replaced by the term 'factor' and since 1909 by 'gene'. Longden (1982) argues that 'chromatid' is a redundant term, because it adds nothing to the understanding of the process of cell division and DNA replication and is a possible source for confusion. The terms 'chromosome', 'homologous chromosomes' and 'chromatide' in particular confuse students. Firstly, because they look similar. Secondly, because the term 'chromosome' is being used for different concepts in different contexts. Chromosome is synonymous with a DNA-strand in the context of duplication, with a 'pair of chromatids' during mitosis and meiosis, and with every individual chromatide after they have separated. These cytology-related difficulties will be

discussed in more detail further on (section 3: cytological processes).
The confusion concerning the 'gene-allele' concept and the 'chromosome-chromatid -homologue chromosomes' in the cytological processes was also studied by Huisman (1999) through analysing Dutch schoolbooks and interviews with Dutch students and teachers. He found similar misconceptions and concluded that several schoolbooks could contribute to an inadequate understanding of the 'gene-allel', and 'chromosome-chromatide-homologue chromosomes' concepts.

In conclusion, biology, and in particular school genetics, is complicated by imprecision in the use, and a lack of consensus of the meanings of particular terms (Institute of Biology, 1987).
The question remains how to solve the problems students have with the genetics terminology. Pearson & Hughes (1988) suggest that an adequate selection in the use of genetic terms in education should be made to prevent extensive terminology and to avoid confusion. However, they do not offer selection criteria. Besides, the discussion among authors on the genetics terminology shows that using the genetics terminology appropriately is not easy, not even for genetics education researchers (Smith 1991; Browning & Lehman, 1991).

2. Mathematical nature of Mendelian genetics tasks

The mathematical nature of Mendelian genetics is another source of difficulties that students face in learning genetics. Although students often understand the probabilistic nature of real-life problems and have no difficulties in determining the chances, they fail when they have to apply the same chance events in the context of genetics (Kinnear, 1983). It seems that students have difficulties in transferring the mathematical knowledge and insights from one context to another. The mathematical expressions, which are symbolic, cause the problems that students face (Bahar *et al*., 1999). Students indicated that in genetic crosses a lot of symbols are used and that they do not understand the crosses because they are not good in math. The problems students have with the mathematical nature are also due to the fact that the symbols are not used consistently by teachers and textbook writers (Bahar *et al*., 1999). Therefore, it is not surprising that Thomson & Stewart (1985) found that students often manipulate symbols and adjust algorithms without correct insight into the underlying genetics laws. The Punnett square is also often used routinely by students without considering the probabilistic nature of meiosis and genetics (Kinnear, 1983). The Punnett square model is a grid showing symbolic representation of gametes from parent organisms on the outside and combined symbols on the inside. The grid represents a statistical array of possible gametes and zygotes. Students have to pick ratios by either appearances (phenotype), or genetic makeup (genotype) out of the Punnett square, or have to answer probability questions concerning possibilities of appearance of a certain trait. One of the main problems is that students perceive ratios in genetics as deterministic (Collins & Stewart, 1989), which maybe due to the automatic use of the Punnett square model. They may think that ratios are fixed by frequent and rote use of Punnett squares in solving a problem (Longden, 1982). Cho *et al*. (1985) showed in their content analysis of the three main biology textbooks used in the United States of America,

that these textbooks do not mention the limitations of using the Punnett square in solving genetics problems, and that they do not relate Punnett squares to the biological processes and concepts like the random segregation of chromosomes. By placing emphasis on rote procedures it is likely that students think that ratios are fixed and perfect.

3. Cytological processes

Bahar *et al.* (1999) indicated that a main source of difficulties students experience with Mendelian genetics might be the difficulties in understanding mitosis and meiosis. Lewis *et al.* (2000a; 2000b) confirmed this in their study with 14-16 year old students. Students' understanding of cell division appeared to be limited, confused, and inconsistent. Students made little distinction between mitosis and meiosis, and had a poor understanding of the purpose, processes and products of cell division. Examples are the idea that genetic information is shared, but not copied at cell division, and the belief that the genetic information in a cell is determined by the type, function, or location of the cell (Lewis 2000a; 2000b). The sources of all these problems appear to be a lack of understanding of chromosomes, and of the relationship between chromosomes, genes and genetic information (Lewis *et al*., 1997; 2000; 2000a; 2000b).

So, students experience difficulties with cell division processes, in particular meiosis, which seems to originate from a lack of understanding of chromosomes. Research done is this area can be divided into students' misunderstandings about the *chromosome structure*, and a lack of understanding of aspects of the *process of meiosis* itself.

Stewart *et al*. (1989; 1990; 1994) reported on students' misunderstandings about the chromosome structure. In their study, 50 American high school students from grade 9-12, who all received instructions in meiosis, were asked to solve a mono- and dihybrid cross problem while thinking aloud. In these interview sessions students were asked to clarify their answers with drawings of the chromosome behaviour. They found that students used both correct and erroneous models (the one-, two- and four chromosome models) of chromosome-gene behaviour during meiosis to explain solutions to the problems (figure 3.1).

These alternative views of meiosis that students hold and use in solving traditional classroom genetics tasks, may lead to an underestimation of their knowledge or thinking ability, and to an overestimation of the genetics knowledge of other students, when only correct answers are taking into account (Stewart *et al*., 1990).

Moreover, the 'chromatide' and 'chromosome' concepts are often confusing. Students do not realise that those chromatids are identical, tightly connected to each other by the centromere. Brown (1990) also reported this inadequate concept of chromosome duplication into chromatids. Brown conducted a large-scale study with 614 A-level biology students, who had to construct a pair of homologous chromosomes during metaphase 1 with pipe-cleaners. Students did not know that sister chromatides carry the same allele(s), and consequently are identical.

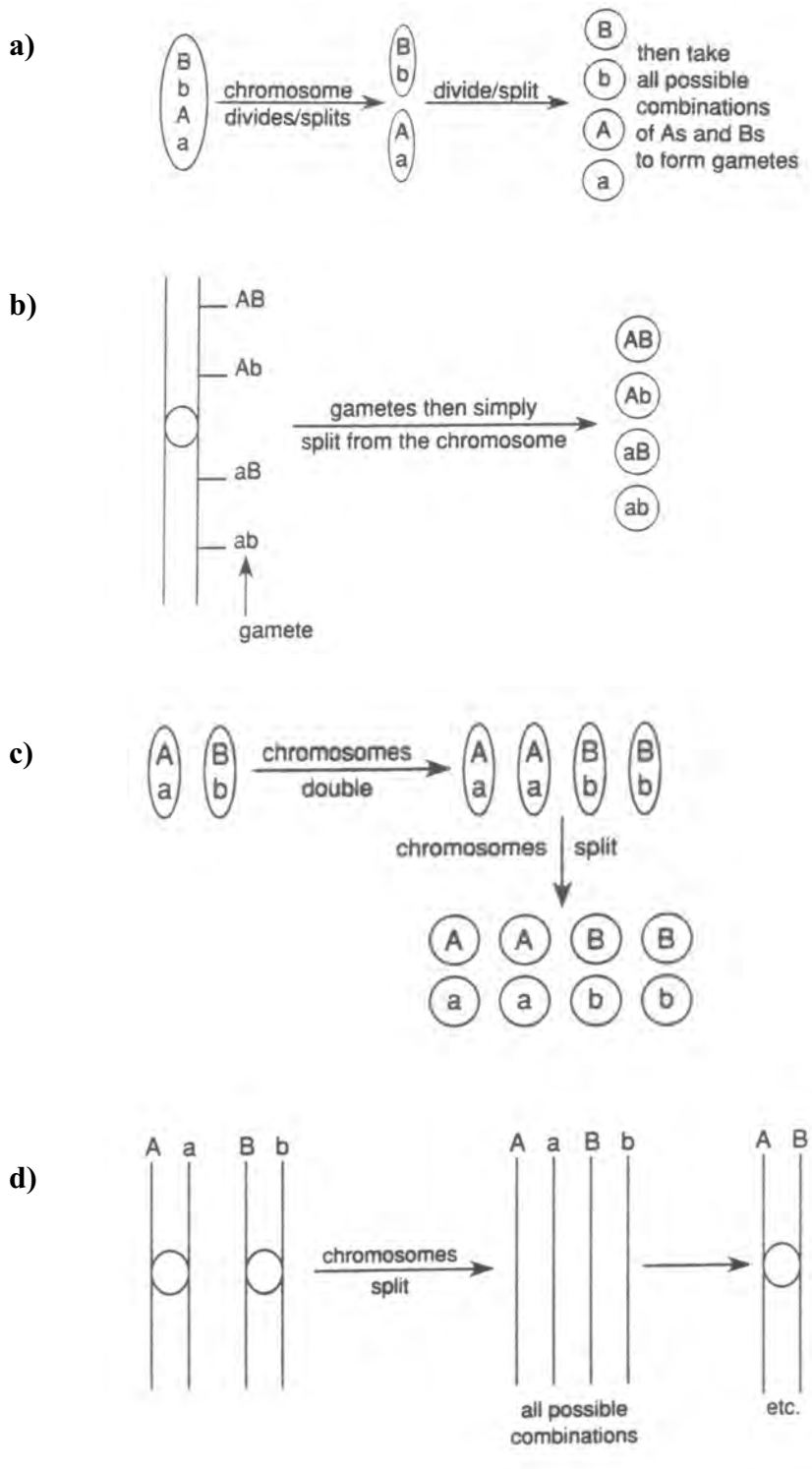


Figure 3.1 ***Examples of students' one (a,b) - and two (c,d)-chromosome models used to explain the chromosome-gene behaviour during meiosis.*** After: *Stewart et al. (1990) and Stewart & Hafner (1994)*.

Brown (1990) differentiated three types of misconceptions about alleles on the chromatids as shown in figure 3.2. Also the concept 'locus' was not clear to a lot of students. They labelled alleles at different positions on homologous chromosomes.

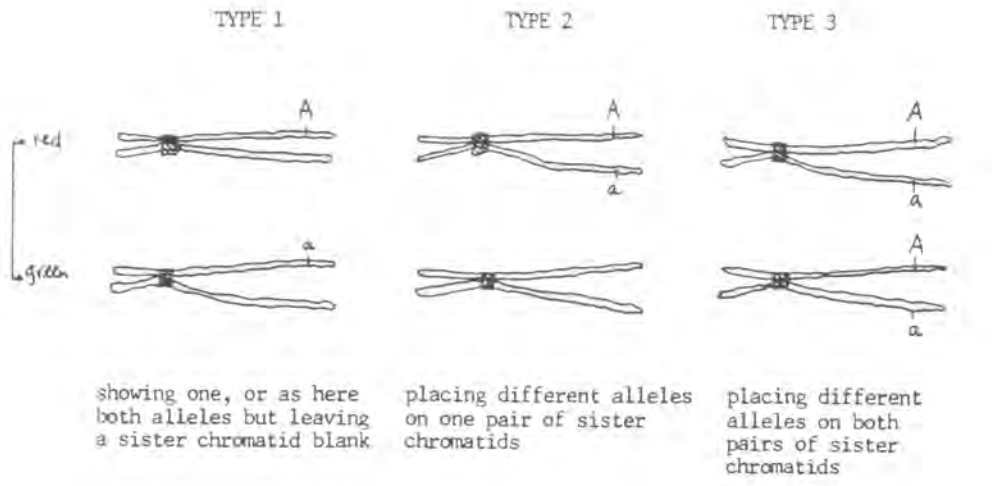


Figure 3.2 ***Misconceptions about alleles carried on sister chromatids;*** *from: Brown (1990).*

The work of Kindfield (1991; 1992; 93/94, 1994a; 1994b) focused on the difficulties different expert groups (university students and professors) had with meiosis. During an interview, the participants had to solve a problem of possible gamete formation in an eukaryotic organism. Kindfield also reported on chromosome misconceptions in these groups, like the confusion that the chromosome structure is a function of ploidy (Kindfield, 1991). In this misunderstanding students think that: 1) in haploid cells chromosomes always consist of double-stranded DNA molecules, 2) in diploid cells chromosomes always consist of two connected double-stranded DNA molecules, and 3) the two DNA-molecule chromosomes in diploid cells (or zygote) are not formed by replication, but by joining of two single-DNA-molecules, one of each parent (the formation-by- fertilisation misunderstanding) (figure 3.3).
Besides, Kindfield (1994a, 1994b) reported on misunderstandings about (parts of) the process of meiosis. The major problem is that students (and sometimes even experts) do not understand that meiosis consists of sub-processes and that each specific event occurs at one unique time. There are misunderstandings in the relative timing of replication, crossing-over, alignment and segregation. Longden (1982), Moll & Allen (1987) and Smith (1991) also reported on these misunderstandings about meiosis. In addition, Longden (1982) and Kindfield (1994) suggest that misconceptions could be attributed to the lapse of time between the introduction of meiosis and genetics in textbooks, and Kindfield (1994) indicates that textbook diagrammatic representations of chromosomes are often unclear and misleading.

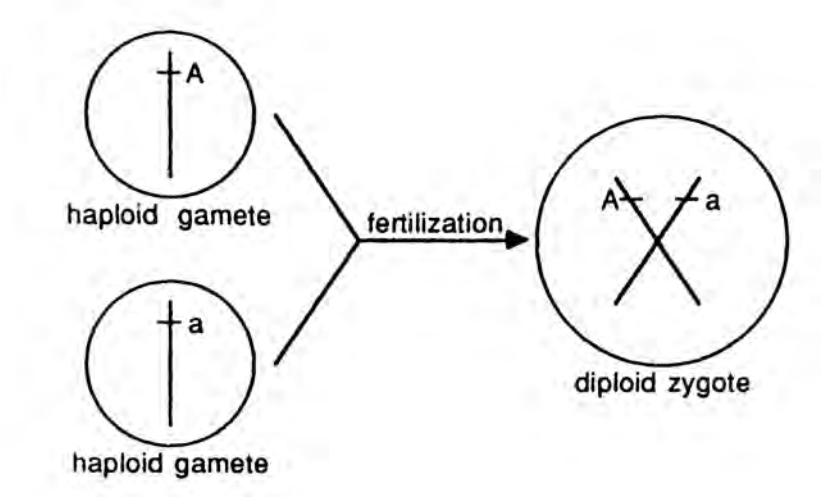


Figure 3.3 ***Formation by fertilisation mechanism of two-DNA-molecule chromosomes***. *Each haploid gamete contains single-DNA-molecule chromosomes, represented here by lines labelled with the A and a alleles respectively. The diploid zygote contains a two-DNA-molecule chromosome formed by joining of the A and a single-DNA-molecule chromosomes upon fertilisation*. After: Kindfield (1991).

Most of the textbooks investigated by Tolman (1982) and Cho *et al*. (1985), dealt with meiosis and (Mendelian) genetics in different chapters and they made no efforts to relate these two topics. Chromosomal division is discussed in meiosis, while allelic segregation is presented in Mendelian genetics. The sequence in which these topics are presented in biology textbooks could be the reason that students have difficulties in relating the concepts of meiosis and genetics (see also section *4*: abstract nature).

For the identified problems with the process of meiosis, and chromosome structure and behaviour various solutions have been proposed. Kindfield (1994) and Brown (1990) indicate that the process of meiosis and mitosis should be presented in the context of the cell cycle, to clarify the timing of duplication of chromosomes, but Bahar *et al*. (1999) warn against teaching the topics of meiosis and mitosis side by side, because it could reinforce the confusion between them. Lewis *et al*. (2000a) suggest to focus on the purpose of each type of cell division rather than on the process. Kinnear (1992) and Kindfield (1992, 1994) suggest the use of diagrams in helping students to construct and develop an adequate insight into the chromosome behaviour and structure during the process of meiosis. Cho *et al*. (1985) also emphasise the role of specific diagrammatic representations and suggest a psychological sequence of instruction: genetics/ meiosis/ chromosome theory.

Encapsulating, quite a lot suggestions have been made to diminish the difficulties that students have with meiosis. Although many of these suggestions are concrete and could be easily tested and implemented into school practice, this unfortunately remained undone. On the other hand, there are various practical activities described, like ‘Modelling mitosis & meiosis’ (Clark & Mathis, 2000) and ‘Role-playing

mitosis' (Wyn & Stegink, 2000), which illustrate these processes and make them concrete to students. Their suggestions are based on positive experiences with these practicals in the classroom, but they are not founded by empirical research data. One exception might be the 'Bajema strategy' described by Mertens & Walker (1992). In this strategy students need to draw the chromosomes with genes in four outline drawings of cells proceeding through the stages of mitosis and meiosis, and trace the sequence of events. The Bajema strategy was designed as a learning activity for students, but proved also to be useful as a diagnostic and predictive tool (Mertens & Walker, 1992). For students it was a means of concretising the relationship between chromosome and gene transmission in the process of mitosis and meiosis. For the teachers it was a tool to identify students' misconceptions of mitosis and meiosis, which can serve as the starting point for clarifying instruction. Furthermore, the Bajema strategy served as a predictor of students' success with future examinations of meiosis and Mendelian genetics in the introductory genetics course.

4. Abstract nature due to the sequencing of the biology curriculum

The difficulties in learning genetics are commonly associated with the relationship between meiosis and genetics and the sequence in which the topics have been taught. As already explained in section *3*, school textbooks are sources of misunderstandings. Cho *et al.* (1985) investigated the three most widely used biology school textbooks in America (Otto *et al*., 1981) and concluded that the conceptual organisation of these schoolbooks is inadequate. The three textbooks discussed meiosis before genetics, and treated the two as separate topics. Moreover, the topic of meiosis was isolated from that of heredity, and Mendelian genetics was discussed within the chapter heredity. Since meiosis deals with the separation of alleles during sexual reproduction and genetics concerns the tracing of alleles from parents to offspring, these two concepts should not be separated in the textbooks, but the relations between them should be made explicit (Tolman, 1982). Other authors (Longden, 1982; Kindfield, 1994) suggested that the difficulties students encounter in learning genetics are due to the delay between the introduction of meiosis and genetics in the textbooks. Tolman (1982) suggests a new sequence that flows from meiosis to genetics, while Ausubel *et al*., (1978) argue for a sequence which runs from genetics to meiosis and then to chromosome theory. Which sequence will be best is difficult to say beforehand. But it is important to notice that the difficulties students have in understanding the genetic relationships could be due to the delay and separation of topics (like cell division, life cycle, Mendelian genetics, and inheritance) in the curriculum by months or even years. In our view this fragmentation contributes to the abstract nature of genetics, because students have difficulties in relating these different genetics concepts. Schoolbooks (and teachers) often do not make these relationships explicit. This could contribute to students' difficulties in relating genetics tasks with concrete biological phenomena. Moreover, in solving genetic problems, students have to translate texts and pedigrees in diagrams, which is calling on symbolism and mathematical calculations (see section *2*), all at the same time. Students have difficulties in constructing a symbol key, for which they should be able to differentiate between related structures such as gene

and allele, and descriptors such as dominant/ recessive and homozygous/ heterozygous. Using upper case and lower case letters, subscripts and superscripts, and different combinations of letters and other symbols, can create confusion when students lack the understanding of how the symbols are related to the concepts of heterozygosity/ homozygosity and gene/allele (Thomson & Stewart, 1985). The symbolism and mathematical calculations make Mendelian genetics abstract and difficult for students, because they are often not able to relate these features to real biological phenomena, like the underlying process of meiosis. Automatic use of the Punnett square by students in solving genetics tasks (Kinnear, 1983; Collins and Stewart 1989), without meaningful insight into this model, only enhances the abstract (and 'symbolic') nature of genetics.

5. The complex nature of genetic: a macro-micro problem

The complex nature of genetics is another reason why genetics is difficult to learn and to teach (Bahar *et al.,* 1999; Collins & Stewart, 1989). The structure of the content knowledge of genetics is complex, and students have to use this complex knowledge in solving complex genetics tasks (Collins & Stewart, 1989). Genetics concepts refer to different levels of biological organisation, and students have difficulties with linking these different genetics concepts and processes with these different levels.

Several science education researchers noted that when concepts and processes of a subject belong simultaneously to different levels of organisation, students have difficulties in learning the subject (Lijnse *et al.*, 1990; Sequiera & Leite, 1990). Mind that the levels of organisation are appointed differently by researchers in the different science disciplines.

Marbach-Ad & Stavy (2000) who investigated students' cellular and molecular explanations of genetic phenomena, distinguished the macroscopic, microscopic and sub-microscopic level in genetics (biology). They suggested from their study, in which they investigated three relatively large populations of 9^{th} graders, 12^{th} graders and pre-service biology teachers, that students should first be exposed to various phenomena in human beings or higher organisms, in macro-terms only. So they suggest to start on the macro level, and when dealing with the micro-level and trying to link the macro- with the micro level, it would be better to deal with lower organisms.

Johnstone (1991) introduced a model, which distinguishes three levels of thought in chemistry education, the macro-, the micro- and the symbolic level. His macro-level refers to tangible and visible concepts, and the sub-micro to 'invisible' concepts, like 'compound' and 'elements'. In chemistry the elements are represented by symbols in reaction equations. He declared that in much teaching the three levels are mixed up and dealt with simultaneously and that teacher may be unaware of the demands being made on the students. He argues for teaching chemistry on the macro level only, instead of inflicting all three levels simultaneously on students. Moreover, Johnstone draws a comparison between his levels of thought in chemistry with those in physics and biology.

In a later study with Bahar *et al.* (1999) he applied the three level model to the subject of genetics. They argue that the complexity of genetics is connected with the

occurrence of ideas and concepts on these different levels of thought: the macro- (plant of animal), the micro- (cell), and the biochemical level (DNA). They explain that a lot of processes on the macro-level are elucidated at the sub-macro (micro) level (like genes and chromosomes), which are represented by symbols (e.g. Aa and //). With these symbols students have to calculate ratios and probabilities. Often they have to reason back from this level of representation to the macro-level, for instance when they have to determine the probability of a certain genotype and translate it into a phenotype answer. Bahar *et al*. (1999) suggest that in teaching practice, teachers should confine themselves to one level at a time. Students have to develop this thinking on the different levels of thought, gradually. It has to be noticed that Johnstone firstly differentiated three levels of thought instead of levels of biological organisation. In chemistry, the macro–micro division may be sufficient, because in general there is only distinction between compounds, molecules and elements. However, in biology there are more levels to be distinguished such as the 'supra-macro' level of populations and communities. Consequently, Johnstone's model would not be (completely) applicable to biology, in contrast with the 'level-matrix' introduced by Boersma & Thijssen (1991) and Boersma (1999). The 'level-matrix' consists of levels of biological organisation (vertically) and knowledge levels (horizontally), and is designed to develop subject matter sequences. A sequence starts in the cell of the matrix that is defined by the organismic organisational level and the first knowledge level. From there on it is prescribed to move horizontally (ascending or descending to a next level of biological organisation), or vertically (to a next knowledge level) to an adjacent cell. This procedure can be repeated as long as necessary. Each next step means descending to a lower organisational level, ascending to a higher organisational level, or moving to a next knowledge level.

Another suggestion made on how to deal with the complexity in biology, is the 'otension approach' described by Olsher (1999) (proposed by Millar). Olsher (1999) indicated that the biology curriculum in Israel refers to biological processes that take place in the cells of living organisms, and that students in the 7^{th}–9^{th} grade are expected to acquire some knowledge of these processes. These processes are usually taught from the domain of biochemistry, the level that cannot be perceived by the sensory system of students. So, learning the relationship between the macro- and micro-systems, by using concepts of the domain of biochemistry is not a basis for meaningful learning of new biological concepts and it tends to induce misconceptions (Dreyfus & Jungwirth, 1989; 1990). In his study Olsher tries out the 'otension' approach for teaching scientific principles, which means 'showing the theory in action'. The 'otension' assumption is, that showing interventions and their results would promote students asking meaningful questions about the biological processes that take place in the 'black-box', which is the micro-level. So, in this view students' questioning is therefore central to their learning of scientific concepts. The study showed that this was not easy to achieve, mainly because the micro-level and molecular 'actors' involved in the processes are unknown to the students.

The above discussed studies show that different researchers are reporting on the difficulties in relating concepts on the macro- and micro levels in science education. In genetics many concepts are on the micro- and sub-micro level and are beyond

senses, such as DNA, genes, and chromosomes. Students have little or no experience in constructing such concepts (Bahar *et al*., 1999; Johnstone, 1991). Maybe they know the definitions, or are able to solve pedigree problems or use Punnett squares by applying tricks, but often they have no real understanding of and insight into the related concepts. Marbach-Ad (2000) also showed that students may use concepts and terms from the micro level, like 'gene/DNA is encoded for a trait', but they were unable to explain the mechanisms and intermediate stages involved in the link. Students used for instance the correct genetic term in answering a question, but the additional interviews revealed that the students used a concept of 'gene' (micro level) as synonymous with 'trait' (macro level). So, using proper terms in answering genetic questions does not necessarily indicate that a student understands the scientific meaning of a term. This risk in misinterpretation of students' understanding of genetics has also been noticed by Stewart *et al.* (1990).

Summing up, science education researchers are well aware of the difficulties students experience with interrelating the macro-, micro and sub-micro level. Genetics is a complex subject to learn and to teach, because genetics concepts are linked to different levels of organisation, and students have difficulties in interrelating the genetic concepts and processes of these different levels. Almost all the above discussed studies advise to start education of a (science) topic on the concrete macro-level, i.e. the organismic level in biology. Moreover, the level-matrix of Boersma & Thijssen (1991) emphasise to ascend and descend from the organismic level to the next level of biological organisation in order to adequately structure the complex biological content.
But, as Bahar *et al*. (1999) stated "It will need time to develop experimental experience of the macro, careful control of vocabulary and concepts in the sub-micro and phased introduction of the symbolism", which indicates that there are no implemented solutions to the complex nature of genetics yet.

Conclusions

The reviewed literature on genetics education identified five major domain-specific difficulties, described in this section. It has to be noticed that these different problems that students and teachers perceive in learning and teaching genetics, are not isolated problems. These difficulties are in a way all related to one another and can reinforce the problems students' experience. Students face problems in representing genetics texts into schemes and symbols, and vice versa in reading schemes and symbols. Knowledge of the extensive genetic terminology is required for understanding a classical genetic problem. Moreover, they have to do mathematical calculations with those symbols in solving the problem, and to connect these probabilities with biological phenomena. The structuring of the biology curriculum in which the topic of meiosis is isolated from hereditary adds to the abstract character of genetics. Students have poor understanding of the genetic relationships, due to misunderstandings about the process of meiosis and the underlying chromosome behaviour, and encounter difficulties in linking the different concepts of the macro-, micro and sub-micro level.

The described domain-related difficulties identified by research into genetics education are often well defined and several suggestions have been made to solve these difficulties. Unfortunately, these implications for educational practice are rather vague in character. Educational researchers often refrain from testing the recommended solutions in school practice. Research is mainly carried out in laboratory-settings instead of classroom-settings, and development and field-testing of curriculum materials unfortunately remains undone.

3.3 Biology teachers' perceptions of learning difficulties in genetics

Reviewing the literature on genetics education revealed several problems in learning and teaching genetics (section 3.2), and also revealed that there is a gap between theory and practice. Moreover, most of the reviewed investigations into genetics education have been carried out in the United States and United Kingdom. Besides a difference in language, the school systems in these countries differ from that in The Netherlands. Little information is available about the problems students and teachers face in Dutch upper-secondary schools. Nevertheless, we expected that the teaching and learning problems in genetics would not differ that much. To verify this expectation, and to explore the Dutch context, focus group interviews with biology teachers were arranged. The identification of the main problems in Dutch upper-secondary school should enable us to plan further research activities, aimed at improvement of genetics education.

The focus group interviews

The focus group method was used to identify problems that Dutch biology teachers encounter in genetics education. The focus group interview or discussion is a qualitative research technique for gathering in-depth data about perceptions, feelings and opinions of small groups of participants on a given problem, experience or other phenomenon (Basch, 1987; Assema *et al*., 1992). The advantage of this method is that it is interactive; group interactions may help to gain quantitatively and qualitatively richer data. This small-scale inquiry is not meant to generalise.
A letter of invitation was sent to 63 secondary school biology teachers who were participating in our teacher education network. They were phoned to inquire whether or not they were willing to participate in a focus group interview. 24 biology teachers were willing to do so, and finally 19 participated. Upon enrolment, three groups were formed, consisting of 6 or 7 biology teachers each with substantial classroom experience. Each two-hour session was audio-taped and transcribed. These records, along with the moderator's notes, provided the raw data used for analysis.
The overall goal of the discussion was made clear by the moderator by presenting the research question, i.e. which learning and teaching problems in genetics do Dutch biology teachers identify, and how do they explain and cope with these problems. Since some group members might dominate, the session started by giving each participant an opportunity to express the problems he or she was encountering

in genetics education. The first hour of the discussion focused on inventory of problems the participants perceived. In the second part, emphasis was on the explanations and solutions they could suggest for these problems. In co-operation with the participants the problems, explanations and solutions were defined and noted on the black board.
The problems that were collectively registered during the three sessions functioned as the first global categorisation for analysis, and were depicted in a matrix. The audio-tapes were transcribed verbatim. By close reading of the transcripts a list of key ideas, words, phrases and concerns was compiled and compared with the registered difficulties. Next, participants' ideas and quotes were classified and depicted in the matrix in accordance with the depicted problem categories. In case of overlap in problem definitions in the three different group sessions, the categories could be thickened and reduced. Parts of the transcripts and analysis matrix were presented to a second analyser. In case of differences in interpretation and or categorisation, agreed upon decisions were made after discussion. Finally, 10 meaningful problem categories could be extracted (table 3.1) (Knippels *et al*., 2000). The labels of the categories refer to relevant characteristics of subject matter and/or students, to which the teachers attributed the problems they identified. An overview of the results and problem categories was sent to the participants to inform them, and in order to verify if the researchers' interpretation covered their contribution to the group discussion (member check). The 10 problem categories appeared to be adequate and remained unchanged (table 3.1).

Conclusions

The aim of this investigation was to determine the main difficulties in genetics education as perceived by the Dutch biology teachers, and to compare these with the difficulties identified by the international literature. These focus group interviews confirm our expectation that learning difficulties in genetics, identified in the international literature, are also being perceived by Dutch biology teachers. No striking new difficulties were found; the categories of problems (table 3.1) are more or less comparable with those identified in the literature (section 3.2), i.e. the domain-specific vocabulary and terminology (1); the mathematical content of genetics tasks (2); the cytological processes (3); the abstract nature due to sequencing the biology curriculum (4); the complex nature of genetics (5).
The focus group interviews added some specification to these five categories as well as some practical problems from the teachers' view, i.e. category 4 (Image), 5 (Examination) and 10 (Differences between students) (table 3.1). These practical difficulties have to be taken into account in designing an adequate learning and teaching strategy. The abstract and complex nature of genetics, the terminology, and cytological processes (9 'Cell division') are described in both cases. Moreover, some labels are named differently but the essence of the problems is comparable. For example, 'probabilistic reasoning' (3) in the focus group interviews and 'mathematical content of genetics tasks' (2) in the literature review, cover the same problems. As well as category 7, in table 3.1 that deals with representation of genetic knowledge in symbols, has been discussed as part of the 'abstract nature'-problem in the literature review.

Table 3.1 ***The main problems in learning and teaching genetics perceived by Dutch upper- secondary school biology teachers (n= 19) in random order .***

Category	Description
1. Abstract nature	Alienation from real biological phenomena due to the disconnection of inheritance, sexual reproduction in general, and meiosis in particular.
2. Complexity	Inheritance has to do with all levels of biological organisation and adequate understanding of genetics requires back-and-forward thinking between molecular, cellular, organism, and population level. Simplification of inheritance easily leads to conceptual problems.
3. Probabilistic reasoning	Students who perform poorly in mathematics often also do so when solving genetic problems; see also differences between students (10).
4. Image	Inheritance may be perceived as a difficult topic in biology, resulting in poor motivation or giving up behaviour.
5. Examination	Mendelian genetics is just a small part of the final exam, consequently no much time is allotted to this difficult subject, although spending some extra time would be obvious. Current practice is to teach and learn tricks instead of insightful problem-solving behaviour.
6. Terminology	Genetics is rich in terminology, but not all terms are necessary for adequate understanding. Furthermore, students are unwilling to memorise relevant terms; see also image (4). In addition, teachers and authors of curriculum materials do not always use terms consistently and explicitly. Inadequate translations of terms from English into Dutch (e.g. 'sex-linked') and politically correct language (e.g. 'genetic modification' instead of 'genetic manipulation') can also result in misunderstanding.
7. Pedigrees, Punnett-square diagrams & symbolising	Students face problems in representing and reading genetic knowledge in(to) schemes and symbols; see also problem-solving (8). These problems may increase in connection with the abstract nature of genetics (1) and its richness in terminology (6).
8. Problem-solving	Students not only have difficulties with the representation of problems (7), but they also lack problem-solving and reading skills.
9. Cell division	Students have an inadequate understanding of the process of meiosis, and do not always understand the differences between mitosis and meiosis. Consequently, students acquire a poor conceptual basis of genetics.
10. Differences between students	Relevant prior knowledge and cognitive maturity is required for an adequate understanding of genetics. Students may differ in these respects; see also image (4). Furthermore, differences may also be related to opting for or out chemistry and mathematics courses.

So, the difficulties defined in the focus group interviews are more subdivided, but the essential difficulties defined by both sources are the same.
However, it has to be noticed that the focus group interviews answered only part of the research question, i.e. Dutch biology teachers' perceptions of learning problems in genetics. Comparison of our findings with those reported in the literature may be biased due to the data sources used and the nature of the data connected with them. For example, teachers' perceptions of students' problem-solving behaviour, extracted from focus group interviews cannot just be equated with findings from observation studies. For that reason the focus group interviews will be completed with content analysis of schoolbooks and classroom observations. Nevertheless, at this point, the main learning and teaching problems reported in the literature seem to be verified by these Dutch biology teachers.
The second aim of these focus group interviews (and literature review) was to identify key issues to address in this PhD project. We decided to focus further research activities on the *abstract and complex nature of genetics* (table 3.1, category 1 and 2, section 3.2 problem 4 and 5). The sequence of subject matter, in particular the disconnection with the process of meiosis, is likely the underlying key issue, which needs further study. In this context the relevance of genetics to the life sciences and its positioning within the biology curriculum has to be reflected and elaborated on. We are not saying that the other categories of problems are less important, or will not be dealt with at all, but the focus will be on the abstract and complex nature that goes to the heart of genetics itself. Other categories refer to more general learning problems in biology (for example *representation and symbolising* and *problem solving*). Furthermore, in September 1997 a project started at our Centre aimed at the tuning of subject matter content of mathematics, biology, chemistry and physics and co-operative teaching of common topics (Van der Valk *et al*., 1998). In this project mathematics and biology focus on *probabilistic reasoning* in the context of genetics.
As already postulated in section 3.2, in the educational research literature almost no attention is being paid to the science *content*. Most educational research in science does not aim at developing content specific educational (didactical) knowledge, but aims to contribute to general educational theories and skills (Lijnse, 2000; Fensham, 2001). Focusing on the abstract and complex nature of genetics means taking a domain-specific approach. Because most of the problem categories defined in table 3.1 are more or less interrelated, we choose for the overall problems. Distinguishing the different levels of biological organisation will help to sequence the genetics content and concepts so as to cope with the complex nature.

3.4 Explorative case study

The focus group interviews confirmed our expectation that the learning difficulties concerning genetics in the Dutch school systems are comparable to the problems identified in the international literature on genetics education (section 3.3). Moreover, we decided to focus further research activities on the abstract and complex nature of genetics. The focus group interviews identified the educational

difficulties from the biology teachers' perspective, which is, however, only one perspective. In order to gain more insight into the students' perspective, to gather more in-depth data about the abstract and complex nature of genetics, and to try out some ideas for an educational strategy, an explorative case study was initiated.

A traditional genetics course

In the explorative case study thirteen lessons of a traditional senior general upper-secondary (5H, table 2.1) genetics course were observed and audio-taped, between October 1999 and December 1999. The biology teacher, who also participated in a focus group discussion (section 3.3), had 36 years of teaching experience in upper-secondary biology classes. The open interview method was used to clarify the rationale of his genetics education practice. Furthermore, the 22 students of this 5H class were asked to keep a personal notebook in which they had to reflect on their learning outcomes, perceived difficulties, and questions that had come into their mind. In addition, face to face interviews were conducted and audio-taped, to gather more in-depth information on their observed and reported learning difficulties and to probe their genetic reasoning skills.

In an open face to face interview the biology teacher was asked about his ideas on the complex and abstract nature of genetics, and the rationale of his genetics education practice. He answered: *'My approach is, to start with a concrete complex genetic task, and solve this step by step in the lessons to come. The complex example is challenging for the students, and they will experience that they can not solve this problem yet. Subsequently we are going to solve this problem in different parts. A lot of these steps are repetition, and I hope that in the end all these different little steps will lead them to an insight.'*

This genetics course was not the first acquaintance for the students with genetics. A basic genetics course was already taught in the second year of lower secondary education. Furthermore, the processes of cell division (mitosis and meiosis) were taught in the previous year.

The genetics lessons started with an example of a cross with guinea pigs, with black long hair, and white short hair. The parental and F1 generation was discussed, and terms as phenotype, genotype, homozygote, heterozygote, dominant and recessive were repeated. Also, the representation of alleles in capital and lower case characters was discussed. In the second lesson the F2 generation and the use of the Punnett square was demonstrated by means of the guinea pig example. The main themes of the following lessons (3-13) were:

3. lethal genes and blood type (intermediate alleles)
4. repetition and independent and dependent hereditary
5. exercising (monohybrid) genetics cross problems
6. dihybrid crosses
7. exercising mono- and dihybrid cross problems in groups
8. human genetics: video on hereditary diseases in a family
9. sex chromosomes
10. pedigrees, representation and colour-blindness
11. exercising practice pedigree problems
12. pedigrees

13. exercising pedigree and genetic cross problems

So, the lessons focused on solving genetics tasks, in particular mono- and dihybrid crosses, which is a general approach in traditional upper-secondary biology education. Students had to solve multiple genetics problems and predict chances of traits in the next generation. The personal logbooks of the students and the questions asked by the students during the lessons showed that they at first were struggling with the multiple genetics terms and had difficulties in solving the genetics problems. It seemed that they learned by rehearsing a lot of genetics problems and often by means of trial and error, but that they did not really grasp the genetics concepts. They repeated until they 'got it', like the next quotation of Bianca's[1] logbook shows:

> Genetics is difficult to me. When you get a genetics problem I always start with writing down the information given in a task. After that it is often like 'And what to do now?' Then I often consulted other students in my class (or the teacher), and together we could solve the problem, because everyone could contribute a small part in solving the problem. If I then looked at the answer I thought 'of course, actually it's logical'. My only problem was that I often didn't know how to continue. For the rest I understood everything.

The answer is 'logical' to her, but the problem is that she has difficulties to come to this answer independently. Bianca's quotations are contradictory. It seems that she has no real understanding of the Mendelian genetics task. She wrote down the information given in a task, but did not know what to do with this information. Consequently, it seems a trial and error approach, without connecting biological phenomena with information (and symbols) in the genetics task. This difficulty with connecting real biological phenomena to genetics tasks and crosses is also illustrated by the next quotation from Susan's personal logbook. She did not understand what exactly is depicted in a Punnett square.

> I have discovered that genetics is really difficult to understand. […]
> It is not clear to me how you exactly build up a Punnett square. I don't know how many possibilities you can depict horizontally and how many vertically in order to cross.

Susan stated that she did not know how many possibilities you can depict in the Punnett square. Besides, she did not express *what* is depicted horizontally and vertically. It seems that Susan did not realise that the possible gametes from the parents concerning the trait under consideration are depicted in the Punnett square. When students do not see the relationship with the *preceding process of meiosis*, resulting in the formation of gametes, the Punnett square becomes a fixed diagram and tool. Consequently, it is logical that they do not now 'how many possibilities' they can depict because they do not know 'what' (i.e. gametes) is depicted and by means of what process (i.e. meiosis) it is formed. However, it was observed that the teacher did mention the preceding cell division process meiosis in his explanation of a genetics cross problem. Evidently, telling the relationship is not sufficient.

The observations of the genetics lessons and the difficulties expressed in the students' personal logbooks, confirmed the problems with the abstract and complex

[1] All students are allotted fictive names.

nature of genetics in classroom practice. Most students lack a meaningful insight into genetics, e.g. they use algorithms to solve genetics tasks or do so by trial and error. As a consequence they have difficulties in explaining for instance, why their answers to genetics tasks were correct or incorrect, or how some hereditary phenomena will occur. In this stage of the study it became clear that the introduction to genetics is crucial. Genetics education should not primarily focus on solving genetics tasks, but should start with concrete features and emphasise the basics or main lines in inheritance. The main problem with the abstract and complex nature is that students can not see the relationships between the genetics concepts on the different levels of biological organisation. In particular the relationship between sexual reproduction and inheritance, in which the crucial process of meiosis is embedded. Instead of exercising a lot of genetic crosses, we prefer to emphasise the main lines, and reasoning skills. In order to help students to understand and to discover these relationships by themselves, an 'active' learning approach is needed (section 1.3), because only telling these relationships showed not to be sufficient.
The relationship between (sexual) reproduction, including meiosis, and inheritance, is one main line: the germ cell line in a life cycle. The second line is the somatic cell line, which includes the concept that all cells of an organism have the same chromosomes or genetic information, due to mitosis. These two main lines may be helpful in defining the biological content of the genetics course.
In order to find out to what extent students are able to distinguish these two main lines and to relate the genetics concepts of these main lines, they were interviewed about it. In addition, we were interested at what point students get stuck in their reasoning pattern, and what ideas or misunderstandings make them to stagnate. This could help us in designing an adequate learning and teaching strategy for genetics.

Students' interviews

The interview design

In the second part of the genetics course six students (4 girls and 2 boys, age 16-17) of the 5H class were interviewed to probe their genetic reasoning skills and to get more insight into their difficulties with genetics. Moreover, these interviews were used to try out some ideas for learning activities and their sequencing in a learning and teaching strategy for genetics.
At the beginning of each interview, taking 50 minutes, the students were told that the interview would be a joint enterprise in reasoning about how genetic information is passed on to next generations, and how genetic information is passed on within our bodies. To create an open atmosphere, it was emphasised that there were no 'wrong' answers. A sheet with illustrations of a couple, a child of the couple and a grandchild of the parents, was shown (figure 3.5). During the interview they could point at the specific person they were talking about and could write and draw on this sheet (see figure 3.5), to support their answers and reasoning patterns.
The two major reasoning lines probed during these interviews, were the somatic cell line and the germ cell line within a life cycle. It was probed whether students could distinguish between them, and were able to explain and reason on the differences

between the two important lines in inheritance. The open interview started with the question: *'Do you think that the offspring will be affected when a mutation occurs a) in the genetic material of a somatic cell, for instance a colon cell, or muscular cell, b) in the genetic material of a gamete?'* Subsequently, the interviewer only invited the students to explain their argumentation in more detail, or asked questions to encourage them when they got stuck.

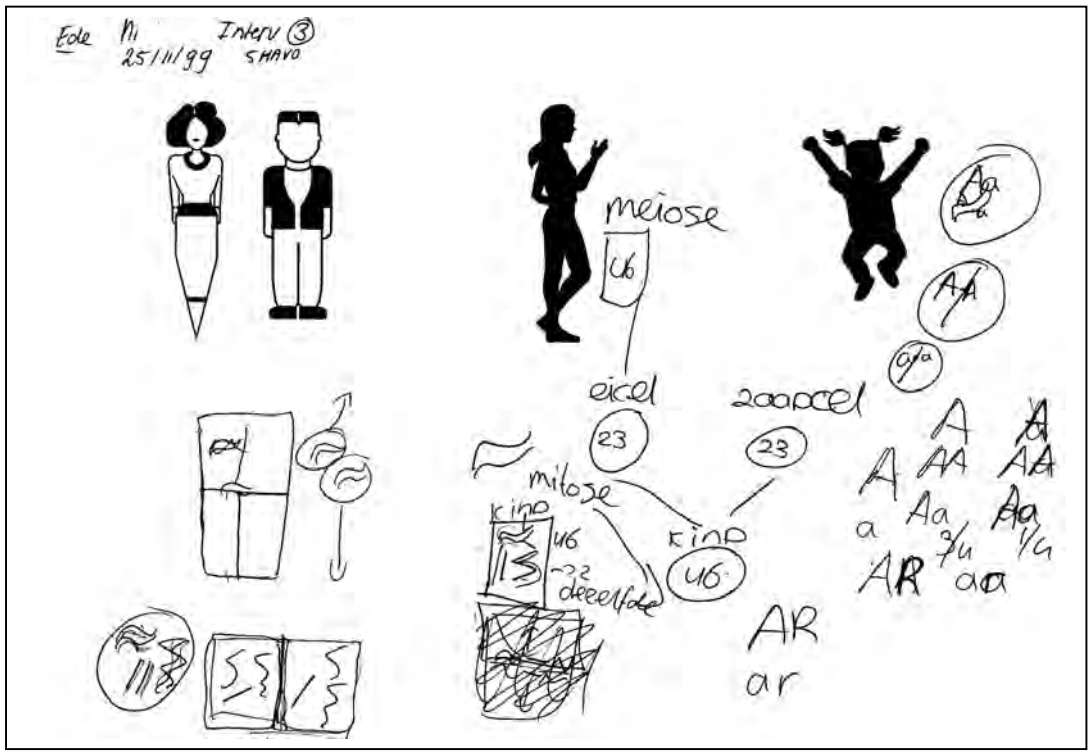


Figure 3.5 ***Example of the sheet with illustrations used during the interviews, and the drawing and notes made by a student (Nellie) during the interview.***

The correct answer to the question runs as follows:

a) *In* a body all cells contain exactly the same genetic information, because they are copies of the first cell (zygote) you originated from. The cell division process responsible for that is mitosis. So, all the cells in your body are genetically the same (except gametes), i.e. contain exactly the same chromosomes. So, there is *unity*.

Depending on the apparent understanding of the students, a next step to cell specialisation could be made. How is it possible that cells in your body differ in form and function, although they contain the same chromosomes? The explanation is that different parts of the chromosomes (DNA) are activated in different cells.

b) The germ line includes the concept of generations; parents pass on genetic information to their offspring. Half of the genetic information of the father and half of the genetic information of the mother (i.e. one chromosome of each homologue pair), is passed on through their gametes, to the next generation. Meiosis is the cell division process resulting in gametes. Subsequently, the merge of gametes provides a new unique genetic combination in the offspring. So, the germ line is responsible for genetic (and biological) *diversity*. Gametes and the preceding process of meiosis are the crucial link between generations.

In the last part of the interview, students were asked what they thought to be the connection between what had been discussed in this interview, and what had been

taught during the genetics lessons, especially the genetic crosses.
The interviews were audio-taped. The audio-tapes were transcribed and analysed by close reading of the protocols, and highlighting the genetics-reasoning patterns of the students.

Interview outcomes

The most salient results were, that students' first response to the starting question was that there is indeed a difference in effect between a mutation in the genetic material of a gamete or a mutation in the genetic material of a colon cell; gametes are involved in the process of sexual reproduction, and therefore a change in the genetic material of a gamete could effect the offspring. A colon cell has nothing to do with sexual reproduction, and therefore does not have impact on the offspring, but could have an impact on the individual in which the mutation occurred. The next quotation of a student's answer to the starting question in the interview will show this:

Eva: Yes that makes a difference. Because in a colon cell, uh an egg cell when it merges, that will be passed on to the next generation. And the colon cell, well that one you will never pass on to the next generation, that one you just keep yourself. And that can give you some trouble, when a mutation occurs in it, but not the offspring. That makes a difference.

Most students were well aware that all somatic cells in a person contain the same genetic information, and that they are formed by a cell division process that copies the genetic information (chromosomes). However, all six students experienced difficulties in explaining the germ cell line. They were well aware that both parents pass on genetic information to their offspring, but there was confusion about what exactly is passed on, and what the relationship is between the process and products of meiosis. The fragment of the interview with Paula illustrates her confusion on the two cell division processes, because she never really linked them to their purpose and position in the life cycle.

(R is researcher)

R: Would there also be cells without chromosomes?

Paula: No I don't think so, I don't know.

R: How do those cells originate in your body?

Paula: By division. Mitosis, meiosis, one of those two I think.

R: Yes, those are indeed two important processes, mitosis and meiosis. Can you indicate the most important difference between the two?

Paula: Yeah, no! That is what I'm wondering each time, what actually the difference is. I know we learnt both last year, and then I knew it. But I have really forgotten it. I was thinking about this yesterday in class, I didn't know the difference. I actually don't know… yes the meiosis is the reduction division or something like that, I don't know.
[…]

Paula: And this is with reproduction cells and the other with normal cells. I don't know it exactly I just guess.

R: Well it doesn't matter we will try to solve the problem together. When the meiosis is for reproduction cells and the mitosis for other cells as you say, what is the difference between those two? Why should there be two cell division processes, what could be the function?

Paula: Yeah that is why, I don't know, I 'm guessing reproduction cells and other cells.

R: Well that is correct, the one has to do with reproduction cells and the other with the other cells in your body. When we can find out what the difference is between reproduction cells

and body cells, than we can also reason why there are two different cell division processes.
[…]

Paula: Well, father gives 23 chromosomes, so that makes me doubting. He does not give uhm, he has 46, but he doesn't give all the 46. It is only a part.

R: You say he gives 23 chromosomes?

Paula: Isn't it? It is 46 isn't it, 23 of both.
[…]

R: 23 chromosomes? And which 23 are that [*pointing at her drawing*] how does he get 23 chromosomes?

Paula: Well…I don't know. That is something like you have crammed into your head, and why I don't know.

Moreover, students had difficulties with the chromosome concept and especially with homologue chromosomes. They were either not aware of the fact that there are pairs of chromosomes, or they thought that homologue chromosomes were identical. In particular, many students held the idea that homologue chromosomes are identical which accounted for a lot of confusion. As a consequence they thought that all the egg cells or sperm cells of an individual could be genetically identical. A quotation from the interview with Nellie and a quotation from the interview with Eva will show this:

(R is researcher)

R: But how is the egg cell formed? How did mother receive her genetic material?

Nellie: They come from her parents…. She has 23 pairs. Half from your mother and half from your father, 46 chromosomes in total.

R: Yes. And now she is forming egg cells.

Nellie: Oh yes of course, if she makes an egg cell…wait a minute…then she has copied one. Then half of that [*referring to the chromosomes*] goes to this one and half to that one. Well, and then …uh eventually you have two of the same.

R: So, you have two exactly the same egg cells?

Nellie: Yes, because they have replicated themselves, so you just have two that are the same.

(R is researcher)

Eva: In normal cell division, they must always be exactly the same, those cells after the division. And in gametes, yes, gametes too stay always the same of course, but they will not, not uh exist of two pairs.

R: And does it matter if you got this one of a pair in the cell or that one? [*Pointing at her drawing of a cell with pairs of chromosomes*]

Eva: Well! One site of the pair is in the female site and the other site is in the male site. But if it matters which one, whether the left site or the right site, so to speak, is in the male or the female doesn't matter. I don't think so.

R: Ok, but we were already talking about what is in you.

Eva: Yes that's right.

R: And then indeed one is from the woman and one from the man. One originated from your father and one from your mother. But, when your mother makes an egg cell.

Eva: Yes

R: Then these are two chromosomes from your mother?

Eva: Yes. Yes ok!

R: And of these two, she gives one…

Eva: Away. No, I don't think it matters. No, I can't imagine. Then I have never read that, or learnt it or noticed it.

R: Ok, so these two are the same?

Eva: Yes, they form a pair together.

When students got stuck in this idea of identical homologue chromosomes, the interviewer asked them how they thought their parents got their genetic information. Or asked them about their brothers or sisters: 'Do all siblings have exactly the same genetic information?' This question that refers to the concrete organismic level and their real life experiences, made them realise that there was something wrong in their reasoning pattern, and that their parents could not make identical gametes. The continuation of the interview part above with Eva shows this:

R: Ok, you say those two are the same. [*Pointing at a homologue chromosome pair in her drawing*]
Eva: Yes, I think that they will be the same. If, yes, I just said that it doesn't matter which one, which one comes in the egg cell. So, then I think that they will have to be the same. Otherwise it would have mattered.
R: Yes. But when they are the same, I don't know, do you have a brother or a sister?
Eva: Yes! A younger brother and sister.
R: A brother and sister, if you verify, we are going to reason back. So, for you, your father and mother have brought a sperm cell and a egg cell together and also for your brother and sister.
Eva: Yes.
R: So, did they get the same information?
Eva: Oh yes! That is also something! No, you will not receive the same information. Yes, I'm thinking, they have to be different.

Other students did not know that gametes are formed in the process of meiosis, or that due to this cell division process the number of chromosomes will be halved. Consequently, their zygotes had double chromosome numbers. Some students solved this problem by dividing the zygote into two cells with each half the chromosome number.
The genetics terminology and symbols often confused students. The fact that students use the wrong terms for certain genetics concepts, makes it difficult to interpret what they intend to say or what they really understand. In the next interview part, Irene draws lines in a cell to support her explanation. The interviewer asked her what she meant with those lines:

(R is researcher)
R: Ok, you say one line, and what does that line represent?
Irene: No, this [*she points at the line*] is where the chromosomes are situated, on this line.
R: Yes, and what is the line?
Irene: Oh yeah, what was it? …I don't know it anymore. This is the nucleus and on this is your DNA, and on that are your chromosomes, like brown eyes and blue eyes, or whatever? In this cell are two lines, and in this cell are also two lines [*she is talking about an egg cell and sperm cell*], they come together and become, one line of these and one line of the other …uh.
[….]
R: And on these lines are the 'chromosomes'?
Irene: Yes, your traits are on that.
R: Ok, so on the lines are your traits. I think you just confuse some terms.

Irene seems to confuse the term 'chromosome' with 'gene'. Moreover, she mixes up the terms DNA, chromosomes and traits: '*on this* (the line) *is your DNA, and on that are your chromosomes; your traits are on that'*. This can make the conversation confusing when you are not aware of the fact that she means something different

with this term. Also in a class situation, or a written test, this could mean that the teacher thinks she does not understand it at all, but in fact she just uses the wrong term.
Moreover, students had difficulties in relating the process of meiosis with the content of the genetics lessons. During the genetics course the mono- and dihybrid crosses were dealt with and the students had to solve genetics problems. In the interviews most students did not realise, or were unable to explain, the relationship between meiosis and the representation of a monohybrid crossing in a Punnett square. Some students literally said, *'I can't remember much about meiosis, because it was one year ago that the subject was taught'*, although they used this process implicitly every time they had to solve a monohybrid cross. Moreover, the teacher explicitly mentioned the process of meiosis when explaining a classical genetic cross, and draw gametes on the blackboard. Apparently, only telling this connection does not make that students see and understand the relationship between meiosis and inheritance. Therefore, in developing a new educational approach for genetics, it is important that students should explore the relationships themselves in order to get an adequate insight into genetics.
So, most students were unable to transfer knowledge from one situation to another on their own, implicating that they do not have a meaningful understanding of the genetics concepts, yet. In solving genetics tasks they mostly apply algorithms without a real insight into the related biological processes. Their knowledge seems to be linked to a certain situation or kind of question asked. The next quotation from the interview with Nellie illustrates this. We were talking about genetic crosses, and she was asked to clarify what she had depicted in the Punnett square she drew.

(R is researcher)
Nellie: This is a gene from mother, this is a gene from father, gene from mother, gene from father…uh. No, that is not possible…since there is two times the gene of mother in it… well yeah! I really make something out of it!
R: No, it doesn't matter, it is difficult when you have to verbalise what you are doing.
Nellie: I am always just doing it, you don't think much about it, about what you are doing.
[…]
You know how you have to write it down, but what exactly everything is… what is what?

Conclusions

The open interviews showed that a lot of these students knew facts about, for instance, mitosis or meiosis, but when they had to use these from the reproductive point of view, they were unable to integrate them meaningfully.
Nevertheless, it turned out that during these interviews most students were able to find out the connections and relationships themselves, albeit with some help. When their thinking aloud process stagnated, the interviewer asked questions that helped them on the way. When students got confused about chromosome numbers in a gamete or zygote, or whether homologue chromosomes were identical or not, the hint about the origin of these chromosomes was effective. Asking how they thought the parents got their chromosomes, so hinting about the relationship between the cells and the parents. Making again the connection with the individuals, the concrete organismic level, was successful. Also, visualising the chromosomes and cells students were talking about, by making drawings on a paper helped them to clarify

their reasoning pattern and to see what they were doing wrong or did not understand. So, the second goal of these interviews, i.e. to try out ideas for learning activities seems to be attained. These guided activities in the interview focused on connecting processes, in particular meiosis and mitosis, and concepts of the germ cell line and the somatic cell line in a life cycle. We saw that most students had difficulties with the germ cell line, and in particular in positioning the process of meiosis, and in understanding the purpose and products of meiosis. The somatic cell line was quite clear to most students. They knew that the cell division process copies the genetic information, and that somatic cells are not involved in the sexual reproduction process. By emphasising the somatic cell line and the germ cell line in the life cycle, these students were helped to connect the processes and concepts of these two main lines in the context of inheritance. Students themselves noticed that they gained more insight during the interview. At the end of the interview, Paula realised that until then she just reproduced what had been taught in class, but she had no real understanding of what she was doing or what had been taught.

Paula: Yes, I think it is much clearer now. At least, for me it has become clearer. I did it all, but as a matter of fact more like 'this is how you have to do it, just cram it into your head that this is how you do it', than really saying, 'this is what I'm talking about'.

We may conclude that focusing on the germ cell line and somatic cell line in a life cycle seems to be a promising approach, because students have to apply their knowledge and clarify their genetics concepts in more detail in a new situation. This approach made students realise and adjust their own misunderstandings in an active way. In a class situation the guiding role of the interviewer could be replaced by the teacher or built into the design of a learning activity. Moreover, this approach could be an adequate method for the teacher to signal misunderstandings among the students.

Students' interviews before a genetics course

The approach used in the open interviews with six students that attended the traditional genetics course (previous section) seemed to be fruitful and could be converted into an adequate learning activity. But what about students, who did not receive this genetics course yet? Could they spontaneously use their prior knowledge to connect hereditary phenomena and genetics concepts in the contexts of the somatic and the germ cell line? For that reason, we extended the interviews to six students from a secondary pre-university education (4V, table 2.1) class of the same school. These students only had been taught a basic introduction to genetics in lower-secondary biology class (2V), next to lessons about sexual reproduction and cell division, i.e. mitosis and meiosis. The students were between 15 and 16 years old. Moreover, these interviews could help to get insight into students' notions of heredity and into their vocabularies. These insights could be useful in designing an adequate introduction for the strategy and scenario of the first case study.
At the beginning of each 50-minutes interview, the students were told the purpose was to see if we could reason together on the topic of heredity. They were told that the interviewer knew that they had not yet discussed that topic in biology class. It

was emphasised that it was not about 'good or wrong' answers.
These interviews started with the question: '*How do you imagine inheritance, and what do you think hereditary traits are?'* After discussing some examples of traits and their possible heritable nature, focus was on how they thought genetic traits are passed on to a next generation. The interviewer was rather distant in the conversation and mainly asked for clarification or substantiation, or asked questions that could be helpful to students when they get stuck.
The interviews were audio-taped, and the audio-tapes were transcribed. The transcripts were analysed by close reading of the protocols and highlighting three topics:

1. Students' examples and notions of genetic traits.
2. Students' perceptions of inheritance.
3. Students' ideas and reasoning patterns about the passing on of genetic information to a next generation, in particular their ideas about sexual reproduction, meiosis, gametes, chromosomes, and their interconnection.

The most eminent features that could be extracted according to these three categories will be subsequently outlined.

Students' examples and notions of genetic traits

Students' immediate responses to hereditary traits were examples like, *'eye colour' 'blue and brown eyes' 'hair colour' 'everything' 'nose' 'length' 'intelligence'* and your *'character'*. Moreover, they were questioning themselves whether character and intelligence were hereditary. They thought to some extent, but they were not sure about that. Like the quotation of the interview with Roos will show.

> I think that character is also hereditary, I mean when you father is always very angry, or something like that, then you will also have that to some extent.
> […]
> Well, I think something physical is always really hereditary. But, let's see mental things will not always be hereditary. I think that you will take something from your mother, and when your mother is really neatly with every thing, you will take that from her. Some character features you really get from your parents.

Most students were well aware that not everything is hereditary and that traits were also determined by the environment, for example through the way you were brought up and through imitating behaviour of other people. The next two fragments of the interviews with Karin and Saskia will show this:

(R is researcher)
R: What more do you think hereditary traits are?
Karin: Eye colour. Yeah, everything. Everything is hereditary.
R: What do you mean with everything? How you look like, the way you are?
Karin: Yes, character also, I think…
Of course it has also to do with environment, the way your character can develop. I mean, you can have a talent for uh, for instance playing the piano. But, I don't have a piano at home. So maybe it can not display.
(R is researcher)
Saskia: I think for instance feeling for the ball in football is indeed hereditary. That you are good in sports, but I think that is also due to your environment.

[…]
Maybe that touch, the fact that you are good in sports, that uh…you will pass on, I think. Because, my father is very afraid of the ball, well I am too. He is very bad in sports and so I am. I think that is hereditary.
[…]

Saskia: The way I connect with people, is the same as my mother does. I think.

R: Yes, and that also could be hereditary, or it could be through upbringing.

Saskia: Well, I think it is a mixture, because she is brought up quite differently from the way I am. So, I notice things that are quite different, but sometimes, you act the same, because you live in one home. We associate with another in the same way, also with other people. But she was brought up differently, so some things she does different from the way I do.

Students' perceptions of inheritance

Students' perceptions of inheritance showed that something is given to the next generation that determines the hereditary traits. In this respect some students mentioned chromosomes and genes, others only mentioned 'something'.
Some answers to the question '*how do you imagine inheritance?'* were:

Karin: That has something to do with chromosomes. That you got something from your father and from your mother, and yes, that there is a combination made, or something. That one is stronger than the other, as to genes. For example brown eyes dominate blue, that kind of things.

Ida: Euh, yes that genes will be passed on to your children, or something. Yes, uh inheritance, yes, uh I don't know. That you both from your father and mother uh… that it is mixed up uh… during division and that occurs in the children.

(R is researcher)

R: Yes, you say that you pass on genes.

Saskia: Yes and those genes contain your features, all in codes and so on. And they come together when the egg cell and sperm cell merge. So, then you have genes of your mother and of your father, and those contain codes, and uh…so the traits. So, that becomes a child, and then it has those traits.

(R is researcher)

Fien: Yes, just what you have got from your parents, uh…have received, that makes you your person. Because you are all chromosomes, so that uh… yes, those you get from your parents, isn't it? So, you just get things from your parents. You have such a chance, of one to so many that you get a hereditary disease for instance, or something. I have heard something like that, but I am not sure.
[…]
We have seen a video once, on thyroid gland something. But I don't know exactly what it was anymore.

R: You already said something about 'what you got from your parents, and how you are now'

Fien: Yes, something like that. Yes, they got that of course again from their parents, so it is passed on from generation to generation.

Most students used their family as an example in their explanations. When they were not sure about a statement they made, they automatically verified it by looking at their own family members. They made comparisons between themselves, their brothers and sisters, their parents, and grandparents, to decide whether or not something could be hereditary. An example is the quotation from the interview with Roos.

(R is researcher)
Roos: Well indeed, the shape of the fingers is hereditary too. Because I have, uh my mother has exactly the same hands as I have. You can see that really well, really like 'wooh you really have exactly the same'.
R: Yes.
Roos: And that is really weird, because at home we have, …eh my father is actually rather small (in length) and my mother is average. And I have three sisters, two older sisters and one baby sister, and they are really small. And I am average in length. Really strange, they are 1.60 m and I am 1.72 m, really weird.
R: So you already indicate that you for instance have certain features that your sisters have not.
Roos: Correct, and that is genetics.

So, referring to real life experiences with heredity in the lessons should start with students' families.

Students' explanations of passing on genetic information

Most students realised that there are two cell division processes. They could relate the process of mitosis to division of somatic cells, and meiosis to gametes, but they had difficulty to explain how these cell division processes run. The process of sexual reproduction in general was clear. They knew that the egg cell and sperm cell merged, and that the gametes contained chromosomes (or 'something that determines genetic traits'). But they had difficulty to explain the purpose, process and products of meiosis.

(R is researcher)
R: So, here we copy the cell, and what does happen in case of meiosis? What is the main purpose?
Marta: Well, uh merging of the chromosomes of father and mother. Thus, from the 23 pairs of chromosomes, of uh… those uh. Father and mother have both 23 pairs and that have to become one pair of 23, for the child. So, half of father for that chromosome and half of mother… and that joins together.

The fragment shows that Marta is confusing some concepts; she explains fertilisation instead of meiosis. She knows that both father and mother pass on only half of their chromosomes, but she is confused about the pairs of chromosomes.
Also the chromosome concept was not clear to all students, some even thought that '*chromosomes are genetic traits'*, like the fragment of the interview with Roos shows.

(R is researcher)
Roos: Well both have 23 chromosomes, first they had 46, every individual has 46, but they are being divided. And that is what you exist of, because there are 23 from your father and 23 from your mother....
R: Yes.
Roos: And the hereditary traits are in that.
R: Yes, and what are those 23 you said?
Roos: Genetic traits.
R: So, 23 genetic traits?
Roos: Yes, chromosomes, but…
R: Chromosomes. Is that the same you think, genetic traits and chromosomes?
Roos: Euh, yes I think so. Yes.

R: It has indeed a lot to do with each other but….
Roos: Yes it has…uh, but I don't really understand how it is possible, that that is becoming you. Because in that case everybody would be the same.

Besides confusing chromosomes and genetic traits, students had also difficulties with the homologue chromosome concept. Students were either not aware that there are pairs of chromosomes or they hold the misunderstanding that homologue chromosomes are identical. In addition they had difficulties in relating these cellular processes and structures with the genetic traits they discussed in the beginning of the interview. The next quotation from the interview with Saskia illustrates these confusions about homologue chromosomes, the number of chromosomes in a gamete (process of meiosis) and the relationship of chromosomes with genetic traits in the individual.

(R is researcher)
Saskia: In meiosis half of the DNA is pulled apart, removed. […]
Well this is already 2 that becomes 4 and than 6 until 23, and that is removed. So they are not separated like that because you need to keep those two together [*she refers to the 2 chromosomes of a homologue pair*].
R: You are now forming an egg cell?
Saskia: Yes
R: And that merges with a sperm cell.
Saskia: Yes.
R: So, then you have it four times...? [*Referring to four chromosomes in the* zygote]
Saskia: Well no, but if, no but my egg cell contains only my eye colour, so to speak. I inherit only one of those two.
R: You mean that you inherit the eye colour only from father or only from mother?
Saskia: Yes, and that is my egg cell and there the sperm cell has to join.
R: So then we have, uh wait, so you have every trait once. So you have inherit your eye colour from your mother *or* from your father?
Saskia: Yes.
R: Okay, but what are those pairs in the cells? Because you were talking about pairs a moment ago.
Saskia: Yes, but I think only one of them works, or… I really don't know. I think the other one does not work or something like that.
R: But it is present?
Saskia: Yes, yes the other one is present. And I think that one is again, well …I don't know, that is not possible, because there are also four chromosomes…
R: Well yes, then you get a lot of chromosomes at once.
Saskia: Yes, but I think that it is just throwing them away, or something. I don't know it, but I think you can also inherit things from your grandfather and grandmother.
R: Yes, how is that possible?
Saskia: Because they are still in it, when those two are both in the cell [*referring to the egg cell*] and a sperm cell merge, then there are also two in it, so then you have four but three are out of order.
Well how is that possible…?
R: Oh, so then you have four chromosomes.
Saskia: Yes...
R: Well I think we are losing track here. It is also really difficult to explain.
Saskia: Yes, but I don't know where… uh and which, whether they stay together and whether they are both active. The one from father and the one from mother, which one do you inherit? And does the other one disappear than? I don't know.

When students got stuck in the homologue chromosome concept, it was helpful to students when the parents or grandparents, were brought up for discussion. 'How do you think your mother got her chromosomes? And your father?' 'What do you think your parents pass on via their egg or sperm cell?' And to emphasise that one chromosome of the homologue pair originated from mother and the other chromosome of the homologue pair originated from father. This clarified that the chromosomes of a homologue pair are not identical, and that a genetic trait is determined by (at least) two alleles; one that originated from mother and one that originated from father.

Conclusions

The two rounds of interviews revealed the same kind of difficulties in relating genetic traits on the organismic level with, chromosomes and gamete formation by meiosis, on the cellular level. Especially the concept of homologue chromosome is unclear and confusing to these students. So, in a new educational approach the relationship between inheritance and meiosis should be made explicit and meaningful to students.

Students think of inheritance and genetic traits in a rather concrete way, albeit restricted to themselves and their family. There were no students that gave examples of other animals or plants. So, genetics lessons could well start with these concrete examples to evoke a global interest, to raise meaningful questions and to motivate them to learn more about the topic of inheritance.

3.5 Content analysis of school genetics

Another important educational source is the textbooks. Mostly, the schoolbooks are influential in determining the content and the sequence of subject matter. Therefore, the content of the textbook *(Biologie overal-6V*) used by the biology teacher of the first case study was explored. It may be clear that the sequencing of the genetics content is of great importance. A quick scan of the chapter on inheritance in this textbook, revealed that the arrangement of the content did not meet our criteria for an adequate sequencing, i.e. to start on a concrete organismic level the senses have access to, and gradually descend to the 'lower' cellular level. Moreover, the relationship between sexual reproduction, meiosis and inheritance is not made explicit. Do these findings apply to other biology schoolbooks as well? To answer this question we started a university graduate research project at our department.

This research project was carried out by Van de Put (2001), who analysed three recently revised upper-secondary biology textbooks: *Pasteur, Biologie voor jou* and *Nectar (4V)*. In his content analysis he focused on how textbooks deal with the levels of biological organisation, and how they relate meiosis and inheritance. Different genetics terms were classified in levels of biological organisation: i.e. organism, cell or molecule. From each textbook two chapters were analysed, the one on meiosis and the one on Mendelian inheritance. Furthermore, the authors of the

textbook were interviewed about the rationales of the subject matter sequencing in the textbook and their views on dealing with the levels of biological organisation.
The main findings of the content analysis of the three upper-secondary textbooks were:

- The textbooks fail to start on a concrete level and to gradually descend to the less concrete levels.
- The textbooks use more than two levels of biological organisation per paragraph, which can contribute to the complexity of genetics and induce confusion for students.
- Relationships between different genetics concepts are not made explicit.
- The textbooks are inaccurate in the use of levels of biological organisation and in the use of genetics terms that are restricted to certain levels of biological organisation. Implicit change of levels of biological organisation was found in the analysed texts. Terms such as dominant and recessive should be related to allele, and homozygote and heterozygote should be related to genotype, e.g. 'an individual with a heterozygote genotype'.

In addition, authors of textbooks are not aware of learning difficulties associated with levels of biological organisation.
The main recommendation concerns the implementation of research findings by schoolbook authors.
So, the content analysis of these three frequently used Dutch biology textbooks, showed that there is no explicit attention to levels of biological organisation in the chapters on meiosis and inheritance. Moreover, the relationships between these chapters and between concepts were not made explicit. Therefore it is concluded, that textbooks are an important obstacle in learning genetics.

3.6 Towards a preliminary learning and teaching strategy

So far, chapter 3 discussed the explorative phase of the developmental research project in which various data sources were used to identify the main learning and teaching difficulties in genetics, in particular the abstract and complex nature of genetics. The various research outcomes discussed in this chapter provided ideas and criteria, which a preliminary educational strategy for genetics should meet. Designing and developing a preliminary strategy required the interrelating of the outcomes of the different theoretical and practical explorations. It is a process of backward and forward thinking between the outcomes of the different sources taking into account our framework of research, i.e. perspective on and position in learning and teaching theories and the recent developments in biological research and education (figure 3.6). From the different explorations more in-depth knowledge was gained (table 3.2). Besides, four main design criteria for a learning and teaching strategy aimed to cope with the abstract and complex nature of genetics, could be extracted.

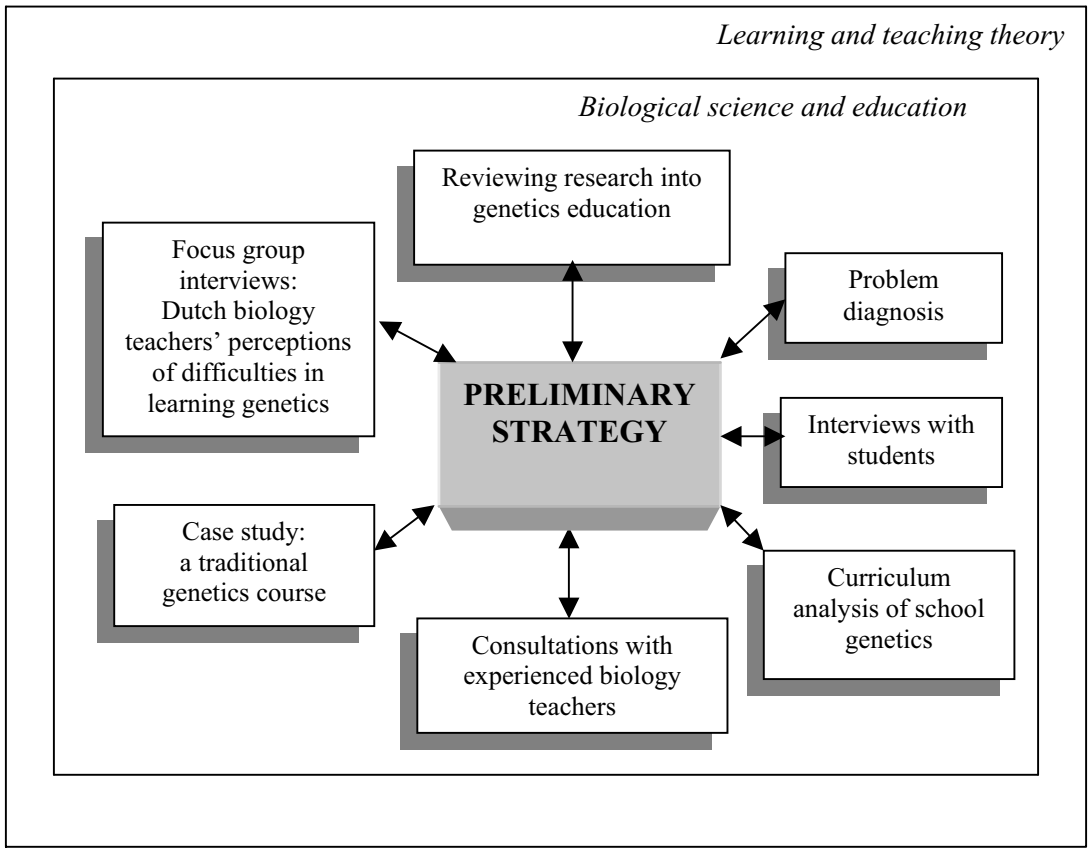


Figure 3.6 ***The interactive development of a preliminary learning and teaching strategy after theoretical and practical explorations and taking into account our framework of research.***

Clarifying the abstract and complex nature of genetics

Based on interrelating the outcomes of the different research activities discussed in this chapter, and depicted in table 3.2, the key difficulties in learning and teaching genetics can be stated in more detail. As to the abstract and complex nature of school genetics, our understanding increased as follows.

In teaching practice, a separation in time and space of the topics inheritance, reproduction and meiosis seems to be responsible for the abstract nature of the subject. Instead of the common approach to start genetics at the biochemical or cellular level (Olsher, 1999; Johnstone, 1988; 1991), we expect that starting at the organismic level could reduce the difficulties that students experience with genetics. Besides, the use of everyday life contexts and problems that have personal or societal relevance could reduce the abstract nature of genetics further and might motivate students.

The complex nature of genetics refers to the manifestation of heredity phenomena on different levels of biological organisation, and use of different corresponding vocabularies.

Table 3.2 ***Research outcomes of the explorative phase.***

Source	**Main results and indications extracted**
1. Theoretical orientation on general learning theories and on biological science and education: Chapter 1 section 1.2 and 1.3.	- Students should be actively involved in their learning process and their prior knowledge should be taken into account. - The learning process should be guided by the teacher and/or learning activities toward the intended learning outcomes. - The problem posing approach seems a fruitful and adequate way of motivating and actively involving students in content specific learning processes. - The developments in biological science & education underline the importance of gaining a coherent and integrative picture of biology. - Importance of emphasising the key concepts, their interrelations, and the main lines in inheritance in order for students to gain a coherent and meaningful insight into biology (genetics). They will have a structuring function in learning and integrating the more specific knowledge in a domain. - In biological research integration of research and knowledge on the different levels of biological organisation is increasing.
2. Literature review **3.** Focus group interviews with Dutch biology teachers (n=19)	- Identified difficulties in research literature on genetics education outlined in section 3.2 are comparable to difficulties perceived by Dutch biology teachers (outlined in section 3.3) - Two key difficulties are selected and clarified: the abstract and the complex nature of school genetics. 1. Separation of inheritance from reproduction and meiosis results in abstract subject matter (inadequate positioning of meiosis in the sequence of subject matter, curriculum). 2. The occurrence of heredity at different levels of biological organisation accounts for its complexity. - The extensive genetic terminology reinforces the difficulties that students experience with genetics.
4. Case study: observation of a traditional genetic course	- The traditional genetics course focuses mainly on training in solving genetic cross problems (confirmed in the literature). - Students are not able to interpret the Punnett square in a biologically meaningful way. They do not see the relationship between meiosis (the formation of gametes) and the biological meaning of a Punnett square in a genetic cross task. - Students use trial and error in solving genetic cross problems; they apply tricks or algorithms without any real insight into genetic principles. So, the acquisition of knowledge is context dependent and consequently transfer of knowledge is poor (also indicated in the literature). - Being told by the teacher or textbook that there is a relationship between meiose and inheritance (and other key concepts) does not contribute to students' understanding of these relationships.
5. Case study: interviews with 5H students (n=6)	- More insight into students' reasoning patterns, including conceptual obstacles: meiosis (process, place, purpose and products) and homologue chromosomes. - Distinguishing explicitly between the somatic cell line and the germ cell line in a life cycle helps students to understand that growth & development and sexual reproduction are linked with different cell

	division processes (mitosis and meiosis) enabling genetic continuity (cf. asexual reproduction) and diversity (cf. sexual reproduction). - Active learning rather then being told about cell division processes helps students to discover relationships and to get a meaningful insight into genetics.
6. Interviews with 4V students before the genetics course (n=6)	- Students spontaneously refer to their own family when explaining hereditary problems. - The concept of ' homologue chromosomes' accounts for difficulties. - Relating the homologue chromosome concept with sexual reproduction (meiosis) and concrete features of their parents, i.e. one chromosome from father and one chromosome from mother, could help the students to get a better understanding. - Meiosis, a crucial process in inheritance, takes a lot of thought for students.
7. Content analysis of schoolbooks	- The investigated schoolbooks do not explicate the crucial relationship between sexual reproduction, meiosis and inheritance. - No explicit attention is paid to the use of levels of biological organisation; implicit changes from one level to another, usually more than two levels per paragraph, is common. - Schoolbooks contribute to the difficulties that students experience, to not acquiring a coherent conceptual understanding and an overall picture of genetics.

Adequate understanding requires backward-and-forward thinking between molecular, cellular, organismic, and population level, as well as interrelating the different structures and processes of these levels. The extensive genetic terminology enhances the difficulties that students experience with the abstract and complex nature of genetics.
The complex nature of genetics can be illustrated by sickle cell anaemia (figure 3.7). In order to fully understand this genetic disorder, one should be able to interconnect phenomena and concepts on different levels of biological organisation. A minor change in DNA (point mutation) leads to a different amino acid, resulting in a change of the three-dimensional structure of haemoglobin and blood cells, which causes problems in the blood circulation and a lower oxygen absorption. This will result in symptoms of the disease (organismic level). On the population level, sickle cell anaemia heterozygosity is related with protection against malaria. Thanks to this selection benefit the sickle cell allele remains in the population (figure 3.7).
So, inheritance on the organismic level can be explained by describing phenomena on the lower levels and by using different genetics concepts. An adequate understanding requires backward-and-forward thinking between those levels of biological organisation. Biologists, including biology teachers have interiorised this thinking skill and use it automatically. Students trying to learn genetics get into trouble, because biology teachers and schoolbook authors often jump implicitly from one level to the other.

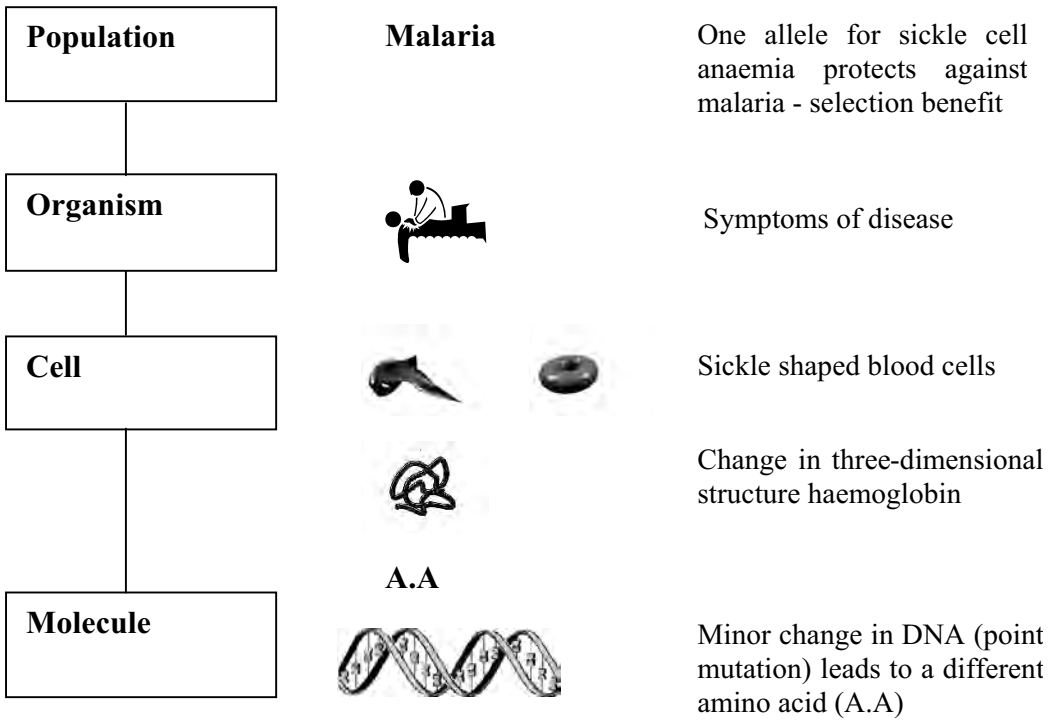


Figure 3.7 ***The complex nature of genetics: manifestations of sickle cell anaemia on different levels of biological organisation.***

Defining design criteria

In order to cope with the abstract and complex nature a learning and teaching strategy for genetics will be developed, based on design criteria extracted from the explorative phase in this study (table 3.2).

The results from the literature review and the focus group interviews indicate that it is important to *adequately sequence the subject matter, making conscious use of the levels of biological organisation, and paying attention to the relationship between inheritance, sexual reproduction and meiosis.*

The results from the literature review and the focus group interviews indicate that it is important to *adequately sequence the subject matter, making conscious use of the levels of biological organisation, and paying attention to the relationship between inheritance, sexual reproduction and meiosis.* The case study (source 4 and 5) suggests that *students need to explore and discover these relationships in inheritance themselves.* The focus should not be on solving traditional genetic cross problems, but on interconnecting the key concepts in inheritance (source 1): sexual reproduction, meiosis and genetic traits. The active exploration of these relationships by students was tried out in an interview setting (source 5), by distinguishing the somatic cell line and the germ cell line, and relating these to cell division processes, i.e. mitosis and meiosis. This was a fruitful exercise, so the two basic cell lines in a

life cycle should be explicitly distinguished and an active learning approach should be used.

Interviews with other students (source 6) to probe their prior understanding revealed that genetics *should start with an introduction on the concrete organismic level, preferably by focusing on similarities and differences* in family traits. Starting from hereditary phenomena in their own families might be motivating. These interviews also confirmed that the learning and teaching strategy *should explicitly relate inheritance, sexual reproduction and meiosis, and emphasise the crucial role of meiosis (process and purpose) in hereditary*.

From the content analysis of schoolbooks it can be concluded that *the sequencing of contents and activities in the learning and teaching strategy and materials should not follow the biology textbook. In our sequence the relationship between sexual reproduction, meiosis and inheritance should be explicated as well as the levels of biological organisation.*

Finally, these different conclusion can be reformulated and integrated in four main design criteria, which the preliminary learning and teaching strategy for genetics should meet:

1. *To adequately sequence the subject matter, genetics education should start on the concrete organismic level students are familiar with, and should gradually descend to the cellular level.*
2. *The relationship between meiosis and inheritance should be dealt with explicitly.*
3. *Two main cell lines, the somatic line (mitosis) and the germ line (meiosis) should be distinguished in the context of the life cycle.*
4. *Students should explore the relationships between the levels of organisation themselves, guided by the structure of the learning activities (and/or teacher) according to the problem posing approach*

The development of the learning and teaching strategy for genetics, based on these four design criteria, will be discussed and outlined in chapter 4.

Chapter 4

Towards a solution - development of the yo-yo learning & teaching strategy

4.1 Introduction

In chapter 1 and 3 the explorative phase (figure 2.3) has been discussed. The main learning and teaching difficulties with genetics were determined, promising learning activities were tried out, and four design criteria were extracted, in order to arrive at a design of a learning and teaching strategy for genetics and an accompanying scenario.
In the second phase, the cyclic research phase (figure 2.3), presented and dealt with in this chapter, the design criteria and ideas are converted into a first learning and teaching (LT) strategy. The LT strategy for genetics will be converted into a context specific scenario and field-tested. Several research cycles are needed to optimise the LT strategy for genetics. Three case studies in different schools have been executed.
Firstly, the specific contexts of the three case studies will be discussed in terms of school environment, levels of education, number of students, number of lessons etc. (section 4.2). The specific data sources used per case study in order to evaluate the scenario and to reflect on the LT strategy will be outlined in section 4.2 as well.
Secondly, the design of the first LT strategy, its conversion into the scenario, and the results of this first scenario in classroom practice will be presented and discussed (section 4.3). The evaluation of the scenario and reflection on the first LT strategy (figure 2.2) resulted in a revision of the LT strategy for genetics (section 4.4). This second LT strategy for genetics has been tried out in the second and third case study, presented and discussed in section 4.4. This second research cycle finally resulted in the 'yo-yo' learning and teaching strategy for genetics, which will be elaborated in section 4.5.

4.2 Procedures and research contexts

Section 2.3 outlined the developmental research design of this study, and discussed the cyclic research phase in which three case studies have been planned (table 2.1). In this section we will outline the specific contexts of the three case studies and the methods of data gathering and analysis.
In table 4.1 we will firstly provide a general description of the schools, including student population and signature of the school. The data are based on the national school statistics 2001 and quality-indication of the Inspection of Education (http://www.trouw.nl/scholen/). Besides, the three biology teachers of the case studies provided a personal characterisation of their school. Secondly, table 4.1 will give an overview of the specific form, number and age of students, and number of genetics lessons per case study.

The schools in the first and second case study can be typified as rural schools with few allochtonous students, whereas the school in the third case study is an urban school with a high percentage of allochtonous students (table 4.1).

Table 4.1 ***Characterisation of schools involved in the case studies and details on the cases.*** *Number in between brackets indicates the national level for pre - university education. (...)* indicates the national level for general secondary education.*

General school indicators	**First case study**	**Second case study**	**Third case study**
Name and place school	CSG Dingstede Meppel	RSG Broklede Breukelen	Dr FH de Bruijne Lyceum, Utrecht
Signature	Denominational	State (public)	Interdenominational
Number of students	1107	820	881
% allochtonous students	0 (5)	1 (5)	23 (6)*
% secondary students graduating without delay	51 (60)	54 (60)	44 (53)*
Average grade national exam	6,4 (6,4)	6,4 (6,4)	6,3 (6,3)*
Case study			
Time period	January – February 2000	November - December 2000	February - April 2001
Grade and Level	Two 6V classes	Two 4V classes	One 4H class
Number of students	6V1 : 8 students 6V2: 16 students	4V1: 17 students 4V2: 18 students	4H: 13 students
Age students	17-18	15-16	15-16
Number of biology lessons (50 minutes) a week	3 lessons	2 lessons	2 lessons
Number of genetics lessons	6	4V1: 8 4V2: 7	14

All three biology teachers indicated that their school has a pleasant and open atmosphere both among colleagues and regarding the interaction with students.

Data collection

In every case study extensive data sets were collected. In this section we will specify the various data sources per case study and outline the methods and timing of data collection.

An overview of the specific sources used per case study is depicted in table 4.2. The various data sets were collected during and in between the genetics lessons of a case study.

Table 4.2 ***Data sources per case study***

Data sources	First case study	Second case study	Third case study
Observations	✓	✓	✓
Audio-tapes:			
group discussions	✓	✓	✓
class discussions	✓	✓	✓
teacher	✓	✓	✓
Worksheets	✓	✓	✓
Written tests	✓	✓	✓
Think-aloud protocols of the written test	✓		
Students' logbooks	✓		
Evaluation interviews and discussions teacher (audio-taped)	✓	✓	✓

Classroom observations and audio-taping

In all three case studies, the whole sequence of lessons was observed and audio-taped in the classroom. Besides, the teacher carried a tape recorder throughout each lesson. During class discussions, notes were made of what was put forward by students and the teacher. Notes made on the blackboard were copied. An important observation point was the kind of questions students asked at what point in the lesson and how the teacher dealt with these questions. During group work, groups were observed, and each group was audio-taped on a different tape recorder. Group work was observed in order to see what students were doing and to offer help where they needed. Moreover, this setting offered the opportunity to have conversations with individual students, and thereby to investigate how activities were interpreted or what they meant by certain words or sentences that they said or had written down. Often this gave a first indication of what students still found difficult (or where they get stuck), how they perceived a learning activity or what was unclear in a worksheet or activity. These findings could then be used to make for instance small adjustments in worksheets for the second class in that case study. Usually, also a brief consultation with the teacher took place, concerning the way in which the lesson had proceeded so far, what still needed to be done, how specific outcomes could be used in the remaining part of the lesson.
The scenario directed the observations during a field-test.

Reflection with teacher

After each lesson the actual process in class was discussed with the teacher on the basis of observations and teacher's experiences with the lesson. The teacher could express his or her impressions and point to what went smoothly and to any difficulties or obstacles. Moreover, the teacher expressed what he/she thought the students grasped well or not, and why. The course of the lessons was reflected upon and parts in which the actual process differed from the scenario were selected.

Practical arrangements were discussed and prepared. Usually these discussions took place the same day, or at fixed points during the week, and were all audio-taped.

Students' logbooks, worksheets and written tests

After each lesson, the worksheets of all students were copied, and were returned to them at the beginning of the next lesson. In the first case study students also kept a personal logbook, which was copied and returned after each lesson.

Every case study ended with an individual written test, that took one lesson and was discussed the lesson after. In the first case study, two students made the written test thinking aloud while audio-taped. Moreover, in the first case study the genetics questions for the school-internal examinations were designed in collaboration with the teacher. These written data were collected. Also, the written answers on the genetics questions of the final examination were copied. At the end of the course the teaching sequence in its entirety was evaluated and reflected on by the teacher. These discussions were also audio-taped.

Data processing and analysis

All audio-tapes were transcribed verbatim, including addition of line numbers and column for notes during analysis; written tests, examinations, students' logbooks and worksheets were typed out and put in matrices in order to get a good overview and to make it easy to compare the different answers of students.

The domain-specific philosophy, the key difficulties in learning and teaching genetics, and the desired learning outcomes guided the data analysis. Analysis of the qualitative data aimed at reconstructing the actual learning and teaching processes, which were subsequently compared with the intended processes. Continuing discussions with supervisors and colleagues were helpful in monitoring the coherence and internal consistency of the procedures. The participating teachers were consulted during revisions of the strategy and scenario.

Analysis of the learning and teaching processes and outcomes of the scenario in practice according to the different data sets was structured by distinguishing different curriculum levels (Van den Akker, 1988; Kuiper, 1993), i.e. the:

1. Written curriculum (curriculum documents: scenario & LT materials)
2. Interpreted curriculum (teacher's perception)
3. Executed curriculum (learning and teaching activities in the classroom)
4. Experienced curriculum (students' perceptions)
5. Realised curriculum (learning outcomes)

The various data sources gave information on and insight into these different curriculum levels. For instance the written test (and worksheets) provided information about the realised curriculum, while observation of the genetics lessons and audio-records corresponded with the executed and experienced curriculum. Discussions with the teacher before, during and after a field-test mirrored the interpreted and experienced curriculum from the teacher's perspective.

In analysing the data sets, the next steps in the process of primary analysis (research question ❶, figure 2.2) can be distinguished.

The main line in analysing the learning and teaching process and outcomes were the transcripts of the audio-taped group and class discussions. The analysis repeatedly

focused on these transcripts, because they contain the most complete and authentic information. Every word said by the teacher had been recorded and the students' group discussions during an assignment had been taped separately. Besides, salient observations were used to start the analysis of transcriptions. In interpreting and validating these transcripts of the group and class discussions, the observation notes as well as the audio-taped and summarised evaluation with the teacher were used (triangulation). As additional sources concerning the *outcomes* of the learning process, the worksheets and written test(s) were used (figure 4.1).

Figure 4.1 ***Complementing data sources.***

The main analysis steps per data source and the relationship between the complementing data sources will be subsequently outlined. Emphasis was on discourse analysis and reconstruction of the learning and teaching processes by inspecting and interrelating data from different sources.

Observations
Notes made during the open observation of the scenario in practice included:
- students' reactions and questions;
- teacher's questions and answers to students questions;
- students' motivation;
- notes on blackboard.

These observation notes per lesson were helpful in analysing and interpreting the transcripts of the audio-taped group and class discussions. They provided a first rough impression of the adequacy of the content structure and the sequence of learning activities per lesson.

Evaluations with the teacher
The summarised transcripts of the audio-taped evaluations with the teacher - before, during and after the genetics course - provided information about:
- the teacher's view on and experiences with the (previous) lessons;
- his/her impression of the adequacy of the learning and teaching process;
- perceived strong and weak points in the (sequence of) learning activities;
- his/her perception of students' experiences;
- what practical adjustments and preparation were required for the next lessons.

The evaluations were helpful in interpreting the *class and group discussion*-transcripts.

Audio-taped class and group discussions
The analysis included the following steps:

1. Close reading of the transcripts with the salient observations in mind. Underlining striking phrases; noting key words and raised ideas in column.
2. Underlining students' reasoning patterns and assigning key words. Indicating what went right and/or wrong in their reasoning pattern. Noting train of thoughts that arose during this process.
3. Repeating previous steps with the analysis question(s) in mind (which focused on reading and interpreting the transcripts). Marking (additional) phrases that attracted attention with the analysis question(s) in mind. Summarising first answers to analysis questions, with references to protocol fragments that illustrated the answer.

4a. Regarding *teacher's explanation and class discussion transcripts*:
noting succeeding subjects dealt with in column next to the transcript. Noting when explanation was not univocal, and indicating in column the indistinctness. Verifying this step with the teacher's perception of the adequacy of these executed learning activities expressed in the *evaluation discussions*.
Noting whether the teacher's explanation corresponds with the intended teacher's explanation in the scenario.
Underlining reactions and questions of students and answers/reactions of teacher. Comparing these with the *observation notes*.

4b. Concerning *students' group discussion transcripts* during an assignment:
comparing summarised patterns, and underlined phrases with the written answers on the completed students' *worksheets*. Looking for explanations of (in)correct written answers through inspection of their lines of reasoning in group discussions.
Finally, verifying whether the students' (in)correct lines of reasoning are still present in the answers of the *written test*.

Written test
Analysis included the following steps:

1. Marking the written answers by means of the correction key (verified by the teacher) and depicting the marks per question in a matrix in order to compare the students' answers.
2. Determining the average final mark per class and the average response scores per question per class, and for the whole group of students participating in the different case studies. The average response scores per question indicated the quality of learning outcomes per class in a case study.
3. Dividing their questions into different content items (e.g. cell division, reproduction, chromosome behaviour, interrelationship certain genetics key concepts). The written answers and average response scores indicated which parts they grasped or did not grasp yet.
4. Feeding back to the findings from the *audio transcripts* in order to verify whether students' answers and reasoning patterns were adequate during the learning activities.

Worksheets
Analysis of the worksheets included the following steps:
1. Counting the number of right and wrong answers, and indicating the accurateness of the explanation.
2. Indicating lines of thought, reasoning patterns in the (incorrect) answers.
3. Distinguishing categories of lines of thinking in particular concerning the inadequate answers (e.g. same mistakes students made in their reasoning pattern, terms that were unknown, processes that were misunderstood, incorrect relationships).
4. Comparing written answers with lines of reasoning in *audio-taped group discussion*.

This primary analysis of these complementing data sources gave insight into the adequacy of the content structure and sequence of learning activities in the scenario (research question ❶, section 2.3 and figure 2.2).
The second step in analysing is reflecting on the LT strategy, with the outcomes and insights of the primary analysis in mind (research question ❷, section 2.3 and figure 2.2). As reported in section 2.3, in the reflection on the outcomes of a case study different types of reflection activities can be distinguished:
1. weighing the findings of the case study,
2. discriminating between coincidental, crucial and context specific findings,
3. being alert to findings which can lead to adjusting the LT strategy.

Reflecting on the LT strategy is a process of thinking backward-and-forward between the domain-specific philosophy of LT genetics and the scenario (figure 2.2). The findings of the case study were decontextualised in the reflection activities. The focus is on findings that indicate modifications to be made in order to improve the LT strategy for genetics.
Finally, after the last research cycle of the empirical research phase, the whole sequence of cyclic development of the LT strategy and testing the scenarios in practice are evaluated and reflected on in retrospect. With the knowledge and experience of the three case studies in mind, the process is reflected on and the final LT strategy (theory) for genetics can be outlined.

4.3 The first case study

4.3.1 Designing the first learning and teaching strategy

Designing a first LT strategy for genetics required the interrelating of the outcomes of different theoretical and practical explorations (figure 3.6, table 3.2) as well as creativity. As outlined in section 3.6, the explorative phase of the developmental research approach resulted in four design criteria, which an adequate LT strategy for genetics should meet, i.e.

1. To adequately sequence the subject matter, genetics education should start on the concrete organismic level students are familiar with, and gradually descend to the cellular level.

2. *The relationship between meiosis and inheritance should be dealt with explicitly.*
3. *The two main cell lines, the somatic line and the germ line should be distinguished in the context of the life cycle.*
4. *Students should explore the relationships between the levels of organisation themselves, guided by the structure of learning activities (and/or teacher) according to the problem posing approach.*

Thinking back and forth between these criteria gradually gave rise to the first LT strategy for genetics and subsequently its scenario. In designing the strategy, we had to imagine and consider how students would interpret information. From their perspective we had to consider which problems, solutions, questions will be elicited by a certain task and what would stimulate students to take a next step in the sequence of learning activities.

Criterion 1, largely determined the sequence of the subject matter in the LT strategy for genetics, i.e. *'genetics education should start on the concrete organismic level students are familiar with, and gradually descend to the cellular level'*. So, this criterion led to the assumption that the levels of biological organisation should be dealt with step by step, starting at the organismic level and gradually 'zoom in' on the next level. Moreover, the learning activities should connect to the students' everyday life experiences, i.e. hereditary phenomena in human beings. Students at this age are oriented towards their appearance. The organismic level is the level with which they are already familiar (see section 3.4 on interviews with students). Starting at the organismic level with the focus on humans may therefore induce recognition and global motivation. This decision is in accordance with Boersma & Thijssen (1991) who postulated that the organismic level is the adequate level to start a learning and teaching sequence. Based on these considerations, derived from criterion 1, the first part of the structure evolved and is depicted in figure 4.2.

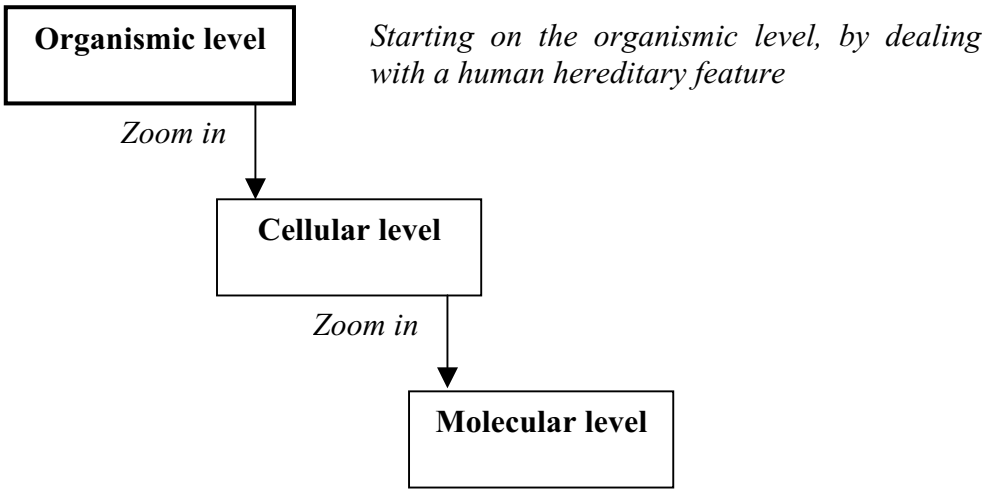


Figure 4.2 ***The first part of the structure of the LT strategy for genetics that evolved according to design criterion 1.***

Subsequently, the following questions were raised. How do we get students to descend (zoom in) from the organismic level to the cellular level? How can we get them to see the relationship between heredity features and sexual reproduction on the organismic level and meiosis and chromosome behaviour on the cellular level? What learning activities are required to guide students to the next level of biological organisation?

Firstly, when students have to descend a level, they need to see the purpose of descending, it has to be meaningful to them. This can be established by letting students encounter a (genetics) problem and/or question on the organismic level, that they only can solve by using genetics concepts of the cellular level.

So, the learning activities had to be designed in a way that students are guided to a next level, or for instance would encounter a problem that they only could solve by using concepts of that level (*criterion 4*). This implied that the successive learning activities should answer the question or solve the problem. *Criterion 4* says that learning activities and their sequence have to be designed in a way that students will come across questions.

Secondly, co-operative learning situations could stimulate the process of interrelating the different genetics concepts on the different levels of biological organisation. The essence of the difficulties in learning and teaching genetics is the absence of explicit relationships between the different levels of biological organisation and the relationships between acquired genetics knowledge on these levels and real biological phenomena. The results of the explorative case study showed that just explaining these relationships to students is not effective (section 3.4). Students should be actively involved in the integration of new information into their existing knowledge. When students have to solve and discuss a problem (task, question) in groups, they have to explain their genetics concepts in their own words. The interaction, questions and problems of students in the group stimulate them to consider the genetics concepts in more detail and to seek for relationships to make out a case. Consequently, group work settings (co-operative learning situations) will be used as an important teaching method.

Criterion 2 and criterion 3 are essential as to the biological content structure in the LT strategy for genetics. Distinguishing explicitly between the somatic cell line and the germ cell line in a life cycle helps students to understand that growth & development and sexual reproduction are linked with different cell division processes (mitosis and meiosis) enabling genetic continuity (cf. asexual reproduction) and diversity. Integrating these criteria with the first part of the design that was derived from criterion 1, implicated that the learning activities should start on the organismic level and refer to the reproduction processes. The key concepts in reproduction and inheritance should be explored in successive learning activities.

As was reported in section 3.4, it was tested whether students could reason along the somatic and germ cell line, and students' first notions on heredity and genetic traits were probed. This gave rise to the first two learning activities in the sequence: the 'introduction and orientation' (LA 1, table 4.3) and a group discussion about the germ cell line and somatic cell line in the context of passing on genetic information to the next generation (life cycle) (LA 2, table 4.3).

Moreover, the process of meiosis is a crucial link in inheritance and especially 'homologue chromosomes' is a difficult concept for students (sections 3.2, 3.3, 3.4). This gave rise to the development of a chromosome practical, in which the cell division processes and the behaviour of chromosomes are visualised, and students have to relate genetics concepts of the organismic level (hereditary traits) to genetics concepts on the cellular level (meiosis, chromosomes, gametes, zygote) (LA 4, table 4.3). When students have to *apply* these concepts in a practical they may become more concrete and meaningful to them.
Together the above-discussed considerations gave rise to the first LT strategy for genetics, outlined in table 4.3. In figure 4.3 the general structure of the first LT strategy for genetics is depicted according to the levels of biological organisation.

Figure 4.3 ***Structure of the first learning and teaching strategy for genetics***

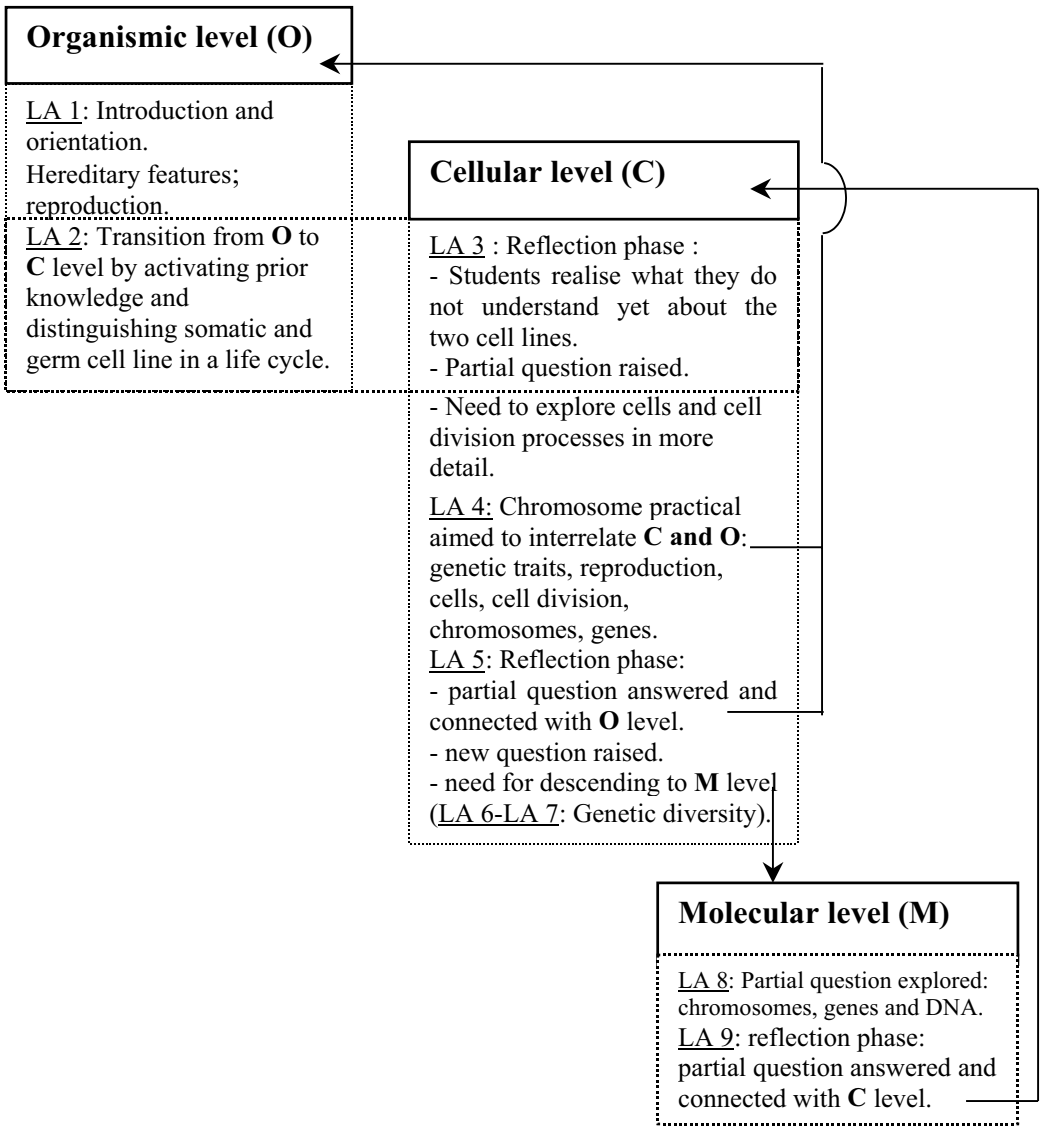


Table 4.3 ***Outline of the first learning and teaching strategy for genetics***

Sequence of problems	Sequence of learning activities (LA)
• What does inheritance mean and how do hereditary traits look like? • How are hereditary traits passed on?	**LA 1**: *Introduction and orientation on the **organismic** level*. Whole class discussion and brainstorming on students' first notions on: - (non)Hereditary traits (in humans) - Influence of environment and upbringing on hereditary features - Reproduction. - What makes you look like your parents but not being identical to them?
• What are the differences between the somatic cell line and the germ cell line in an individual's life cycle? • How are the cell division processes, mitosis and meiosis, related to these two lines? • What are chromosomes?	**LA 2**: *Group work*: *Transition from the **organismic** level to the **cellular** level by distinguishing the somatic and the germ line in an individual,* by: - Discussing the influence of a mutation in the hereditary material of a somatic cell and gamete on the next generation. - Relating hereditary features of the offspring with the genetic basis of the parents. - Relating the cell division processes, mitosis and meiosis, to the somatic cell line and the germ cell line. - Activating students' prior knowledge on these topics in their own words. Students realise what they do not understand yet and/or where they get stuck in their reasoning pattern.
• What are the structures that are passed on and determine a genetic trait?	**LA 3**: *Plenary reflection on LA 2. Whole class discussion and comparison of the group answers on LA 2.* Topics to discuss are: - Somatic cell line; germ cell line - The relationship of the two cell lines with mitosis and meiosis - Sexual reproduction, formation and fusion of gametes, fertilisation, zygote with a new unique genetic combination - Gametes contain half the number of chromosomes of the parent(cell), one of every homologue pair. The purpose of reproduction is to pass on chromosomes (genetic basis) from a parent to their offspring.
• What are genes? • What is the relationship between genetic traits on the organismic level and chromosome behaviour and structure on the cellular level? • How are these genetic traits passed on?	**LA 4**: *Group work: chromosome practical. Relating hereditary traits (phenomena) on the **organismic** level to chromosome behaviour and structure on the **cellular** level.* Active integration and visualisation by means of coloured paper strips (chromosomes) of : - somatic line and germ line - process of meiosis and gamete formation - formation of a zygote - chromosome behaviour during these processes - gene arrangements - relationship gene location and genetic traits in the offspring
	LA 5: *Whole class discussion and reflection on the chromosome practical.* Relating and discussing the applied concepts in the practical: gene, chromosomes, homologue chromosomes, cell, cell division (meiosis and mitosis), gametes, zygote, sexual reproduction, hereditary traits.
• How unique is a person's genetic basis?	**LA 6**: *Individual task*: Calculating variety. Calculating how many genetic different gametes one individual can form, and how many genetically different zygotes one parent-couple can form, to get an idea of the huge variety.
	LA 7: *Whole class discussion and reflection on LA 6.* Comparison of and reflection on students' answers to LA 6. Notions on variety and sexual reproduction are discussed: the forming and

	fusion of gametes are random processes, which add to an enormous genetic diversity, and produce unique individuals.
• What are chromosomes and genes made of?	**LA 8**: *Individual task: Transition from **cellular** structures (chromosomes) to the **molecular** level* Critical reflection on a newspaper article reporting on the identification of chromosome 22. Students identify the biological questions that arise when reading the article and students note how they picture chromosomes and genes (what they are built of) after they read the article. **LA 9**: *Plenary discussion and reflection on LA 8 and providing additional information.* Students' questions are discussed, compared and answered. Relating and discussing the chromosome and gene structure. Additional information is provided by the teacher.

4.3.2 Designing the first scenario

In the previous section the development of the LT strategy for genetics based on the four design criteria has been discussed. Subsequently, the LT strategy was converted into a scenario. The scenario is the context specific description of the learning and teaching activities, intended and expected learning and teaching processes and objectives (see section 2.2). The specific context involves two classes of the highest level of pre-university education (6V) (table 4.1 and table 2.1). The topics that were already dealt with in the preceding school year were cell division processes, mitosis and meiosis, and sexual reproduction. Molecular genetics was the first topic of the current school year. So, it is not the students' first acquaintance with the cell division processes, and basic knowledge on these topics could be expected. Taking into account the multiple studies concerning genetics education and the problems that still exist in learning and teaching genetics (chapter 3), we were assuming that the prior knowledge is not extensive and partly incorrect.

So, the first LT strategy for genetics was converted into a scenario, consisting of successive learning activities, teaching methods, aims and levels of biological organisation. Furthermore, as an elaboration of the scenario, accompanying learning and teaching materials were developed, including worksheets, assignments and practical materials. To illustrate the representation of a learning activity in the scenario and the accompanying teaching material (e.g. worksheets) an example is depicted in appendix 1. Besides, the worksheets of the chromosome practical (LA 4) have been published on the Internet (http://www.nibi.nl/bulletin/5-2001.html).

The scenario was planned for six lessons (table 4.1) and was meant as an introduction course to sketch the main lines in inheritance. This course should serve as an adequate and meaningful basis for the regular genetics lessons to come. The genetics course was finished with a written test and one lesson in which the written test was discussed, giving feedback on students' answers to the written test and questions asked. The arrangement of learning activities per lesson is depicted in table 4.4.

The overall intended learning outcome was characterised as a *competence* (section 1.2): *students should be willing and able to use genetics concepts meaningfully, i.e. they should be able to distinguish the levels of biological organisation, to see the*

relationships between those levels and to relate sexual reproduction and heredity in a life cycle.
To assure the validity of the scenario we discussed it with other researchers of our department starting from the theoretical underpinning and paying attention to coherence of the design ('peer debriefing'). In co-operation with the teacher of the first case study practical adjustments were made, concerning the feasibility of specific learning activities, the wording of the teaching materials and worksheets, allotted time, and connection to prior knowledge of the students.

Table 4.4 ***Actual arrangement of the learning activities and duration per lesson in the first case study.***

Lesson number	Learning activity	Time in minutes
1	LA 1 : Introduction and orientation organismic level	20
	LA 2: Group work. Transition from the organismic level to the cellular level by distinguishing the somatic and the germ cell line in an individual.	20
	Students' logbooks	10
2	LA 3: Plenary reflection on and discussion of LA 2.	15
	LA 4: Group work. Chromosome practical. Relating hereditary traits on the organismic level to chromosome behaviour and structure on the cellular level.	30
	Students' logbooks	5
3	LA 4: Group work. Chromosome practical.	30
	LA 5: Whole class discussion and reflection on the practical (LA 4)	20
4	LA 6: Individual task. Calculating variety.	10
	LA 7: Whole class discussion and reflection on LA 6.	5
	LA 8: Individual task. Reflecting on newspaper article. Transition from cellular structures (chromosomes) to the molecular level.	15
	LA 9: Plenary discussion and reflection on LA 8 and providing additional information.	10
	Students' logbooks	10
5	Written test	50
6	Discussion on written test	30

4.3.3 The first scenario in practice

The scenario was field-tested to find out whether it met our expectations and to reflect on the adequacy of the underlying LT strategy for genetics (section 2.2, figure 2.2). The learning objectives provided evaluation criteria. These objectives referred to levels of biological organisation and to key concepts respectively.

1- *Levels of biological organisation*. Are students able to:

- **a.** distinguish the levels of biological organisation?
- **b.** descend (zoom in) meaningfully from the organismic level to the cellular level, and from the cellular level to the molecular level?
- **c.** interrelate the different levels and genetics concepts on these levels?

***2**- Key concepts.* Are students able to understand and explain that growth and development, and sexual reproduction, are linked with different cell division processes enabling genetics continuity and diversity, i.e. are they able to:

- **a.** distinguish and describe the biological meaning of the somatic and the germ cell line in the life cycle?
- **b.** explain the position of mitosis and meiosis in the life cycle?
- **c.** explain the relationship between sexual reproduction, meiosis and inheritance (do they see meiosis as the linking process between generations)?
- **d.** explain and reason the process of meiosis and chromosome behaviour & structure?

The field-test sought to answer the following research questions:

❶ *To what extent could the nature and sequence of the learning activities in the first scenario be considered adequate?*

❷ *What indications can be extracted from comparison of the observed learning and teaching processes and outcomes with the scenario, for revising the learning and teaching strategy?*

The overall goal of the first research cycle was to improve and refine the first version of the LT strategy for genetics and its scenario through tracing design errors and considering modifications concerning the nature and sequence of learning activities. These learning activities should facilitate an internally consistent learning and teaching process.

Levels of biological organisation (1[1])

The sequence of the learning activities is designed according to criterion 1 stating that gradually descending from the organismic level to the cellular level is desirable. So learning activity (LA) 1 starts on the organismic level, LA 2 is meant to account for the transition from the organismic level to the cellular level, discussed and reflected on in LA 3. Subsequently, LA 4 interrelates heredity phenomena of the organismic level with hereditary phenomena on the cellular level, discussed and reflected on in LA 5. LA 8 and LA 9 accounted for the transition from the cellular level (cellular structures, chromosomes) to the molecular level.

In LA 1 students started on the organismic level by reflecting on external features, looking at themselves and their families, and giving examples of hereditary traits. In both classes of this first case study, students were well able to give all kinds of examples of hereditary traits. Firstly, the standard examples out of schoolbooks: *eye colour, hair colour, tongue rolling*, *hereditary diseases e.g. breast cancer, haemophilia,* but as the whole class discussion proceeded also examples like: *personality (easy agitated), shape of fingers, hip size, everything.* The non-hereditary traits were more difficult. They came up with *language*, the language you speak and accents in a language are determined by your environment, however, pronunciation problems such as lisp, or the ability to learn new language were again hereditary.

[1] Number refers to the key theme number (p. 76-77) and according analysis questions

Moreover, students also had to elaborate on the influence of upbringing and environment on hereditary traits in the whole class discussion. The purpose of the whole class discussion was that students come across questions, e.g. how is it possible that you look like your parents, but are not identical to them? This activity largely came up to our expectations. Students wondered what exactly genetic traits are. Their reactions incited the teacher to raise all kinds of questions, and moreover signal all kinds of misunderstandings on hereditary traits, like the next transcript quotation will show.

[1^2:1.C.1][2] ,T is teacher

T: Okay, so now we are back to features like nasal profile, length of fingers, shape of the tongue, all genetic traits. But you said aids is hereditary? How do you inherit aids?

Trudy[3]: From mother to child.

T: Yes, but how do you inherit it?

Trudy: When one of your parents is a carrier.

T: When one of the parents carries aids, the children will get it.

Peter: Could be.

T: So, what we discussed in lower-secondary biology class about contamination and safe sex, that was all for nothing?

Trudy: No, because it is also possible to get it when you are carrier of the disease and have sex with someone else, then you can pass it on.

T: Yes, is there anyone who can feel the differences between being a carrier of aids and being a carrier of a hereditary heart disease or breast cancer?

Esther: Yes, heart disease and breast cancer are in the genes and aids is a virus, that's not in your genes.

T: But you could say that aids is a trait, whether it is hereditary or not?

Jenny: I think it is not hereditary, unless you get aids by a mutation in your genes.

Esther: But when it is hereditary, then it only has to be due to the genes, so aids is not hereditary.

The quotation shows that students are discussing, and trying to determine what a 'trait' is, what 'hereditary' means, and what the difference is between passing on something (the disease aids) to the next generation, and passing on a hereditary disease to the next generation. For Trudy the fact that the disease is passed on from mother to child is the criterion for 'hereditary'. Esther explains that there is a difference between passing on a 'virus' via blood, and passing on a hereditary disease via 'genes'. This whole class discussion (LA 1) makes that the teacher, as well as the students, can signal the first misunderstandings they hold on hereditary traits.

The introduction phase was designed to raise questions and to signal misunderstandings, and like the above quotation [1^2:1.C.1] and outline showed, it came up to that expectation. Besides, the introduction phase should account for global motivation and a leading overall question that can be used to cross-refer to during the teaching sequence. Such a central question gives structure to students

[2] Protocol fragments are indicated as **[case study number ^{class}: lesson. source. serial number fragment]**. Data sources are abbreviated as follow: written test (T), worksheet (W), group discussion (G), whole class discussion (C). So, e.g. [2^1:1.C.8] indicates: [second case study $^{class\ 1}$: lesson 1. whole class discussion. serial number 8]. N.B. the third case study included only one class.

[3] All students are allotted fictive names.

during the teaching sequence in a way of 'Why are we doing this? Why do we need to explore and deepen certain aspects?'. When the overall aim of the course is made explicit to students (by means of a central question), they are able to see that every subsequent learning activity contributes to eventually answering the central question. A central question has to induce in students a sense of purpose for at least beginning to study the topic at hand, and provide them with a first sense of direction concerning were the study will lead them to. Such as, what (kind of) question(s) can I answer after this genetics course?
In the teacher's manual examples of questions, which the teacher could ask or guide the students to in this introduction phase, were given. However, there was not one particular question singled out and emphasised. The central starting question should have been 'What makes you look like your parents but not being identical to them?' This question was indeed put forward in the introduction phase, but it was just one of the questions during the whole class discussion. It was not emphasised as the starting question which students would be able to answer at the end of the genetics course.
This design error resulted in an (for students) illogical transition from LA 1 to LA 2. The students did not experience the intended connection between these two activities as such. They indicated that LA 1 was like a general introduction in order to make them confident with and aware of the fact that the upcoming lessons would deal with a new topic (inheritance), and that LA 2 was the 'real beginning' of the theme. LA 2 aimed at relating sexual reproduction and gamete formation (meiosis), so relating the organismic level and the cellular level. Students had to discuss the influence of a mutation in the hereditary basis of a person's somatic cell and germ cell on the next generation. The need for exploring and distinguishing these two different cell lines is lacking when students do not have a central question by which they start to wonder how differences in offspring occur (and that they occur). This lack in coherence between LA 1 and LA 2 was also indicated by the teacher during the overall reflection and evaluation of the teaching sequence at the end of the course.
So, analysis *question 1b* can not be fully affirmed. The levels of biological organisation were descended, but the descending was not meaningful to students.

The *modification* of the introduction phase should address the above discussed design error: the modified LA 1 should result in putting forward (by students or teacher) and emphasise the central questions addressed in the genetics course: *What makes you look like your parents but not being identical to them?* This question should be cross-referred to during the learning and teaching sequence, in order to keep the overall aim (question) in mind. The central question can globally motivate students to take a next step in the learning sequence (e.g. solve a task, discuss a problem with other students), because they sense the purpose of extending their knowledge on inheritance.
The remaining design of the introduction phase (LA 1) should be left roughly unchanged: the students were well able to discuss their first notions on and share their prior knowledge of hereditary features. They were able to reason about the influence of environment and upbringing on hereditary traits and they encountered misunderstandings and questions they were not able to fully answer yet.

LA 2, however, needed to be modified in the perspective of an adequate *sequence*. The findings indicated an abrupt transition from LA1 to LA2, which was due to lacking the purpose for transition, but also because there is an abrupt descending from the organismic to the cellular level. When the first modification of the central question is taken into account, it shows that in answering this question the first step should be to explore the reproduction mechanism that gives rise to the offspring, in more detail. Therefore, the transition from the organismic level to the cellular level had to be more gradually and more explicit. This first trial dealt with pre-university (6V) students. The cell division processes were already taught in preceding lessons and school years. One of the aims of LA 2 was that students discussed their prior knowledge of and clarified their ideas on the somatic and germ cell line and the related cell division processes mitosis and meiosis.
Therefore, the first LT strategy for genetics and its scenario is adjusted at this point. A learning activity is inserted in which the sexual (humans) and asexual (potato's) reproduction mechanisms on the organismic level will be compared. To enable students to explain the hereditary differences in offspring of the two reproduction mechanisms on the organismic level, the underlying differences in cellular processes have to be explored. Consequently, this learning activity and a whole class reflection on this activity (LA 2 and LA 3 in second version of the design) will evoke the need to descend to the cellular level, to explore the cellular structures and processes that explain these hereditary differences in offspring in a next learning activity.
The modifications should solve the problems experienced in this first trial, i.e. the abrupt transition from the organismic to the cellular level, and the missing motive for students to descend a level of biological organisation.

Interrelating the levels of biological organisation (1c[4])

The first learning activities (LA 1 to LA 3) in the sequence accounted for the introduction and elaboration of the organismic and cellular level. The next step is to interrelate the genetics key concepts on these different levels.
In the chromosome practical and the whole class reflection on this practical (LA 4 and LA 5), students had to follow the processes and to relate the genetics concepts on the organismic level (i.e. hereditary features, sexual reproduction) with those on the cellular level (i.e. meiosis, gametes, zygote, chromosomes, genes, alleles) (Knippels *et al.*, 2001). This learning activity came largely up to our expectations.
In the chromosome practical, a box with paper strips that differed in length and colour (representing chromosomes) was available for every group of students. Students had to pick four genetic traits of a well-known family. Next, they selected three pairs of chromosomes out of the box in order to constitute a somatic cell of the father and a somatic cell of the mother. Subsequently, they needed to form gametes by the process of meiosis and finally to make a correct gamete combination for the offspring. The various concepts and processes on the organismic and cellular level had to be related to each other. This chromosome practical was successful, since students were enthusiastically discussing their genetics concepts and difficulties they encountered in following the processes (Knippels *et al.*, 2001). The visualisation of

[4] Number refers to analysis question 1c outlined on page 76.

the genetic processes on the organismic and cellular level and the fact that they had to actively carry it out with strips of paper and genetic traits of a real family made them understand it much better. The practical made them actively reflect on their genetics concepts and encounter gaps in their conceptual understanding. Especially misunderstandings on homologue chromosomes and the process of meiosis popped up, and students got to question these concepts in more detail. Most students were able to explore the solution themselves, because they could visualise and concretely imitate, and try out the cell division process and chromosome division behaviour, with the strips of paper. The next quotation shows that students signalled their own misunderstandings on the homologue chromosomes concept and that they tried to solve their difficulties in the group discussion.

[1^1:3.G.2], T is teacher.
Anne: So, we could form all the descendants, and the division was also correct.
Maartje: Now we have to glue the result [*chromosome combination*] of one child on this piece of paper. Shall we make Nieske?
Wendy: Alright. So three chromosomes.
Maartje: And she will need two more or not? Oh no, no. This is, uh there is only half passed on and the rest will double later on, or not?
Anne: How can we get two X-chromosomes in that way? She did receive one X-chromosome from mother and one X-chromosome from father, or not?
Wendy: Yes, this one is from father and this one from mother, [*pointing out the chromosomes the child 'Nieske' received from father and mother respectively*], this one is from father and this one is from mother.
Maartje: One such thing, is that one chromosome and two chromatides, or…?
Wendy: Yes two chromatides.
Anne: No, one, one chromatide.
Wendy: Than we have taken a group.
[…]
T: Why do you glue the paper strip attached to the other?
Anne: Well, yes, we were wondering whether this is a pair of chromosomes or one chromosome.
T: And have you solved that problem yet?
Maartje: We I'm l not sure yet, I still confuse them.
Wendy: It is a pair of chromosomes with both a chromosome.

The quotation [1^1:3.G.2] shows the students' confusion on chromosomes that consist of two chromatides and two homologue chromosomes. However, as the chromosome practical and their discussion continued they were able to solve this problem on their own. When they had to check whether the child they had constituted had all the hereditary traits they had determined at the beginning of this chromosome practical, they finally fathomed the chromosome problem.

[1^1:3.G.3]
[*The hereditary traits the group of students had chosen at the beginning of the chromosome practical were: curls, abnormality in sight, freckles, light skin]*

Anne: Well what do we have to put on this [*chromosome*] one?
Wendy: That will be uh, light skin or cán be light skin, because we don't know what he [*referring to the child's father*] inherited from his grandmother and grandfather, from his parents, so her grandparents.
Anne: So this one she inherited from her father, so that is also 'no freckles'.
Wendy: This one she didn't receive, no curls. And about this one we don't know anything.

Maartje: But that is so strange, because she received this one with 'light skin', she didn't receive it from her father.
Wendy: But she could also have received it from her mother.
Maartje: Of yeah of course. But what is still strange is that when you put 'tanned fast' and 'no freckles' on this [*chromosome*] you will have two times 'tanned fast' and 'no freckles'. That is a little weird.
Anne: Well that is indeed weird, because in that case this one has to be dominant over that one.
Wendy: You can not know that.
Anne: But now we have progressed a step. The other one is 'abnormality in sight', so there has to be 'no curls' on that one.
Maartje: Well that remains fuzzy, I mean when you have an abnormality in sight you still can have curly hair, or not. You may have received those curls from your father in that case.
Anne: Indeed, I think we didn't have that …uh.
Maartje: I think this is incorrect. These are two chromosomes!
Anne: Yes indeed we have glued them wrongly together, they [*referring to the homologue chromosomes*] should have been unattached.

The latter quotation shows that Anne, Wendy and Maartje are trying to reason the allele location on the parental chromosomes in order to form the correct combination in the child that corresponds with the child's hereditary features. After a lot of puzzling they discover that the homologue chromosomes are not attached to one another, but are two separated chromosomes. In their discussion they link the allele location to hereditary features in the parents and even grandparents, which made them eventually see their mistake regarding initial chromosome formation.

After interrelating the organismic and cellular level in the chromosome practical, LA 8 and LA 9 accounted for the transition from the cellular to the molecular level. Molecular genetics was extensively dealt with in the chapter prior to our intervention. LA 8 and LA 9 were designed to apply this prior knowledge to a new situation, by critically reflecting on and discussing about a newspaper article reporting on the identification of the human chromosome 22. The gene-protein relationship was explained, and the molecular structures were related to the cellular structures and processes.
So, the learning and teaching sequence seemed adequate in interrelating the genetics key concepts on the different levels of biological organisation; however, the written test showed differently.
A comprehensive question in the written test at the end of the lessons was designed to probe whether students were able to relate all genetic processes and concepts, from the organismic level to the molecular level. Analysis of the answers showed that students were able to descend a level in their explanation (*1b*), but they had difficulties in explaining heredity phenomena when they had to ascend. Students were asked to describe how the genetic trait 'eye colour' will pass on to a child of the parents and which processes are involved in the appearance of this trait in the child. They had to describe the processes on the molecular, cellular and organismic level.
The test showed that most students were able to relate the process of meiosis with sexual reproduction. They correctly explained fertilisation and the new chromosome combination that was formed in the zygote. Also the allele combination that would determine the eye colour in the child was not a major problem to the students.

However, most students were not able to explain how these alleles gave rise to for instance brown eyes. So, the formation of proteins (based on the DNA code) that could serve as enzymes in the process of pigment formation was a step most students were unable to make. The next transcript of Iris' answer to the written test will illustrate that she was able to descend the levels of biological organisation and to relate the genetics concepts on these levels, but she could not explain how from the molecular level of the allele the pigment for the eye colour is formed.

[1^2:5.T.4]
Iris: A man and a woman would like to have children. In their bodies gametes are formed by the process of meiosis. The sperm of the man fertilises the egg of the woman after sexual intercourse. In the gametes 23 chromosomes are present with one gene for eye colour. Imagine that the man has blue eyes (bb) and the woman brown eyes (Bb). The allele for brown is dominant, so she has brown eyes. The possibilities after fertilisation are: BB, Bb, bb. The child has a 25% chance to get blue eyes (the alleles are divided in the process of meiosis). The combination of Bb is passed on to the child after fertilisation, and now the zygote contains this information. The zygote will divide and after nine months a child with blue eyes will be born.

Iris describes the main relationships between sexual reproduction, meiosis, gamete formation and the passing on of genetic traits (chromosomes, genes) to the offspring. Except from the fact that she describes the possible allele combinations wrong, (probably due to frequent rehearsal of standard genetic cross problems and routinely use of the Punnett square model), Iris is well able to descend from the organismic level to the cellular level and to relate the main genetics concepts on these levels. However, she is not able to integrate the molecular level, and to ascend from there to the organismic level. The only explanation she gives in ascending is the last sentence ' *the zygote will divide and after nine months a child with blue eyes will be born'*. How the alleles in the zygote can give rise to blue eyes is left out in her explanation.
This example is illustrative for the answers of the major part of the students of the two 6V classes (n = 23), such as '*brown is dominant, so the child will have brown eyes'.* 70% of the students did not explain anything on the gene-protein relationship. However, there were seven students (30%) that explained something on the part of protein production, but most of these students were unable to fully explain the way 'back' from the gene to the pigment. Four of these six students only used the term 'pigment', that was already provided in the question of the test, but did not connect this with protein production. Others did not relate genes and proteins. Not one student explained that the formed protein(s) works as an enzyme in a chemical reaction that forms pigment. The quotation of the written answer of three students shows that their explanations come close, but are not fully accurate.

[1^2:5.T.5]
Tina: I don't understand quite well how the pigment is formed. All the cells contain all the chromosomes for all the traits. Specific cells will produce a protein that takes care of the production of pigment.

[1^1:5.T.6]
Angela: During her [*the embryo*] development in the mother's womb, there also has come

information from the genes (chromosomes) to form green pigment and colour by means of proteins.

[1^1:5.T.7]
Mike: The moment the cells for eye colour are formed, the DNA part (gene) is being read, and that will be expressed in the colour (per cell). All those cells together will form eventually the eye. And some cells will have that colour that is the eye colour.

Tina's explanation that *'specific cells will produce a protein that takes care of the production of pigment'* can be interpreted as 'the protein regulates the chemical reaction that results in the formation of pigment'. However, she indicates that 'cells produce' instead of 'alleles code for' proteins. Mike explains the part of 'DNA being read' but does not mention proteins at all. Angela mentions genes, pigment and proteins, but does not explicit the relationship between those three components.

The essence of the learning and teaching sequence is to descend from the organismic to the cellular level (and molecular level), and to interrelate the different genetics concepts on these levels. The chromosome practical showed that students were able to go backward and forward between the organismic and cellular level when they had to puzzle on the hereditary traits of the parents and their children. However, the levels of biological organisation were not *explicitly* mentioned, and this practical proved to be the only activity in which the students could actively interrelate the levels of organisation on their own (*1c*). The practical guided students from the organismic to the cellular level and back again to the organismic level. The rest of the sequence mainly focussed on zooming in on or descending from the organismic level via the cellular to eventually the molecular level. The written test at the end of the course showed that most students were not able to *ascend* the levels of biological organisation. The reason was that this strategy of descending and interrelating the levels was made clear and explicit to the teacher of the first case study, but not to the students.
The first trial showed that in order to gain coherent understanding, the students should also be able to ascend the levels of biological organisation. It was our implicit assumption that when students were able to descend a level of biological organisation and to understand and relate the genetics concepts on these levels, they 'automatically' were able to ascend these levels and explain the corresponding heredity phenomena. This assumption proved to be incorrect.

To address the above described design error the learning activities should be *modified* in such a way that the transition from one level of biological organisation to the other is more explicit and effective for students. Moreover, the learning activities and/or teacher should guide the ascending of levels of biological organisation.
The chromosome practical is an activity in which students are guided to think backward and forward between the organismic and cellular level. This activity proved to be very adequate in terms of actively integrating the genetics concepts and will be maintained in the second version. The first modification to be made to address the design error, has already been discussed in the previous section: the

insertion of an extra learning activity on the organismic level subsequent to the introduction phase, in order to make the transition from the organismic level more meaningful and effective. This learning activity will be followed by an acquaintance with the cellular level, including cell division processes and chromosomes. These concepts of the cellular and organismic level will be integrated in a new situation, in a subsequent learning activity (LA 1 to LA 6 in the second outline of the educational strategy). Moreover, in the second version the levels of organisation should be more emphasised by the teacher, and the transition from one level to the other should be explicitly mentioned. This has to be integrated in the teacher's manual.
The last modification made is the insertion of a *meta-reflection phase* (LA 16, 17, and 18 in the second version of the LT strategy). By means of a whole class discussion and reflection on the didactical structure of the lessons, this structure will be made explicit. The first learning activity (LA 16 second version) in the meta-reflection phase should focus on the levels of biological organisation students can recognise (and distinguish) in hereditary, and position the different activities of the genetics course on a corresponding level of biological organisation. The second learning activity (LA 17 second version) should invite students to apply the concept of levels of biological organisation to a new situation, e.g. by distinguishing the levels in a text on a hereditary disease and describing the main features and phenomena of the hereditary disease per level, in their own words. In a plenary reflection on LA 17 (LA 18 second version) students' answers will be compared and discussed. By reflecting on LA 17 students will realise that the backward-and-forward thinking between the levels of biological organisation and the genetics key concepts on these levels, is helpful in grasping hereditary phenomena.

Key concepts (2)

Making a distinction between the somatic and germ cell line in the context of the life cycle, and interrelating the key concepts (inheritance, sexual reproduction and meiosis) built the rationale of the biological content structure. It should help students to understand that growth and development, and sexual reproduction are linked with different cell division processes (mitosis and meiosis) enabling genetic continuity and diversity.
LA 2 was designed to explore the somatic and germ cell line in the life cycle and to activate students' prior knowledge of reproduction and the cell division processes. Groups of students had to solve the following problem concerning the relationship between sexual reproduction and gamete formation (meiosis): *How will the offspring be affected when a mutation occurs a) in the genetic material of a gamete b) in the genetic material of a colon cell?*. The written answers on the worksheets showed that 5 out of 6 groups of students answered that a mutation in a gamete could affect the offspring in contrast to a mutation in a colon cell of a parent. One group answered that both mutations would influence the next generation and added that the affect in the gamete would be 'larger'. They reasoned that a mutation in the hereditary material of a colon cell will be passed on to the offspring because it is '*hereditary material'*, and since it says 'hereditary' it will be passed on.
So, based on analysis of the worksheets students were (already on this early point in the learning and teaching strategy) rather able to distinguish and reason the different

affects in the somatic and the germ cell line. However, analysis of the transcribed group discussions revealed that the argumentation behind the (correct) written answers was not always correct and/or complete. Most students were well aware that there is a crucial difference between a colon cell (somatic cell) and a gamete. They were well able to reason the somatic cell line. The germ cell line, however, was for most groups of students not quite clear yet. They were not able yet, to correctly time and link the process of meiosis in the germ cell line. A large number of students thought that meiosis divided the gametes, the zygote, or even the embryo. The subsequent quotations taken from group discussions during the assignment show this confusion.

[1^2:1.G.8]
Wim: But isn't it the case that change has taken place before, uh before meiosis? Meiosis is that, that two things melt together or something like that, or not?
Bram: No!
Don: A reproductive cell is dividing in four, in stead of two.
Bram: Meiosis are the reproductive cells, or not?
Wim: Yes. By means of meiosis you get half of the DNA, and that is put in such a gamete…,that has become the gamete.

[1^2:1.G.9], T is teacher
T: Where does the meiosis play a part?
Jenny: Cell division of the zygote.
Linda: I think it doesn't matter in this case.
Cintia: Yes, but where is the meiosis involved then?
Linda: Meiosis is uh, yes uh…
Jenny: Meiosis is just the formation of an embryo.
Cintia: Of the embryo? I don't know it anymore, I do know what mitosis is.

[1^1:1.G.10]
Anne: A gamete is just a sperm cell in meiosis or not?
Maartje: Yes, I think so.
Anne: A gamete that is simply still in meiosis.
Mieke: Yes, but then you get again the question of: 'yeah, what is meiosis?'
Anne: We don't need to explain that.
Mieke: Okay. And in meiosis the hereditary material is uh…
Maartje: Divided.
Mieke: Divided? Passed on, or not, to the next?
Anne: Do you just have it at once, just like that?
Mieke: Can you imagine when we had to explain mitosis?
Anne: Well that is much easier than meiosis. Mitosis is the same as meiosis in general, only meiosis is simply the half.

Wim [1^2:1.G.8] seems to link the term meiosis to the process of fertilisation '*meiosis is that those two things melt together*' while Bram thinks meiosis are '*reproductive cells*'. Jenny [1^2:1.G.9] implies that meiosis '*divides the zygote*' or is '*the formation of the embryo*'. The three quotations show that students are aware that meiosis is somehow involved in the germ cell line, but they are confused on the biological meaning, products and timing of the process of meiosis.
In case of the somatic cell line, students knew and were able to explain that colon cells are divided by the process of mitosis, and that the genetic material in the colon

cell is copied and passed on to the next generation colon cells. Moreover, students were well aware that a colon cell is not part of the sexual reproduction process, and therefore the genetic material in a colon cell will not be passed on to the offspring.

[1^1:1.G.11]
Anke: A colon cell seems uh, yes that colon cell only has influence on the next generation colon cells that are being made and the gamete, that is passed on. It is only one cell.
Carla: Yes, but when that one divides once, you will have two colon cells, the next two colon cells also get it [*the mutation*] and that four also get it.
Anke: Or the cell will be destroyed and never be used again.
[…]
Carla: But colon cells are not at all responsible for passing on information [*to the offspring*].
Lisa: No.
Carla: So, that will just not be passed on.
Lisa: No that will not be passed on.
Carla: That are other cells that account for that.
Anke: Yes, a colon cell has only influence on your own body.

[1^1:1.G.12]
Anne: Yes, I'm thinking what a change in the hereditary material of a colon cell, uh what the effect will be?
Miep: When you are saying that it will be cleaned up, that it will be replaced each time, than it would have no effect. But it depends on how it [*the mutated colon cell*] will be replaced.
Maartje: Yes that is it! When it is…
Miep: Because, when it is cleaned up and died and there is apoptosis or necrosis, or how is it called, involved, that is that the cell will become neatly. Then it wouldn't become, uh then it just will die. But when it is first divided by division and then disappears, uh yes first divides and then dies, then it already has passed on its information, its genetic information to other colon cells. […]
Maartje: And in a colon cell it only has effect on just that colon cell, or only on the colon. […]
Anne: The affect on the next generations, well that colon cell has of course no affect at all on the next generation.
Maartje: And when there is a mutation in the gamete, then it will be in every cell.
Miep: Of that person, and when that person gets children, then that feature will be in the children.

These latter quotations [1^1:1.G.11] and [1^1:1.G.12] show that the somatic cell line is quite clear to students.
The fact that the germ cell line and the process of meiosis are not quite clear yet, is however not a problem at this point in the learning and teaching sequence. The sequence as a whole is designed to understand and reason the germ cell line, exploring it step by step on the different levels of biological organisation. At this stage students are expected to discuss and share their prior knowledge and to clarify their ideas on the somatic and germ cell line, and to raise questions. These experiences and questions should motivate students to take a next step in the learning sequence, i.e. to explore and rehearse the cell division processes in more detail. The learning activity came up to that expectation. The students were indeed discussing and sharing their prior knowledge and solving the problem of the assignment together. The co-operative setting gave rise to reasoned questions and motivated the students to get answers to their questions. Joyce for instance, explicitly expressed her curiosity to know more about the subject in the group discussion:

[1^2:1.G.13]
Joyce: Yes, I'm really curious now to know what the effect of such a change in the hereditary material of a colon cell are. It will have some effect, I think.

That the task gave rise to content-related questions and discussion is shown by the next fragment of the audio-taped group discussion.

[1^2:1.G.14]
Anton: Yes, but what if from that colon cell a gamete is formed! Is that possible?
Joyce: No, of course not
Anton: How is a gamete formed then?
Joyce: I don't know, I think they already exist. Isn't it?
[…]
Anton: Why can not every cell become a reproductive cell?
Inna: Because it is really in a reproductive cell…
Joyce: In it is all the information to make a child.
Anton: Yes, but évery cell contains áll the information, they only use a small part of it.
[…]
Joyce: Yes, and you have meiosis and mitosis. And meiosis is only for the reproductive cells, isn't it?
Anton: By meiosis a reproductive cell is formed. Yes.
Inna: There is a difference between them, uh, in the course of the stages in it.
Anton: Yes exactly, that is why I was thinking, is it possible to make a reproductive cell out of an ordinary cell by means of meiosis? But I don't know if that is possible.

The written test at the end of the genetics course showed that 19 students (80%) were able to link the process of meiosis with sexual reproduction and inheritance, and to explain the essence of this relationship quite correctly (*2c*). The written answer of Maaike on the test illustrates this.

[1^1:5.T.15]
Maaike: In the process of meiosis the hereditary material of the cell is divided into half and finally you have reproductive cells. When the egg cell and sperm cell merge (each 23 chromosomes instead of 46) there are again 46 chromosomes. In this division and fertilisation the hereditary material is passed on and determines the hereditary of the child.

The answers of Maaike shows that she correctly explains that meiosis results in reproductive cells that contain half the number of chromosomes. She indicates that chromosomes are the structures that are passed on to the next generation and determine the hereditary basis of the next generation. The vehicle used to pass on the hereditary information (chromosomes) is the gamete. Concluding, *analysis question 2c* can be affirmed.
The chromosome practical (previous section) showed that students were eventually able to explain and reason the process of meiosis and chromosome behaviour meaningfully; so *analysis question 2d* can be affirmed. Although, almost all students defined chromatids correctly in the written test, there were still students that indicated homologue chromosomes as 'identical'.
In general, we may conclude that the students were rather able to distinguish and explain the somatic and germ cell line in a life cycle and to link the process of mitosis and meiosis adequately. So, *analysis question 2a and 2b* can be affirmed.

However, with the subsequent case studies in mind which include 4V and 4H classes instead of 6V classes, it would be desirable to explore and emphasise the genetics key concepts of these two cell lines in more detail. The cells, cell division and cellular structures have to be investigated and explored in more detail (LA 4 to LA 6 second version LT strategy) as well as the chromosome-gene concept (LA 9 second version LT strategy).

Finally, a *practical modification*. The learning and teaching sequence for genetics was designed in accordance with the problem posing approach. In this design the learning activities in which students explore and/or investigate certain genetics concepts in group work settings, were always followed up by a whole class discussion and a reflection activity. In a co-operative learning setting (e.g. group work) it is important to discuss the task with the whole class. Reflection is crucial in the learning process, because students get answers to questions that came up during their group work, and it helps them to integrate new concepts into a biological framework. This first case study suffered from a cut back on the reflection time by the teacher. Learning activities were often time consuming, because they were quite new to the teacher. In addition students had to keep their personal logbooks at the end of every lesson, resulting in less or sometimes no time for whole class reflection. This made it difficult to determine whether these learning activities met the expectations, because they were not fully carried out as planned. If the learning outcomes of an activity did not met our expectations, it is not possible to determine whether the learning activity is adequate or whether the students' lack of insight is caused by the cut back in reflection time.
This experience in the first trial resulted in the decision to leave out the students' personal logbooks in the next case studies and to schedule more time for reflection activities.

Conclusions

The overall goal of the first research cycle was to trace design errors and to consider modifications concerning the nature and sequence of the learning activities. As a consequence, the accent of the discussion of and reflection on the executed first scenario was on design errors and not on all the events that ran quite smoothly. This could distort the overall positive appraisal of the first strategy and scenario.

In answering the first research question (section 4.3.3, p. 77) it can be concluded that students were quite able to distinguish the somatic and the germ cell line in a life cycle, and to link these with mitosis and meiosis. Students were also able to adequately connect sexual reproduction with the process of meiosis and inheritance. More precisely, they were able to correctly explain 1) gamete formation in the process of meiosis, 2) fertilisation, 3) the new chromosome combinations in the zygote, and 4) allele combinations that determine a genetic trait in the offspring. However, they had difficulties in explaining how these alleles account for specific genetic traits in the organism. The way 'back' from the molecular level via the cellular level to the organismic level caused problems. So, in general the content structure seems adequate, but relating the hereditary phenomena to cellular and

molecular processes by ascending the levels of biological organisation was problematic.
As to the sequence of the learning activities in the first scenario it can be concluded that the steps in descending the levels of biological organisation should be smaller. In particular the transition from the organismic level to the cellular level (LA 1 and LA 2) proved to be too abrupt and illogical for the students (why to descend to the cellular level?). A central starting and steering question in the introduction phase (LA 1) was lacking, i.e. *How is it possible that you look like your parents, but are not identical to them?*. The first step in answering this question on the organismic level is exploring the process by which the offspring receives its hereditary features: reproduction. In the preceding chapter students have dealt with (a)sexual reproduction. Their first notions are explored and built upon by the comparison of the sexual and asexual reproduction mechanisms (LA 2, second version). Subsequently, asexual reproduction and sexual reproduction are used as an analogy for the somatic cell line (mitosis) and the germ cell line (meiosis), which can be distinguished in a lifecycle. In the succeeding reflection activity (LA 3, second version) the teacher will illuminate this analogy in a whole class discussion. Then the subsequent transition from the organismic to the cellular level will be more gradual and meaningful.
So, in comparing the observed learning and teaching processes and outcomes with the scenario (research question 2, section 4.3.3) we can conclude firstly, that the overall sequence of the LT strategy (i.e. starting at the organismic level and gradually descending to the cellular level) seems adequate, but that the steps in descending have to be *more gradual, more meaningful* and *more explicit*. Secondly, we can conclude that students should also be able to ascend the levels of biological organisation, in order to gain coherent understanding. Our implicit assumption that, if students are able to descend a level of organisation, they will 'automatically' be able to ascend these levels and explain the corresponding hereditary phenomena, was wrong. In order to address this shortcoming, the second learning and teaching strategy should also *explicitly ascend* the levels of biological organisation. The learning activities in the second learning and teaching strategy should enable students to think backward-and-forward between the levels of organisation (e.g. LA 10 and LA 11: the chromosome practical). This will be discussed in more detail in section 4.4.1, the reshaping of the learning and teaching strategy.

In summary, the following revisions will be made:
1. insertion of an extra learning activity on the organismic level (LA 2 and LA 3 second version)
2. emphasis on and cross-references to the central steering question: 'How is it possible that you look like your parents, but are not identical to them?'
3. emphasis on and explicit mentioning of levels of biological organisation in the second scenario and teachers manual
4. addition of a meta-reflection phase to explicate the overall didactical structure of the lessons (LA 16 to LA 18 second version)

Revision 1 and 2 should account for the more *gradual and meaningful* transit from the organismic level to the cellular level. Revision 3 and 4 should account for

making the (transitions in) levels of biological organisation more *explicit*. The meta-reflection phase (revision 4) should enable students to a) distinguish the different levels of biological organisation, and b) position the different hereditary phenomena on the different levels of biological organisation; i.e. think backward-and-forward between the levels of biological organisation.
These outcomes made us restate the aim of the lessons by adding the competence of thinking backward-and-forward: students should be willing and able to use genetics concepts meaningfully, i.e. they should be able to distinguish the levels of biological organisation, to see the relationships between those levels and to relate sexual reproduction and heredity in a life cycle, *by means of thinking backward-and-forward between the levels of biological organisation.*

4.4 Second and third case study

4.4.1 Reshaping the learning and teaching strategy

The formative evaluation of the *first* scenario revealed that a limited number of modifications is sufficient to optimise the LT strategy for genetics. The main revisions to be made have been discussed in the preceding section (4.3.3). The major revision proposal refers to the difficulties students had in ascending the levels of biological organisation. The main idea is that students should not only be able and willing to *descend* a level of biological organisation, they also should be able to *ascend* a level. The essence of the second version of the LT strategy for genetics might be indicated as *'yo-yo learning'* (analogous to the toy yo-yo), because students will be invited to think up and down between levels of biological organisation, and to relate the genetics concepts on these levels (figure 4.4). The toy yo-yo also goes up and down guided by the person who handles it. At first, the learning activities and/or teacher should stimulate and guide the students to also ascend a level, and try to answer their questions or solve their biological problem on that level. In the course of time students hopefully will be able to do this single-handed, i.e. become the persons that handle the yo-yo, and are able to apply the yo-yo strategy as a tool they can use in dealing with hereditary.
In shaping the second version of the learning and teaching strategy according to this idea of yo-yo learning, the following questions had to be answered. How do we get students to ascend a level of biological organisation? How do we get students to apply the yo-yo learning strategy single-handed as a tool they can use in dealing with hereditary problems?
In designing the first version of the LT strategy for genetics we had already postulated that descending a level of biological organisation should be meaningful to students. This was established by a problem posing design of the succeeding learning activities. Could this also apply to ascending? The first version of the LT strategy for genetics also made us realise that these transitions from one level to another should be made more *explicit* to students. In the second version of the LT strategy for genetics the explicit ascending of levels should be established in three ways.

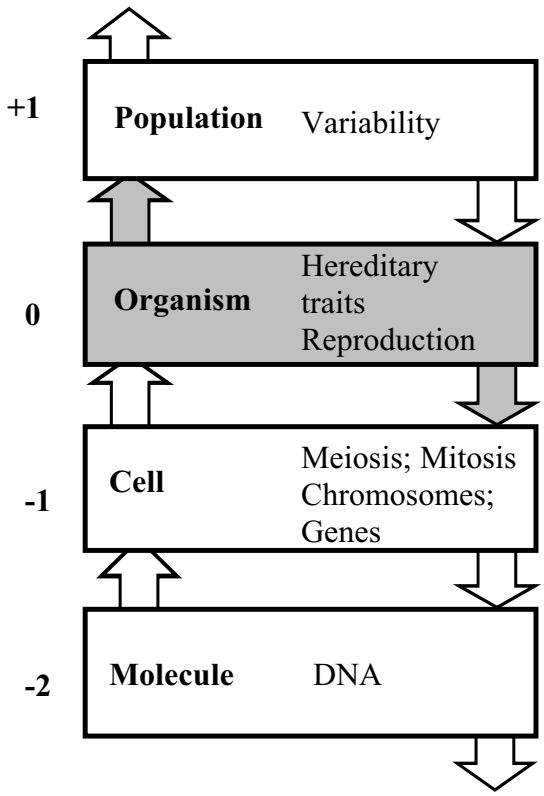


Figure 4.4 ***The yo-yo LT strategy for genetics: thinking backward-and-forward between the levels of biological organisation, starting from the organismic level and interrelating the genetics key concepts on these levels.***

Firstly, in the first part of the learning and teaching sequence, the wording of the question to be answered through a learning activity, will contain the level of organisation students should ascend to. For instance, 'What could be the advantage or disadvantage of asexual reproduction for the potato plant *population?*'. This question explicitly guides students from the organismic level to the population level. Next to the learning activities the teacher will guide this process of ascending and descending. So, the phrasing of the questions to be addressed in the learning activity should be well considered, in order to guide students to a next level. Generally speaking, a 'why' question is not likely directing a student; when we want students to ascend a level, the question asked or the problem posed, should be *functional* in nature. Such as, 'What is the function of mitosis for the organism?' (e.g. growth, cell renewal, healing of wounds). It does not seem always adequate to literally use the term 'function' in the questions, as the above-mentioned example of the potato plant illustrates. 'Advantages and disadvantages' of asexual reproduction for the potato plant can be read as function. Descending a level can be reached by formulating a *causal* question; e.g. what will be the consequences of mitosis for the chromosomes? These considerations will support the design of questions in the learning activities as

well as the kind of questions the teacher can ask to guide the students in ascending and descending the levels of organisation.
Secondly, learning activities will be inserted that make students go up and down between the levels of organisation they dealt with in the preceding learning activities (e.g. LA 7 and LA 10 table 4.5). In the second outline of the LT strategy that evolved (table 4.5), LA 1 to LA 3 deal with the organismic level, and LA 4 to LA 6 with the cellular level. Subsequently, LA 7 guides students in a new situation from the organismic level to the cellular level and back to the organismic level. To adequately solve the problem posed in LA 7, the students need to interrelate the hereditary phenomena on the organismic and cellular level. Subsequently, cellular structures, chromosomes and genes, are introduced (LA 8 and LA 9). The chromosome practical LA 10, makes students to go up and down (yo-yo) between the organismic and (sub)cellular level, and to interrelate the hereditary phenomena on these levels, which is reflected on in LA 11. So, after dealing with a subsequent level of biological organisation in succeeding learning activities, the two levels will be interrelated in a new situation, and in the reflection phase of this activity the connection with the higher level will be made (figure 4.5).
Thirdly, the learning and teaching strategy used in the genetics course will be explicitly reflected on with the students, in a meta-reflection phase (LA 16 to LA 18, table 4.5). The levels of biological organisation will be explicitly distinguished, as well as the steps taken in descending and ascending the levels in order to answer the central question. Moreover, the hereditary processes, features and phenomena dealt with in the preceding learning activities and the levels will be matched.
This third revision will also address the second question that has to be answered in designing the yo-yo learning and teaching strategy. To enable students to apply the yo-yo strategy independently in learning inheritance and/or solve genetics problems, the strategy will be explicated and applied in the meta-reflection phase (LA 16 to LA 18).
Based on the considerations discussed above along with the modifications outlined in section 4.3.3, the second LT strategy for genetics evolved (table 4.5). The general structure of the strategy is depicted in figure 4.5.

Figure 4.5 ***The structure of the reshaped LT strategy for genetics.*** *The inserted new learning activities are highligthed in grey.*

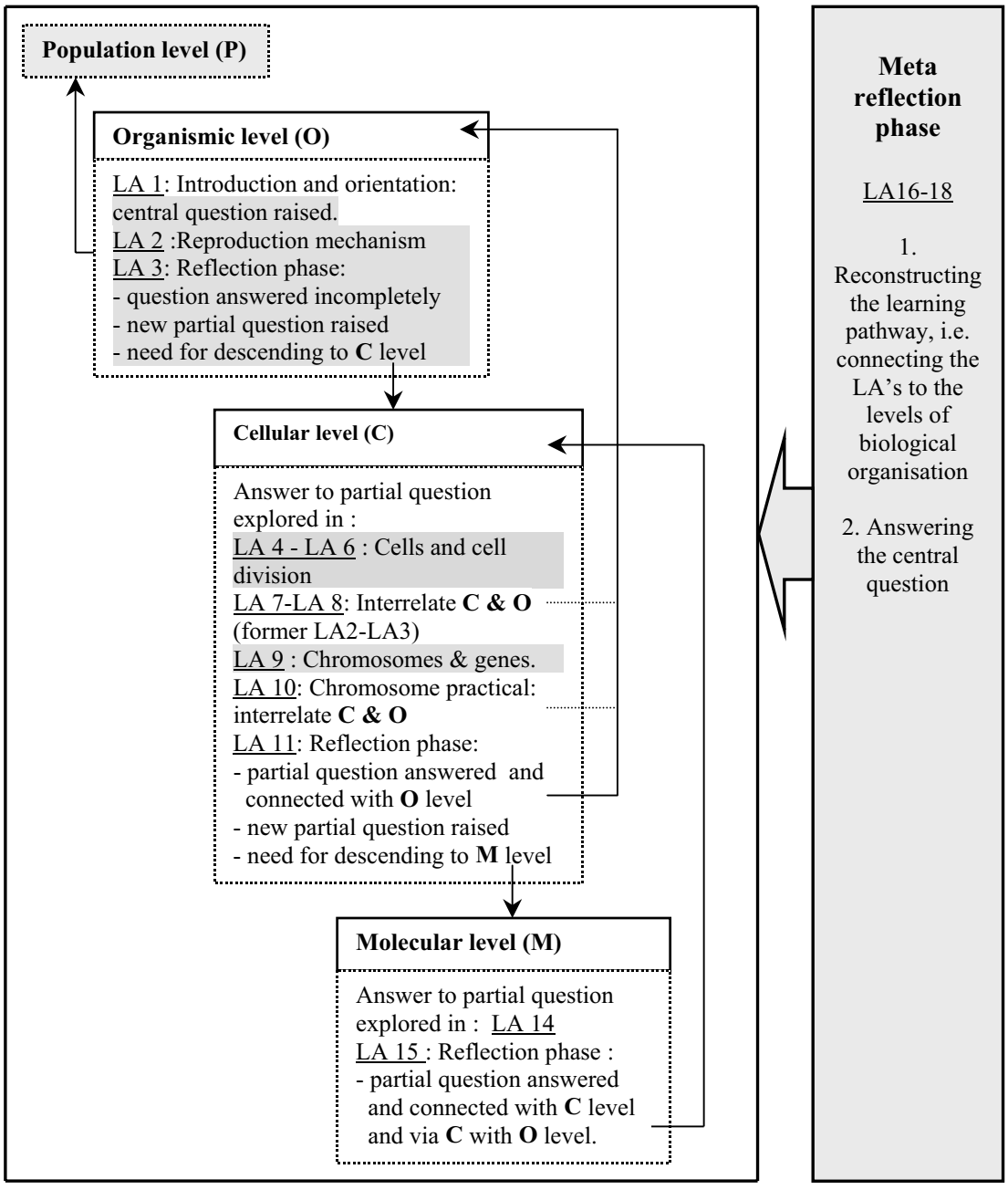


Table 4.5 ***Second outline of the yo-yo LT strategy for genetics.*** *Abbreviations: learning activity (LA), asexual (AR) and sexual reproduction (SR).*

Sequence of problems	Sequence of learning activities
What does inheritance mean and how do hereditary traits look like?	**LA 1***: Introduction and orientation on the* ***organismic*** *level*. Globally orientating and motivating students in a class discussion by referring to their real life experiences of hereditary in humans, discussing their notions on (non)hereditary features, the influence of upbringing and environment on these personal features, which leads to students' amazement and questioning of what is experienced as obviously: • *How is it possible that you (offspring) look like your parents, but that you are not identical to them?* ***Central question(CQ)***
What are the mechanisms for passing on hereditary traits?	Referring to students' prior-knowledge: reproduction links parents and offspring (SR). There are also organisms with (almost) identical offspring (AR). • *What does SR distinguish from AR?*
	LA 2*:Group work, jigsaw method: Investigating SR and AR on the organismic level,* by: Schematising and comparing the steps of AR and SR cycle. Comparing the advantages and disadvantages of AR & SR for the *population.* • Discovering AR offspring identical, SR offspring not identical to parents. • Discovering that in ***AR*** there is one parent and in ***SR*** a union of egg and sperm cell, originating from mother and father respectively, takes place. • Experience now (reflection in action) or in LA3 that they encounter a new question.
	LA 3*: Plenary reflection on LA 2: Towards the* ***C****ellular level.* Class discussion and comparison of the group answers of LA 2: Topics discussed: differences and similarities in AR and SR; advantages and disadvantages of the two reproduction mechanisms; schemas of the two reproduction cycles. For SR the concepts: egg cell, sperm cell, fertilisation, zygote, and new individual.
What are the structures that are passed on in the AR and SR mechanisms? By means of which processes are these structures formed?	• Answer to question posed in LA1 and link this to the CQ: difference is that in AR there is one parent. In SR a union of egg and sperm cell, originating from mother and father respectively, takes place. • Which evokes the need to explore: *What are the structures that are being passed on in SR and AR and how are they passed on?* Need for descending to the ***C****ellular level.*
	LA 4: *Whole class discussion & explanation (information) on the* ***cellular*** *level of cells and chromosomes*: By means of the schemas and knowledge about AR & SR it is established that ***cells***, which contain the hereditary information, are being passed on to the next generation. The cell division process ***mitosis*** is discovered in the discussion by referring to students' prior-knowledge on growth (i.e. zygote divides, grows, by mitosis).
What are the structures in the cell that account for passing on hereditary traits?	• Mitosis is linked to AR. In AR dividing cells, which contain chromosomes, are the vehicle. In AR offspring is (almost) identical to parent, so in mitosis chromosomes must be copied. In SR offspring differs from parents, due to a combination of gametes of both parents. The preceding cell division processes ***meiosis*** can be reasoned starting from the knowledge of mitosis in AR (offspring identical to parent) and the fixed number of chromosomes.
Where are chromosomes located and what happens to chromosomes during cell division?	**LA 5:** *Individual and group work investigating the cellular structures & cell division processes.* Looking at *real* cells and chromosomes under a microscope and at photographs of dividing cells with visible chromosomes. Looking at the cell division processes mitosis and meiosis on video.
	LA 6*: Plenary reflection on LA 5. Discussing what structures students have seen*

and recognised under the microscope and how these structures behave in the cell division processes.

- Resulting in the answer to question posed in LA 3: Chromosomes are located in the cell nuclei. In AR the chromosomes are copied and divided equally among the daughter cells (*mitosis*). So the parent cell divides to form two identical cells. In SR two successive cell divisions result in four germ cells, each containing half the original number of chromosomes (*meiosis*).
- This insight makes students wonder: *How do these cell division processes fit in the life cycle of multi-cellular organisms?*

How do mitosis and meiosis fit in the life cycle of multi-cellular organisms?

LA 7: *Group work*: *Application of previous genetics concepts to a new problem: relating the **organismic** level and the **cellular** level (yo-yo), by distinguishing the somatic and the germ line in an individual*:

- Discussing the influence of a mutation in the hereditary material of a cell in SR (i.e. colon cell and gametes) on the next generation.

Students relate in their own words: hereditary features of the offspring with the hereditary basis of the parents; mitosis and meiosis with the somatic line and the germ line respectively; AR with the somatic cell line, and SR with the germ line. Students realise what they (do not) understand yet and or where they get stuck in their reasoning pattern (reflection in action).

LA 7A: *Homework assignment 'Cells of Robert': Application of the somatic and germ cell line concept to a new situation on the **cellular** level.*
Comparison of the genetic information in different cell types of one person in different combinations (of somatic cells and germ cells). '

LA 8: *Whole class reflection on LA7, discussing and comparing students' group answers,*

- Resulting in answering question posed in LA 6: AR is analogous to the ***somatic cell line***: from the zygote ongoing mitosis leads to growth and development. Any mutation in this cell line will not affect the next generation, contrary to a mutation in the ***germ cell line.***
- Formulate new partial question: *How exactly do chromosomes determine the different hereditary traits in an organism?*

What makes chromosomes determine the different hereditary traits in an organism?

LA 9: *Plenary explanation (information) and discussion on:* Chromosomes, *genes and alleles*. Discussing students' first notions on genes (number of genes in humans).
Chromosomes contain ***genes*** (and alleles) which instruct the cell to produce all kind of ***proteins***. The latter have different structural and functional roles, which are expressed in hereditary traits. Relationship gene and protein.

How do genetic traits on the organismic level relate to chromosome structure and behaviour on the cellular level?

LA 10: *Group work chromosome practical: application of gene, chromosome, cell, cell division, reproduction, hereditary trait -concepts, to a new situation (yo-yo): relating the **organismic** and **cellular** level.*
Active integration and visualisation by means of coloured paper strips (chromosomes) of somatic line and germ line; process of meiosis and gamete formation; formation of a zygote; chromosome behaviour during these processes; gene arrangement; relationship gene location and genetic traits in the offspring.

LA 11: *Whole class discussion and reflection on LA 10: chromosome practical.*
Comparing and discussing students' findings of the chromosome practical. Relating and discussing the concepts: genetic traits, genes, chromosomes, and homologue chromosomes. Inheritance, sexual reproduction, meiosis, gametes, zygote, mitosis,

- Resulting in answering the question posed in LA 8, and in a contextualised and integrated picture of the relationships between the genetics concepts on the cellular and organismic level.
- Following the genetic make-up of their own family makes them wonder: *how unique is a person's genetic basis?*

How unique is a person's genetic basis?

LA 12: *Individual task calculating variety*.
Calculating how many genetic different gametes one individual can form and

	how many genetically different zygotes one parent-couple can form, to get an idea of the huge variety.
	LA 13: *Whole class discussion and reflection on LA 12.* Comparing students' answers on LA 12. Notions on variety and biological meaning of SR are discussed: the forming and fusion of gametes in SR are random processes, which add to an enormous ***genetic diversity***, i.e. unique individuals. • Students are wondering: *How do genes work?* → Need to descend to the molecular level.
How do genes work?	**LA 14***: Individual investigation and application task. Transition from cellular structures (chromosomes) to the* ***molecular*** *level.* Critical reflection on a newspaper article reporting on the identification of chromosome 22. Students identify the biological questions that arise when reading the article and students note how they picture chromosomes and genes and what they are built of.
	LA 15*: Plenary reflection on LA 14 and providing additional information.* Students' answers are compared and discussed. Additional explanation is provided on the chromosome, gene and DNA structure. Answer to question posed in LA 13: The genes in the chromosomes are made of ***DNA***, which stores and faithfully transmits information. The information-carrying capacity of DNA comes from the 4 bases; they are 'read' as if they were letters, making up words of three bases long. These words give the information needed for building proteins, and for organising the activity of the cell.
	Meta-reflection phase
Which levels of biological organisation has been transected in succession? Which hereditary phenomena, features and processes are characteristic for the different levels?	**LA 16***: Whole class reflection on the successive questions and answers in the genetics course and reflection on the related levels of biological organisation*. • Distinguishing the different levels of biological organisation. • Relating different activities in the genetics course with the levels of biological organisation. **LA 17***: Individual task. Application of the levels of biological organisation to a new genetics context.* - Distinguishing different levels of biological organisation in a text on a hereditary disease. - Describing the main features and phenomena of the hereditary disease per level of biological organisation.
	LA 18: *Plenary reflection on LA 17:* Discussing and comparing students' answers to LA 17. In descending from organism to cells and molecules and ascending vice versa biological structures, processes and concepts can be interrelated enabling us to build up a coherent conceptual understanding of heredity. This ***backward-and-forward thinking*** is helpful in grasping hereditary phenomena.

4.4.2 Designing the second and third scenario

In section 4.4.1 the reshaping of the second LT strategy was discussed. Subsequently, the revised LT strategy, including a sequence of problems and learning activities, was elaborated into a second scenario. This took place while simultaneously writing the actual teaching material and taking into account the forms and the constraints of the trial classes.

The second version of the LT strategy and accompanying scenarios have been tried out in two different case studies. Since the major design errors in the first LT strategy were transparent and accordingly modified in the second LT strategy, we

considered the second strategy as sub-optimal. Therefore, it seemed preferable to test the second LT strategy in two different case studies in the lowest grade of pre-university education (4V) and general secondary education (4H). Consequently, case study two and three were close together in time, and the third scenario could only profit from the most striking bottlenecks in the second case study. So, the scenarios of these two case studies only slightly differed, mainly due to the differences between the trial classes.

The second case study included two 4V classes and the third case study included one 4H class (table 4.1 and 2.1). In the two 4V classes the cell division processes, mitosis and meiosis had been dealt with as an introduction to sexual reproduction, and the basic notions of inheritance and evolution had been taught in the preceding school year. In the 4H class these topics had been taught two years before; biology was not taught at all in the third grade. Both teachers had used the same biology textbooks ('Biologie voor jou-2mhv') and indicated that only the basic notions of these topics had been dealt with; repetition would be necessary. So, some prior knowledge on inheritance and the cell division processes could be expected, albeit partly incorrect.

The insertion of the new learning activities (figure 4.5) and the scheduling of more reflection time actually resulted in eight lessons for one 4V class and seven lessons for the other 4V class (because the biology teacher became ill). An overview of the arrangement of learning activities per lesson is depicted in table 4.6.

Twelve periods were allotted in the third scenario, because the teacher and the researcher assumed that students of a 4H class would need more time than students of a 4V class for the same learning activities. Besides, the teacher in the third case study could be more flexible and provide more lessons. Actually, it took 14 lessons due to the school's general test week during our genetics course; two lessons were spent on an extra written test, including a discussion of the test results. An overview of the arrangement of learning activities per lesson is depicted in table 4.7.

In both case studies the genetics course was finished with a written test and a final lesson to discuss the test, to give feedback on students' answers to the written test, and to answer their final questions.

Observations of the executed *second* scenario indicated that the meta-reflection phase needed more attention. For that reason an extra learning activity was added in the *third* scenario aimed at applying the genetics concepts taught to a text on hereditary breast cancer, and discussing students' opinion on testing the family. Besides, the teaching material used in the third case study was extended with a schematic representation that visualised the connection between the levels of organisation and the somatic and germ cell line in the human life cycle (appendix 2).

As outlined section 4.3.2, the validity of the first scenario was assured by peer debriefing. The second scenario was discussed again with other researchers of our department as well as with the biology teachers involved in the case studies. Further adjustments were made in co-operation with the biology teacher of the second case study. After the trial of the second scenario, the third scenario was developed by adapting and refining the second scenario and by discussions with the biology teacher involved in the third case study.

Table 4.6 ***Actual arrangement of the learning activities and their duration per lesson in the second case study.***

Lesson	Learning activity	Time in minutes
1	LA 1: Introduction and orientation on the organismic level.	20
	LA 2: Group work. Investigating SR and AR on the organismic level, by schematising and comparing the steps of AR and SR cycle. Comparing the advantages and disadvantages of AR and SR for the *population*	25
	LA 3: Plenary reflection on LA 2. Comparing and discussing students' answers to LA 2. Toward the cellular level.	5
2	LA 3: Plenary reflection on and discussion of LA 2.	5
	LA 4: Whole class discussion and explanation on the cellular level of cells, cell division, and chromosomes.	20
	LA 5: Individual and group work investigating the cellular structures and cell division processes.	15
	LA 6: Plenary reflection on LA 5.	10
3	Short rehearsal of the main points previous lessons and linking central question with cellular and organismic level (concepts).	5
	LA 7: Group work. Application of previous genetics concepts to new problem. Relating the organismic level and the cellular level by distinguishing the somatic and the germ cell line in a life cycle.	20
	LA 8: Whole class reflection on LA 7, comparing and discussing students' group answers.	10
	LA 9: Plenary explanation and discussion on: chromosomes, genes and alleles.	15
	LA 7a : (homework assignment on somatic cells and germ cells)	
4	LA 10: Group work. Chromosome practical. Application of the concepts gene, chromosome, cell, cell division, reproduction, hereditary trait, to a new situation. Relating the organismic and cellular level.	50
5	LA 11: Whole class discussion and reflection on LA 10: chromosome practical. Notation genetic crosses.	25
	LA 12: Students start individual tasks (homework); calculating variety.	15
	LA 14: Students start with individual task (homework); critical reflection on a newspaper article reporting on the identification of chromosome 22. Transition from cellular structures (chromosomes) to the molecular level.	10
6	LA 13: Comparing students' answers on LA 12, Whole class discussion and reflection on LA 12.	10
	LA 15: Plenary reflection on LA 14 and providing additional information on chromosomes, genes, and DNA.	15
	LA 16: Whole class reflection on the successive questions and answers in the genetics course and reflection on the related levels of biological organisation.	20
	LA 17: Students start with task (homework); Individual task. Application of the levels of biological organisation to a new genetics context.	5
7	LA 18: Discussing and comparing students' answers to LA 17. Plenary reflection on LA 17; recognising the advantage of distinguishing the levels, backward-and-forward thinking is helpful in grasping hereditary phenomena.	30
	Repeating, discussing, and defining genetics terms	10
	Room for questions before the written test	10
8	Written test	50

Table 4.7 ***Actual arrangement of the learning activities and their duration per lesson in the third case study.*** ** Indicates 40-minutes lesson due to meetings of the teaching staff.*

Lesson	Learning activity	Time in minutes
1	LA 1: Introduction and orientation on the organismic level.	20
	LA 2: Group work. Investigating SR and AR on the organismic level, by schematising and comparing the steps of AR and SR cycle. Comparing the advantages and disadvantages of AR and SR for the *population*	25
	LA 3: Plenary reflection on LA 2. Comparing and discussing students' answers to LA 2. Toward the cellular level.	5
2	LA 3: Plenary reflection on and discussion of LA 2.	5
	LA 4: Whole class discussion and explanation on the cellular level of cells, cell division, and chromosomes.	20
	LA 5: Individual and group work investigating the cellular structures and cell division processes (under a microscope and on video).	20
	LA 6: Plenary reflection on LA 5.	5
3	LA 5: looking at the cell division processes on video.	10
	LA 6: Plenary reflection on LA 5; further discussion and explanation mitosis and meiosis.	10
	Short rehearsal of the main points previous lessons and linking central question with cellular and organismic level (concepts).	5
	LA 7: Group work. Application of previous genetics concepts to new problem. Relating the organismic level and the cellular level by distinguishing the somatic and the germ cell line in a life cycle.	15
	LA 8: Whole class reflection on LA 7, comparing and discussing students' group answers.	10
4	LA 7a: Discussing homework assignment 'Cells of Robert'. Application of the somatic and germ cell line concept to a new situation on the cellular level.	10
	LA 9: Students reading small newspaper fragments reporting on genes. Plenary explanation and discussion on: chromosomes, genes and alleles.	30
	LA 10: Group work. Chromosome practical. First step in chromosome practical: selecting four hereditary traits in a well-known family.	10
5	LA 10: Group work. Chromosome practical. Application of the concepts gene, chromosome, cell, cell division, reproduction, hereditary trait, to a new situation. Relating the organismic and cellular level.	50
6	LA 11: Whole class discussion and reflection on LA 10: chromosome practical. Pedigree. Notation alleles in genetic crosses.	50
7	(diagnostic)Written test	40*
8	Discussion on written test	25*
	LA 12: Individual tasks calculating variety.	5
	LA 13: Comparing students' answers on LA 12, Whole class discussion and reflection on LA 12.	10
9	Discussing and example and the notation of alleles in a genetic crosses.	15
	LA 14: (Newspaper article was skipped because students did not read the article) Transition from cellular structures (chromosomes) to the molecular level made by the teacher in discussion with the whole class.	15
	LA 15: Providing additional information on chromosomes, genes, DNA and proteins.	20
10	Discussing homework assignment (genetics terms)	15
	Short rehearsal of the main points previous lessons and linking central question with molecular, cellular and organismic level (concepts).	10
	Discussing and answering students' questions about the molecular level and	

	the relationship with the cellular level.	15
	LA 17: Students start with homework assignment (read text on sickle cell anemia).	10
11	LA 16: Whole class reflection on the successive questions and answers in the genetics course and reflection on the related levels of biological organisation.	15
	LA 17: Individual task. Application of the levels of biological organisation to a new genetics context (text on sickle cell anaemia).	10
	LA 18: Discussing and comparing students' answers to LA 17. Plenary reflection on LA 17; recognising the advantage of distinguishing the levels, backward-and-forward thinking is helpful in grasping hereditary phenomena.	25
12	'LA 19': (the extra inserted LA): Application of the taught genetics concepts to a text on hereditary breast cancer, and discussing students opinions on testing the family.	40
	Room for questions before the written test	10
13	Written test	50
14	Discussion on written test	50

4.4.3 The second and third scenario in practice

The second and third scenario are both based on the same (second) LT strategy, but are tested in two separated case studies. Consequently, the second and third scenario in practice will be discussed as one empirical cycle to test the adequacy of the yo-yo LT strategy for genetics. In the subsequent section, the outcomes of the data analysis of the two scenarios in practice will be discussed in one. The third scenario will only be discussed when it differs from the second scenario.

In this section it is analysed to what extent the intended processes of learning and teaching actually took place. It will outline whether or not the learning and teaching processes are in accordance with the key themes of the scenario and LT strategy. The evaluation criteria and research questions are the same as those of the first case study (section 4.3.3), except for the addition of one analysis question (1d) to the key theme 'levels of biological organisation'. Due to the advanced insight that students should be able to 'yo-yo' between the levels of biological organisation (section 4.4.1) it will be evaluated whether students are also able *'to ascend the levels of biological organisation?*' (1d).

Subsequently, in section 4.5 we will discuss to what extent the yo-yo LT strategy can be considered adequate in coping with the abstract and complex nature of genetics, by reflecting on the sequence of problems and learning activities of the yo-yo strategy. Finally, the general structure of the optimal yo-yo LT strategy for genetics will be outlined, in order to answer the research question presented in the first chapter.

Levels of biological organisation (1)

The sequence of learning activities is based on descending from the organismic level to the cellular and molecular level through posing or raising biological questions that should insightfully guide students to a next level. In order to answer analysis question 1b (see section 4.3.3) firstly, the introduction on the organismic level will be discussed as well as the descending of the organismic level to the cellular level.

Secondly, the transition from the cellular level to the molecular level will be outlined.

The organismic level (1b)

LA 1 and LA 2 deal with the organismic level, which is reflected on in LA 3 (table 4.5). In the introduction and orientation phase (LA 1) the central question (problem) should be posed. A first step in dealing with the central problem will be made in LA 2, in which a partial problem will be studied. In the reflection activity LA 3, the solution to the partial problem will be discussed, and new questions that can only be answered on the cellular level should be raised as well. LA 2 and LA 3 are inserted new learning activities in the second LT strategy and its scenarios, in order to make the transition from the organismic level to the cellular level more gradual. Did they bring about the intended need for descending?

The objective of the introduction and orientation phase (LA 1) is to globally orientate and globally motivate students in a class discussion by referring to students' real life experiences of hereditary phenomena in humans. Phrases such as *'you probably all have heard sometime "well you can see that is one of the Smiths' family" or "you have your mothers' eyes"'* are posed, and student's first notions on (non)hereditary traits and the influence of environment and upbringing on hereditary features are discussed. Discussing students' real life experiences with hereditary should lead to wondering *'What makes you look like your parents but not being identical to them?*' (central question). So, students needed to reflect on external features, by looking at themselves and their families and giving examples of hereditary traits. In all three classes included in the two case studies, students were well able to give all kinds of examples of hereditary traits. In the 4V classes, mainly the standard examples were given: *hair colour, eye colour, earlobe, tongue rolling, length, colour of the skin, hereditary diseases,* while the students of the 4H class also named: *figure, set of teeth, sense of muscular movement, flap-eared, thickness, shape of the face,* etc. The term inheritance did also elicit reactions like, *heirdom and bequest*. For the non-hereditary traits, *dye your hair, perm, scars, injury* and *body parts missing due to an accident* were contributed, and everyone agreed on these features. However, whether *personality, talents,* and *intelligence* were non-hereditary features, incited more discussion and disagreement among the students. It was finally concluded that parts of the personality and your intelligence were hereditary. The discussion these latter examples raised made the transition to the influence of environment and upbringing on hereditary traits easy and natural, like the next quotation shows.

[2^1:1.C.16], T is teacher.

T: So, you say, certain pieces of your personality are hereditary, but not per se everything. Where does that depend on?

Gijs: Environment.

T: That does for instance also depend on the environment. That does mean that who you are is caused by a hereditary basis, yes what you have in you, but is also caused by the environment. So you have hereditary traits and non-hereditary traits. Whether the hereditary traits are exposed depends on where you grow up, Brazil or the Netherlands, in the slums or in Breukelen, whether your parents like it if you played the piano or not, etc, etc. So, it also depends on your environment.

The whole class discussion did not raise many questions for students and the central question was posed by the teacher.

[2[1]:1.C.17], T is teacher.
T: So that means that you look like your parents. You have that specific personality, you have certain features from your parents, but you are not identical to them. Yes? So you look like them, but you are not absolutely the same. Is that the case for all organisms? And now I am making a transit to another part. Is that the case for all organisms, and organisms are plants, animals, humans, you know in biology we are actually animals too. Is that always the case that you look like your parents but that you are not identical to them? Who?
Karin: Dogs have different personalities too.
T: As to personality, animals are neither the same. So animals do look like their parents but are not identical. What about plants?

Like the quotation [2[1]:1.C.17] shows, the teacher draws the conclusion in the whole class discussion that you look like your parents but are not identical to them. She tries to make the transition to the different reproduction mechanisms, by asking the question *'Is that the case for all organisms that they look like their parents but that they are not identical to them?'*. The continuation of this discussion shows that the teacher is speaking (and fills in) more in the whole class discussion than she planned to do and than is desirable from the active learning perspective.

[2[1]:1.C.18], T is teacher.
T: What about plants?
Mart: They are the same.
T: Are they always exactly the same?
Esther: No.
T: What was asexual reproduction?
Leon: Oh yeah.
T: 'Oh yeah', but what does it mean when you have asexual reproduction?
[…]
T: Well, we are now talking about asexual reproduction. Sexual reproduction is with fertilisation and seeds. Asexual reproduction, turnip for instance or take cuttings from a plant […] that is asexual reproduction. So without genders, there is so to speak no sex involved. Do these descendants look like their parents?
Leon: Yes.
T: So, what is in case of asexual reproduction the same? The genetic basis. So, there is something exactly the same, but in case of asexual reproduction, because those hereditary traits have a genetic basis but are also influenced by the environment, there can be small differences that depend on the environment. So, what do we have at this moment: inheritance, depending on your hereditary basis and the environment. We have two types of reproduction, asexual and sexual, and those do not have the same results. In case of sexual reproduction you resemble your parents but you are not identical, how is that possible? There is a mechanism involved. In case of asexual reproduction you have the same story: you look more like your parent but due to environmental aspects there can be differences. There is also a mechanism involved.

Fragment [2[1]:1.C.18] shows that the teacher already directs the students to the differences in reproduction mechanisms that will be dealt with in the subsequent learning activity (LA 2). In fact the main differences in asexual and sexual reproduction are discussed and the teacher even speaks about the 'genetic' basis, a term to be used when 'genes' on the cellular level are introduced. On the organismic

level the term 'hereditary basis' would be desirable. So, the central question as well as the partial problem to be dealt with in LA 2 are incited by the teacher and not by the students themselves.
In the third case study this transition developed more smoothly.

[3:1.C.19], T is teacher.
T: Is that difference clear? [*Difference between hereditary and non-hereditary traits*]. Yes?
Bas: Yes.
T: Okay. Well genetics that is a part of biology that deals with these kinds of problems. What is hereditary, what is inheritance, how does it work? How do you get those traits from your family? And also, why do you look partly like your father, and partly like your mother, and are not you identical to them? And not identical to your brothers or sisters either? These are all problems that raise questions and we are going to try to solve these together in the coming time period. That is actually what this sequence of lessons is coming down to.

The teacher connects the whole class discussion in which students discussed hereditary and non-hereditary traits, with the new subject inheritance and the kind of problems and questions the subject in biology deals with. He previews on the kind of questions this subject raises including the central question, which the students will be dealing with in, and will be able to answer at the end of the genetics course.
Subsequently, the first partial question that arises from the central question is introduced, i.e. '*By means of what process did you receive features from your parents?'* [fragment 3:1.C.20]. As intended, the cellular level is not yet introduced by the teacher (or students). On the organismic level the process of reproduction is connected with inheritance, and the teacher cross-refers to the preceding chapter that dealt with sexual reproduction.

[3: 1.C.20], T is teacher.
T: So, your features are also largely determined by your environment. But also by what you receive from your family. Alright. Then we will engage in the following question, you have received features from your family, from your parents. By what means did that happen? How do we call that process?
Class: (Buzzing.)
T: What did you say?
Piet: The flowers and the bees.
T: No, how do we call the process by which you originated?
Piet: Once upon a time, there was a little flower and a little bee.
T: Okay, you originated from a cabbage. So that bee has reproduced or the flower? What do you mean?
Piet: Both.
T: Both. Okay, of course we are talking about the process of reproduction. You originated by means of reproduction. And that is described in the preceding chapter that you have already learnt. Well, you have read pages of text on how it works, you have a male and a female, they are doing it and a child appears. Reproduction is actually the means of inheritance. So you need to keep in mind those two subjects.

So, in LA 1 the central question as well as the partial problem of different reproduction mechanisms is raised. Subsequently, this partial problem is explored by

the students in a group work assignment designed according to the jigsaw method[5] (LA 2). LA 2 builds upon the preceding chapter of reproduction, and students' first notions are explored by comparing sexual reproduction (SR) and asexual reproduction (AR). First the two reproduction mechanisms are studied in different groups of students, after which they will exchange and explain their answers and compare and discuss the differences of the two reproduction mechanisms in a group of different composition.

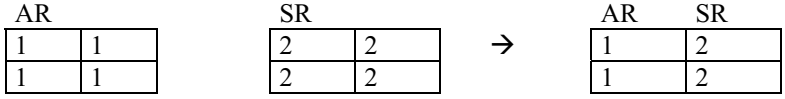
Analysis of the group work protocols showed that the students were well able to explain that the offspring in AR is identical to the parent, but that there will be differences due to influence of the environment. Due to prior knowledge some students even explicitly mention '*genetically identical'*, like Edwin in fragment [2^{1}:1.G.21]. However, students do not yet explain why parent and offspring are genetically identical, or how the offspring originates. The reproduction mechanism is not clarified on the cellular level, yet. The cell division process mitosis is not explicitly mentioned and connected with the AR mechanism (although AR was taught in the preceding school year).

[2^{1}:1.G.21], T is teacher.

Edwin: Is the offspring identical to the parental plant? That is not an univocally question.
T: Then you write that down.
Edwin: Shall I write it down?
T: Yes, and then you have to explain why it is not univocal.
Edwin: Well, it should be, 'genetically identical', and then it would be an okay question.
T: Well, then you say, yes genetically, not due to environmental factors.
[…]
Mart: They ask whether the descendants are identical. He is genetically identical, but of course he [*the new potato plant or potato*] is dropped on a different part of the soil, and on that place is then one worm more, so he is not completely the same.
[…]
Geert: Well, in our case [*asexual reproduction*] you are almost identical to your parents, only due to differences in environment, you change a little bit. But you are almost identical to your parents.

Edwin and Mart explain that the offspring in AR is 'genetically identical' to the parent but due to the environment, such as worms that eat from the potato, there are

[5] **Jigsaw method**: The jigsaw method is a specific cooperative learning technique, in which every student is assigned a specific (learning) task. Just as in a jigsaw puzzle, each piece is essential for the completion and full understanding ('peer teaching') of the final product. In our case de jigsaw method was used in a simplified form: students were divided in groups of four students. Half of the class studied the worksheets on AR and the other half on SR, and discussed the solutions to the stated problems. Subsequently, two of the four students of the 'AR-group' joined with two of the students of the 'SR-group' (see figure below). In this new setting with two 'experts' on AR and two on SR, the group had to solve problems in which the knowledge of both expertise-groups was needed.



some differences. However, they do not give an explanation for the genetic identity between parent and offspring yet. Their discourse remains on the organismic level. Out of the 14 groups of students of the three classes there was only one group that indicated the cellular level in AR after interference of the teacher.

[2^2:1.G.22], T is teacher.
Silvia: Well, here are coming two cells, which form one cell. [*Referring to the SR scheme*]
T: So the difference in mechanism is apparently here. Apparently there is coming something from both parents, that comes together and is the new individual. While in asexual there is only something coming from one parent.
Silvia: Okay.
Anke: So, I have to draw it like this: so one cell and that is asexual. It is like this.
T: Yes! That is a really important difference.

The other groups of students indicated the AR mechanism as *'growth'*, *'same mechanism as in the plant'* or *'copies itself'*, like the next fragments show. The AR mechanism is not yet clarified on the cellular level.

[2^1:1.G.23]
Renske: Well, in case of asexual reproduction the mechanism will be of course exactly the same as that in the plant, so to speak, or not?

[2^1:1.G.24]
Yvonne: Asexual reproduction, then you copy yourself?
Emma: Is that the case?
Yvonne: Yes, the mechanism, what is the difference in mechanism? Asexual reproduction copies (reproduces) itself, it grows so to speak, attached to the plant, like this.
Emma: Yes, and in case of sexual, you have egg cells.
Joost: Question c, 'what is the difference in mechanism?'
Emma: In case of asexual reproduction it grows at it so to speak, attached to the parent, in case of the potato plant.
Michiel: Yes, and with asexual it grows in, uh, yes that is a somewhat strange expression.
[…]
Joost: But actually that also happens in sexual reproduction, there it also simply growth.
Max: Yes, but uh with sexual reproduction you really need a fertilisation.
Joost: Yes, but with asexual you only need one person, and with sexual you need two. I think that is the difference.

Renske's explanation of the AR mechanism as 'the same mechanism *in* the plant', could be interpreted as the same *cell division* process in the plant, i.e. mitosis. Yvonne explains the mechanism as '*copies itself'* and Michiel as *'it grows'*, or '*grows attached to the parent'* (Emma). Actually, biological growth is mitosis, and in the process of mitosis the cell (and chromosomes) are 'copied'. However, the students do not explicitly mention cell division or mitosis at all in their discussion. We may conclude that the students' discourse and explanation of the AR mechanism is fully restricted to the organismic level.

In case of SR students were well able to explain the main steps from parents to offspring, as is shown by the use of concepts such as, male and female, sperm and ovum, fertilisation, zygote, embryo, birth. Moreover, the groups of students explained that the offspring was not identical to the parents, because: a) they are the

result of a combination of the sperm cell from father and the egg cell from mother, b) they are a 'mixture' of the parents, c) there are also non-hereditary traits, d) the environment has an influence.

[2^1:1.G.25]
Renske: Well, sexual reproduction demands a male and a female, a male for the sperm cells and a female for the egg cells.
Emma: Then the sperm and egg cell come together and there is fertilization, next the zygote becomes implanted in the wall of the uterus and then it matures into an embryo and after nine months birth.
[…]
Renske: The offspring is not identical to the parents, because the baby received from both parents features as well as non-hereditary features.
Emma: Yes, personality, a feature, they have a part from their parents, but also a large part from themselves. So, you are not entirely identical to your parents.

[2^1:1.G.26]
Yvonne: Well, we have the father and mother. Father sperm, mother the ovum, and in case the ovum and sperm fuse, an offspring originates.
Emma: Okay, is the offspring identical to the parents? That is of course no. Well, why not? Because you are a mixture of your parents, and not everything is hereditary based, also environment.
[…]
Joost: The most important difference, in case of sexual reproduction you have changes, you have mixtures, and in case of asexual reproduction it is the same.

So, students were well aware that the offspring is not identical to the parents, because it *'receives features from both parents as well as non-hereditary features (Renske)'* or *'got something from both, is a mixture (Emma, Joost)'*. In contrast to the AR mechanism, students were already able to explain some parts of the reproduction mechanism on the cellular level, as is shown by expressions such as 'sperm and ovum do fuse', 'the zygote originates'. However, what precisely the combination of sperm and ovum implies is not articulated. In students' justification of the reproduction mechanism, the cell division process meiosis (and mitosis) is not explicitly mentioned. Actually, the only statements on the cellular level are made in case of SR, and are limited to mentioning the reproduction cells and the zygote.
On the other hand, students were quite able to elaborate on the advantages and disadvantages of the two different reproduction mechanisms on the *population level*. Mentioning the level of organisation to ascend to in the (functional) question indeed guided students to that level. The concepts 'variation' and 'natural selection' were discussed, but students did not use these terms explicitly. Their wording is '*differences between people*' and that the human race will not become extinct due to '*different types of humans'*. In case of AR expressions like *'when you have one good (or bad) quality potato, you get all good (or bad) quality'* are used. The subject evolution, including first notions on natural selection, variation, and origin of species, was taught at the end of the preceding school year (4H two years before). The next fragment shows students' discourse on the advantages and disadvantages of sexual and asexual reproduction mechanisms for the *population*.

[2^1:1.G.27]
Renske: What is the advantage of sexual reproduction? Well, you can make choices, so you have the

option whether you would like to reproduce or not, and you get different types of humans. You don't get one type, but you can nicely combine.
Well, and an example of an advantage? Well, if you have different types of humans, then humans can survive easier so to speak. Because, when you have one type of humans, and that type is weak, then it will become extinct. When you have different types and one type is really strong, then humans will not become extinct very quickly.
[…]

Edwin: What is the advantage of asexual reproduction for the potato plant population? Well, when you have óne good quality potato, you get all good quality potato's, because they are all the same as the mother potato.
An example is that you can copy things. I think it is simply the first answer [*above*].

Geert: When for example one potato is bad, then immediately all the potatoes will be bad.

[2^{1}:1.G.28]

Joost: A large disadvantage is, when one has a disease, then they have all that disease, they are all susceptible to that disease, because they are all the same.

Students are aware of the differences in variety between AR and SR, and that more variety can be an advantage for the survival of the population (e.g. Renske: *If you have different types of humans, then the human can survive easier.)*, but if you have a '*good population'* AR preserves these qualities. So, we may conclude that students were able to ascend to the population level, and reason about differences and similarities of the AR and SR mechanism.

From the students' discourse on the two reproduction mechanisms (LA 2), we may conclude that the discussion and argumentation remains primarily on the organismic (and population) level like this learning activity intended. Students were approaching the cellular level but did not yet explicitly mention the cell division processes. How exactly the reproduction mechanisms on the cellular level works, and how the offspring 'receives the hereditary features' is still a problem for students, to be explored in the subsequent learning activity (LA 3).

Descending to the cellular level (1b)

The first partial question was answered in LA 2: *By means of what process does the offspring receive hereditary features from their parent(s), and is the offspring identical to the parent(s)?* The students had compared the two reproduction mechanisms, the processes by which the offspring receives hereditary features, on the organismic level and had discussed and reasoned that in AR the offspring is (genetically) identical to the parent, and in SR not. Albeit, in the whole class discussion and reflection (LA 3) on this assignment it became clear to them that the connecting step between parent(s) and offspring was still missing in their explanation, and that this step should be explored in more detail in order to adequately answer the partial question. Consequently the following new question was raised: *What exactly is passed on that determined the hereditary features, and how is it passed on?* The need for descending was evoked. Data analysis showed that in practice these questions were largely raised by the teachers.
In the whole class discussion (LA 3), the essence of the two cell division processes and the crucial difference between them should be relatively easy to reason out of the students' knowledge of similarities and differences on the organismic level; all

the groups of students had answered in LA 2 that in AR the offspring is identical to the parent and in SR reproduction it is not. These findings should make the connection with the cell division processes (mitosis and meiosis) natural, and the transition to the cellular level logical and meaningful.
However, in the second case study the teacher simply mentioned the cellular level and the cell division processes as the step in between parent(s) and offspring at the beginning of LA 3 (fragment [2^1:2.C.29]), and referred to it as prior knowledge of the students. Unfortunately, it was not tested whether the students could come up with this solution themselves in a whole class reflection on LA 2.

[2^1:2.C.29], T is teacher.
T: So, in case of these two methods there should happen something different in the organism.[…]
Well, you already have had cell division processes last year. When we are looking at growth and wound healing in our bodies, what do we want these cells to do?
Jeroen: To divide.
T: But what kind of division?
Marian: Mitosis?

The teacher of the third case study first draws schemas of sexual reproduction and asexual reproduction on the blackboard, in interaction with the whole class (figure 4.6). LA2 already indicated that in case of SR students had reasoned the connection between parents and offspring. They had mentioned the reproductive cells and the zygote that originated from the fusion of egg cell and sperm cell. So, the schema of SR with the process 'in between' the parents and offspring on the cellular level originated without difficulties in the whole class discussion and is depicted in figure 4.6. In case of AR the cellular level was not mentioned yet. The students as well as the teacher refer to the 'mechanism in between' as growth (fragment [3:1.C.30]). During the discourse the teacher draws the AR schema on the blackboard (figure 4.6).

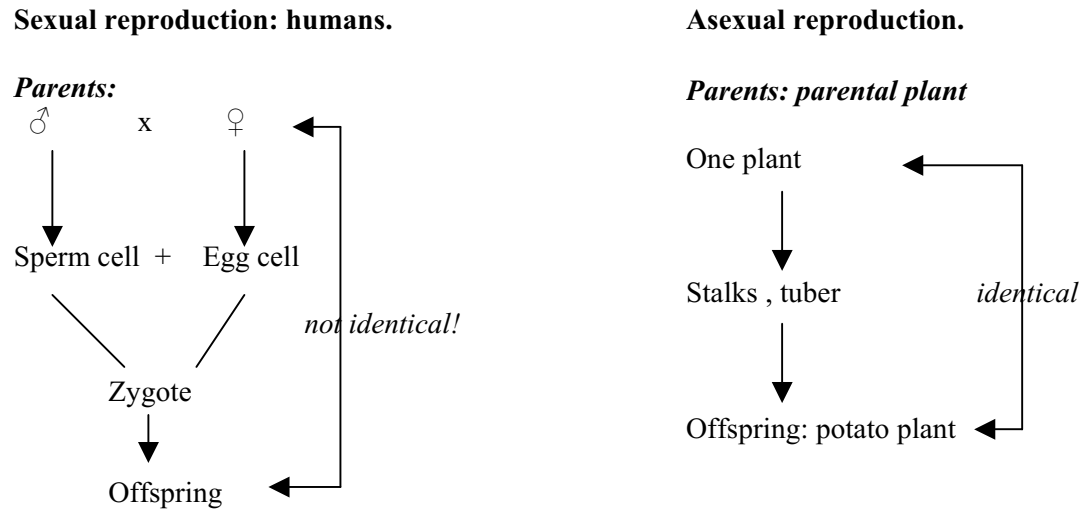


Figure 4.6 ***Teacher's drawings on the blackboard while discussing on AR and SR.***

[3: 1.C.30], T is teacher
T: Well who invented a similar schema for the potato plant*?*
Mieke: One plant.
T: I heard one plant, okay one parental plant. And what does it do?
Klaas: It makes all stalks beneath and above the soil.
T: Those are called tuber.
Klaas: Yes, and from this, little plants originate I thought.
T: In what way?
Klaas: Well that first grows...Alfonso has written it down.
T: So, this grows into…?
Alfonso: Little potato.
T: Indeed, into a new parental or potato plant. Have these potatoes, those potato plants also inherited something from this parent?
Alfonso: They are the same.
T: They are indeed the same. So, you may truly say that they inherited something. They are namely, like Alfonso indicated, completely the same.

The quotation shows that the discourse remains on the organismic level. Klaas and Alfonso indicate that the offspring originates by growth. The teacher draws the conclusion that the offspring has to inherit something, because they are the same as the parental plant.
Subsequently, the schemas were used by the teacher to make the connection with the cell division processes.

[3:2.C.31], T is teacher.
T: So at this point we have…?
Lisa: Egg cell.
T: Correct. What is happening at point 4?
Luuk: Fertilisation
T: Fertilisation, very well. And the cell that originates from the process of fertilisation is called?
Luuk: Zygote.
T: Yes, zygote. And as you know this cell subsequently is going to…?
Linda: Divide?
T: Divide, and how do we call that with …
Guido: Cleavage.
T: Cleavage, really nice. Well, finally after a lot of cleavages a child will originate.
So, we are talking about a zygote and cell division; it is written on the blackboard.

Fragment [3:2.C.31] shows that in case of SR students mentioned cell division, and apparently the term 'cleavage' is common in this class. Out of the SR mechanism the transition to the cellular level seems relatively easy to appear.
In case of AR the students of the third trial had more difficulties in connecting this mechanism with cell division like the next quotation shows.

[3:2.C.32], T is teacher.
T: On the other side [*of the blackboard*] asexual reproduction. Are we talking about cell division too in this case? In case of the potato plant?
Alfonso: No!
T: No? You have a potato plant, and you can see in that schema that a subterranean stalk grows and swells at a certain moment. That is becoming the potato. How does growth work? Yes? You have two possibilities, when you have for example eight cells, then you can make it grow by enlarging the eight cells, but you can also make eight more cells. Then it also

becomes two times as big. What did you say?
Piet: Is growth the making of more cells?
T: Yes, making more cells that is actually growth. Well you have had two schemas, one of the human and one of the potato plant. Where does growth really take place? In other words, where does cell division take place? Let us first look at the potato, we have the stalk.
Alfonso: Where does it grow.
T: At the stalk is growth, indeed. You can see at this point the making of the new potato. The making of the new cells so the stalk is swelling. That is a matter of cell division. There is a rule in biology that says: every cell originates from a cell. Every cell must originate from another cell. Every cell, so also these cells. Also reproductive cells originate from another cell, therefore this cell has to divide. And in case of that potato plant, you have growth, multiply potatoes, split off of potatoes, and those are becoming new plants. Here it reads identical. So, apparently from the cell division process cells originate that are identical to the first cell.
Simahla: Cloning.
T: Cloning, very good.

Alfonso's first reaction is that there are no cell divisions in a potato plant, while he mentioned earlier that the offspring grows at the mother potato plant, fragment [3:1.C. 30]. Apparently Alfonso did not make the connection between growth and cell division in the plant on his own. The teacher makes the connection between growth and cell division by asking *'How does growth work?'* and the concluding answer *'making more cells in actually growth'*. Subsequently he raised the question '*Where does growth, i.e. cell division, actually takes place?*', and the students were able to point that out in the schema. Next, the teacher refers to the AR schema on the blackboard in which they had established that the offspring in AR is identical to the mother plant, and concludes from that observation: *'So, apparently from the cell division process cells originate that are identical to the first cell'*. This was recognised by the students as cloning.
Moreover, the teacher tries to illuminate the analogy between the cell division process related with AR and the growth of the zygote in the human life cycle, in the whole class discussion.

[3:2.C.33], T is teacher.
T: Cloning, very good. But here [*referring to the schematic drawing of SR*] we have a division where that does not happen. This has to be a very special division. When I take the four-cell-stage in this drawing [*worksheet sexual reproduction*] that has originated from the zygote after how many divisions?
Tim: Two.
T: Two divisions. And when I would separate that lump of cells in two, what would originate from that?
Esther: Twins.
T: And what kind of twins?
Guido: Monovular.
T: A monovular or monozygotic twin, and what are the two members of a monovular twin?
Guido: Identical.
T: They are identical. So, you can see here [*referring to the schema of the potato plant*] that when in the normal division groups of cells originate, that you have two identical potato's, or two identical children, in this case.

First the teacher refers to the division of the zygote in SR (fragment [3:2.C.33]). The zygote grows and develops by means of cell division (mitosis). Secondly, he draws

an analogy between a division of the lump of cells that originated from the zygote in two (i.e. identical monozygotic twins) with the identical offspring in case of AR that also originated by means of cell division (mitosis). So, the analogy between AR resulting in identical offspring and growth in organism by division of cells (also identical 'offspring') was made.
Subsequently, the two cell division processes mitosis and meiosis are further explored and explained by the teacher. The teacher concludes that the only bond between parents and offspring are (reproductive) cells.

[3:2.C.34], T is teacher.

T: Well we are actually talking about heredity. You can see that as a matter of fact, heredity is in the cells. The only bond, the only real bridge I could say, between parents and offspring, can be nothing else then that one sperm cell and that one egg cell. Okay? That will be clear.
And now we ask ourselves, how are these cells formed. When I take a cell of the potato, then that cell can become two cells. [*Draws on blackboard: figure 4.7*] yes? That is cell division. When this cell contains hereditary information, apparently cells have that, what should happen then? Suppose that it contains the amount of hereditary information that I will call p. Then this cell should contain half p and this one a half p. Are those cells identical, like in the potato?

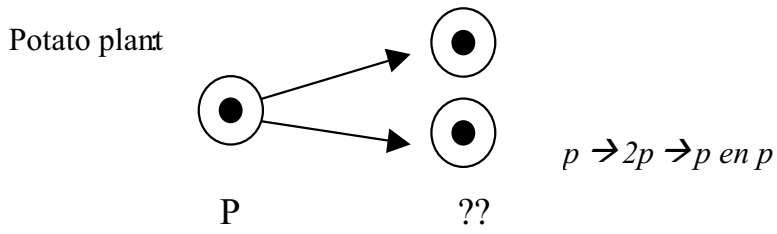


Figure 4.7 ***Teacher's representation of mitosis on the blackboard.***

Saskia: No.
T: No, this is what we want to have for result [*pointing at his drawing (figure 4.7) on the blackboard*]. So, what should this cell do before it is going to divide?
Lisa: Copy.
T: Yes Lisa. In fact it has to copy p into 2p, then purely divide those two p's.
Now the reproduction cells. Reproduction cells originate in the reproductive organs. Now we have a mother cell, we just call it mother and daughter cell because the germ cell is feminine, does not depend on anything else. So, I have here a cell where for instance sperm cells from originate. [*Draws on blackboard: figure 4.8*].
It contains information p, no we call it q, because the potato already had P. Then this cell will, like every other cell does, copy. q becomes 2q, so this one contains the amount of q and this one. Are we done now?
Lisa: No.
T: Why not?
Mark: It still has to divide into two, because…
T: No, we are still at the first step. What did you say? And how many will I have when I draw this picture for the formation of an egg cell and the same for a sperm cell? An egg cell and sperm cell merge, how many q after fertilization? How many q will be in that cell?
Mark: Oh, uh well…one.
T: One? In this scheme it is two. When this is an ovum and another scheme will form a sperm, you will have q + q = 2q. Is that the goal? So, what will happen?
Simahla: They will divide.
T: Indeed. And this one too and this one too. When fertilization occurs, you will have: ½ q, ½ q become one whole q again.

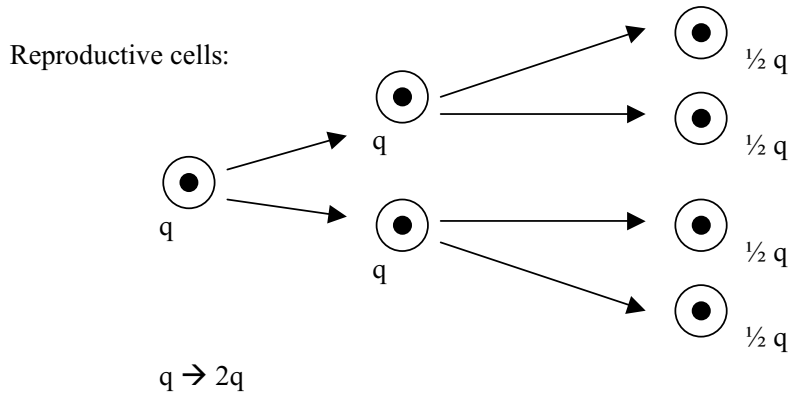


Figure 4.8 ***Teacher's representation of meiosis on the blackboard by the teacher.***

The fragment shows that the teacher cross-refers to the overall subject hereditary and draws the conclusion that 'hereditary must be in the cells' because that is the only bond between parent(s) and offspring. So, at this stage the partial question *What exactly is passed on that determines hereditary features and how is it passed on?*, is answered on the cellular level.
However, the process of meiosis appears somewhat out of the blue. Students more or less accept the fact that the process of meiosis results in '*½ q*' per gamete, but they have not reasoned this on their own. In the line of comparing AR and SR it would have been logical that the students had reasoned the process of meiosis starting from the knowledge of mitosis and the reproduction mechanisms. We have shown that students knew (fragment [3:2.C.31]) that in case of SR the zygote grows by means of cell division ('*cleavage*') in. This knowledge was used to reason the kind of cell division process that had to occur in AR in which the offspring is identical to the parent, in which the hereditary basis is copied. Subsequently, students should have reasoned the process of meiosis out of the (provided) fact that the chromosome number in a species remains the same, and their knowledge that in SR two reproduction cells merge that result in a zygote (and non-identical offspring). These indications should enable students to reason the essence of meiosis, that gametes contain half the number of chromosomes.

Concluding this section, we can say that the transition from the organismic to the cellular level is made by connecting the cell division processes (mitoses, meiosis) to students' findings of identity and non-identity between parent(s) and offspring. However, in retrospect we have noticed that this transition is strongly guided by the teachers. We argued that the process of meiosis should have been reasoned by the students themselves on the basis of their knowledge of mitosis and the AR and SR mechanism.

Descending from the cellular (1b)

The exploration of the organismic level and the transition from the organismic to the cellular level has been discussed in the previous section. In this section we focus on the transition from the cellular level to the molecular level (analysis question 1b).

First the cellular level was further explored in LA 4 to LA 6 (table 4.5). Students studied real cells and chromosomes under the microscope and mitosis and meiosis were shown on video film. In LA 7 and LA 8 (table 4.5) these genetics concepts were applied in a group work assignment; students had to discuss the influence of a mutation in a person's colon cell and gamete on the next generation (somatic and germ cell line in a life cycle). The gene concept was introduced in LA 9, and in the chromosome practical (LA 10) the genetics concepts of the organismic level had to be interrelated with the genetics concepts of the cellular level. Besides, the partial question explored on the cellular level (*What exactly is passed on that determines hereditary features and how is it passed on?*), could now be answered in more detail. Namely, chromosomes are the cellular structures that contain the hereditary information and these are passed on to the offspring by means of (reproductive) cells that originate from mitosis (AR) or meiosis (SR). The next partial question raised was: *What exactly are chromosomes (and genes) and how do they determine hereditary features?* In order to answer this partial question chromosomes should be explored in more detail, and students need to descend to the molecular level (LA 14 and LA 15, table 4.5).
Data analysis of the transcribed audio-tapes of the genetics lessons showed that in the second case study the molecular level was not introduced at the intended spot in the learning and teaching sequence. In the third case study the transition to the molecular level occurred at the intended spot, i.e. after chromosomes and genes had been introduced and students had practised these concepts in application assignments (e.g. chromosome practical, genetic cross problem).
Prior to introducing the molecular level the teacher first repeated the steps that had already been taken in the genetics course, in particular the descending of levels of biological organisation. After descending from the organismic to the cellular level and finally pointing out the chromosomes, the teacher explicitly indicated that a next step had to be made, by descending to the molecular level.

[3:9.C.35], T is teacher.

T: Well, we are still looking inside that cell, and we see chromosomes. We have learnt by now that there are genes on the chromosomes, we called them alleles in genetic cross problems. Now we have another step to make. Because we referred to a barcode, but what exactly is that substance?

Tim: Isn't that deoxyribonucleic acid?

T: Poeh, poeh that is it! Deoxyribonucleic acid, DNA. And then we are looking really detailed. We are looking at molecules. Because DNA is a molecule. It is in fact a really big molecule. So, when we look at inheritance we are not only looking at individuals, organisms, but actually we also have to keep in mind that we are dealing with molecules which accomplish it all. Well what is DNA? It is a barcode, a recipe how you like to call it to create a certain feature. Suppose you want to make a colour, pigment.

The fragment shows that the teacher refers to the concepts chromosomes, genes and barcode, and asks students what substance it is. Students instantly react with DNA. The teacher does not explicitly mention the 'descending to the molecular level', but he refers to it as '*looking really detailed, looking at molecules*', and he explicitly cites that DNA is a (big) molecule. Next he questions '*What is DNA?*' Subsequently the discourse continued to answer that question.

The molecular level was further explored and the teacher explained that DNA is a kind of long chain (molecule) that consists of four kinds of beads A, C, T, G (adenine, cytosine, thymine, guanine), and together with the (sugar-phosphate) backbones they form the DNA helix. Metaphors like a ladder and steps, a language with an alphabet of four letters that can form words and sentences, and a recipe book, were used. A model of DNA was shown. Moreover, the teacher explained that parts of the DNA are called genes and that they code for amino acids, which build proteins outside the cell nucleus. So, the connection between DNA (chromosomes), genes and hereditary traits (until now only explained and used on the cellular level) was made on the molecular level. Besides the teacher connected the DNA with the regulation of processes in the cell and discussed DNA in the context of the cell, using the blackboard (figure 4.9).

[3:10.C.36], T is teacher

T: Are things happening in cells on their own? Suppose you had a cell and a lot of substances together, a kind of chemical factory. When those substances would spontaneously react with one another it would be chaos. And an organism is not called for nothing organism, it refers to the term 'organisation'. No, in the cell nothing happens without agreement of the cell, or else there would be something wrong with that cell. Well, how does the cell regulate those processes? Who does know how we call substances that get processes going?

Tom: Catalysts.

T: He is great isn't he! Well cells have catalysts, we only call them differently here: enzymes. Enzymes are the substances that should be built. And enzymes are proteins. So what actually happens in the cell when we want to make that colour [*referring to his starting example of the colour of a cows' fur*], there [*draws and points at blackboard schema*], a message has to be delivered from the nucleus in that direction. So, from the chromosomes so to speak the message 'make that protein' is sent, because then the process will develop. So, we have a message here [*points at the drawing on the blackboard*]. How is that message for the formation of an enzyme laid down in the nucleus?

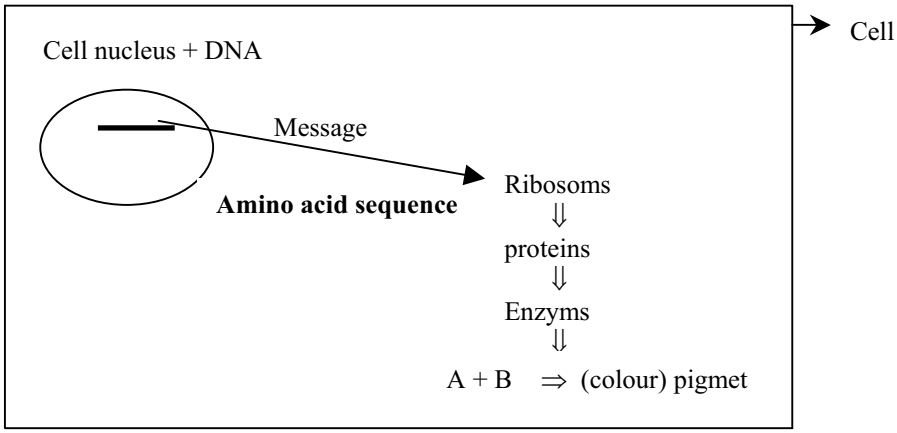


Figure 4.9 ***Teacher's visualisation on the blackboard of how DNA regulates cell processes.***

Stef: On his back?

T: In what shape?

Stef: As a gene?

T: As a gene, and where does a gene consist of?

Els: Of molecules.
T: What molecule?
Stef: DNA.
T: Very well! So, in that big molecule DNA, the recipe to form proteins is established. And that protein is the origination of that feature of that organism, such as the colour of the cell in our example. So, you will understand that in that cell, the DNA is really complicated.

The teacher concludes (fragment [3:10.C.36]) that the DNA in the nucleus holds the messages (*'recipes'*) for the formation of proteins, which play an important role in regulating cellular processes (e.g. colour or pigment in the cows' fur). The molecular structure is explicitly related with the cellular processes and explained in the cell context. The teacher explains that *'things do not happen in cells on their own, otherwise it would be chao*s' and asks students '*How does the cell regulate these processes?*' Students were aware that '*catalysts*' (Tom) or enzymes get the chemical reactions going, and the teacher connects the 'DNA-message' from the nucleus with the protein synthesis.
Although the transition to the molecular level was not the main focus in the LT strategy, we may conclude that the teacher adequately linked the molecular structures in the cell nucleus with the cellular processes in the cell and thereby positioned and interrelated the molecular structures in the context of the cell.

Analysis question (1b) '*Are students able to descend (zoom in) meaningfully from the organismic level to the cellular level, and from the cellular level to the molecular level?'* can be affirmed. Students were indeed able to descend from the organismic level via the cellular level to the molecular level. However, in retrospect we have to conclude that the teachers often strongly guided this process. In the reflection activities the teachers were filling in more than would be desirable in a problem posing approach.

Interrelating the levels of biological organisation (1c & 1d)

Besides descending the levels of biological organisation, the scenario also intended to ascend and interrelate these levels. In the previous section we already showed that students were able to ascend to the population level. Two learning activities were specifically designed for interrelating the hereditary phenomena on the different levels of biological organisation, LA 7 and LA 10 (table 4.5). LA 7 and LA 10 were expected to guide students back and forth between the organismic and cellular level, to make them yo-yo between these levels of biological organisation. LA 10 will be subsequently outlined and discussed in order to answer analysis questions 1c and 1d. In LA 10 the chromosome practical and the whole class reflection on this practical (LA 11) students had to follow processes and to relate the genetics concepts (hereditary traits, sexual reproduction, meiosis, chromosomes, genes, alleles) dealt with in the preceding learning activities, in a new situation. The learning activity guided the students from the organismic level to the cellular level and back to the organismic level. Solving the problems posed in this practical required to think backward-and-forward between those levels (Knippels *et al.*, 2001).

In the chromosome practical, a box with paper strips that differed in length and colour (representing chromosomes) was available for every group of students (figure 4.10).

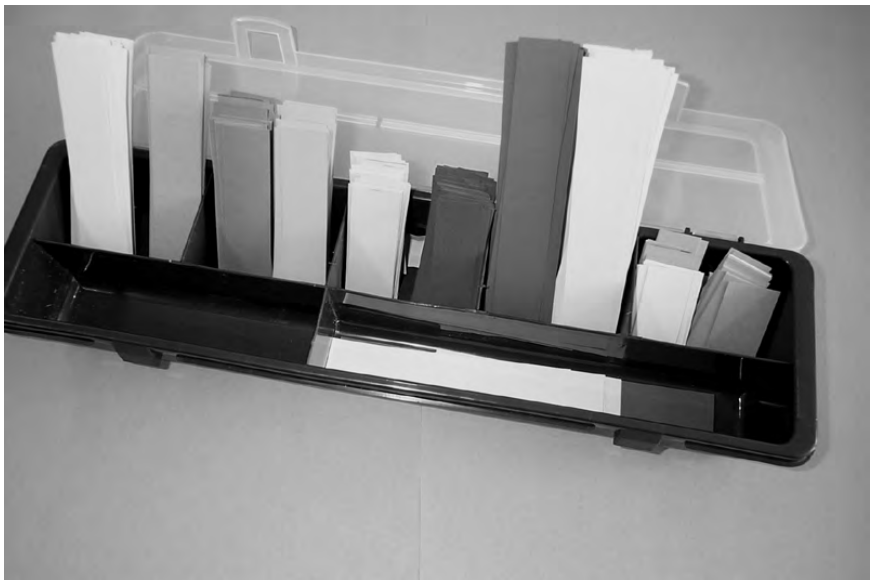


Figure 4.10 ***Chromosome box students used in the chromosome practical LA 10.*** *Consisting of 10 piles of paper strips, varying in length and colour, representing chromosomes.*

The activity started on the organismic level, by selecting four genetic traits of a well-known family. Next, students had to select three pairs of chromosomes out of the box in order to constitute a somatic cell of the father and a somatic cell of the mother. Subsequently, they had to form gametes by the process of meiosis and finally choose the correct gamete combination for the offspring, i.e. the new chromosome and allel combination that corresponds with the genetic traits of the offspring established at forehand (figure 4.11).
So students had to relate various concepts and processes on the organismic and cellular level. Figure 4.11 shows the succeeding steps students had to take in chromosome practical and the involved switching between the organismic and cellular level.

In general the students were well able to go through all the successive steps in the chromosome practical, and they were enthusiastically discussing the hereditary traits in their family, the possible chromosome combination, and were puzzling to get the correct chromosome combination in parents and offspring.
Mostly, students were well able to solve the problems they encountered in the practical by consultation of and discussion with the group members. But, when students really got stuck, the teacher guided them by asking questions that took them to the 'higher' level of biological organisation (with which they were already familiar).

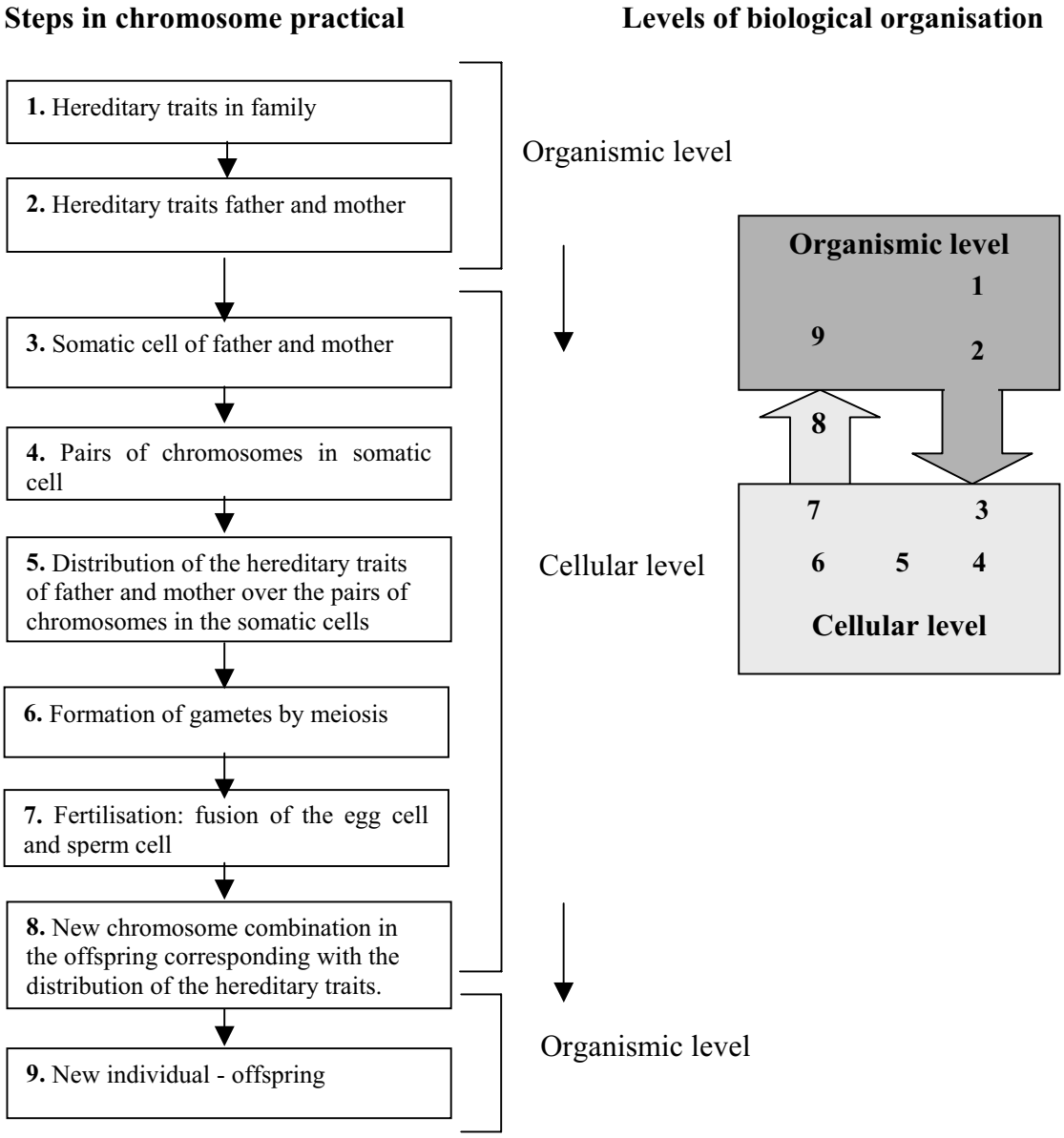


Figure 4.11 ***Successive steps in the chromosome practical representing hereditary phenomena on different levels of biological organisation.***

The next quotation illustrates how the questions of the researcher (co-assisting in the chromosome practical) guided students to the organismic level in order to solve their problem. This fragment shows that the students of the group disagree on the homologue chromosome concepts, and call in the help of the researcher.

[2^2:4.G.37], R is researcher.
R: What do you think is a pair of chromosomes?
Josien: This is a pair of chromosomes.
Maud: Well, we think this is pair of chromosomes, after normal duplication, they are pulled apart.
R: Okay, we are now looking at a normal somatic cell, yes? Which indeed can divide. But what is a pair of chromosomes? How did you receive those pairs?

Loes: You have 23 pairs of chromosomes. And 46 …[*interrupted by Josien*]
Josien: …23 of your father and 23 of your mother.
Loes: Now we have three pairs.
Josien: Father and mother [*pointing at the chromosomes of a pair*].
R: Yes that is a possibility. So you have so to speak a chromosome number 3 of father and one of mother. […]
R: So, now try to solve this problem.
Femke: For if you have two of those pairs,…
Josien: One of mother and one of father…. So they are not the same!
R: So indeed they are not exactly the same.
Femke: Oh yes, okay!

The researcher asks the students '*What a pair of chromosomes is'* and helps them to ascend to the organismic level by asking the question '*How did you receive those pairs of chromosomes?'*. This latter question made students think about the origin of the homologue chromosomes, and they indicated that one originated from mother and the other from father. So, they had to ascend to the organismic level, and rethink the reproduction process on that level, the formation of gametes ('*23 chromosomes of father and 23 chromosomes of mother'*) and rediscover the cause that resulted in non-identical homologue pair.
When students had to constitute the child with the correct combination of chromosomes according to the child's hereditary features (established at forehand), they actively linked hereditary features of the organismic level with hereditary phenomena of the cellular level, to verify their chromosome and gene division.

[2^1:4.G.38]
Yvonne: Well can we make all descendants with the according features? I think so. The according features are blond hair and blue eyes, isn't it?
Emma: Yes, but that means that all the offspring will have blue eyes and blond hair! That can't be right.
Renske: Oh yes, Indeed!
[…]
Emma: Well your mother is not blond is she?
Renske: No.
Emma: So that becomes 'aa' [*indicates recessive alleles (aa) on the chromosomes*]. I just assign them a location. And tongue rolling, is that dominant?
Yvonne: Yes, so many people can do that. Mostly it is dominant when so many people have it.
[…]
Emma: But we have a father *and* a mother.
Can we now make all the children? Otherwise…, look these are the cells of father and mother, and all three children have to originate from there, from the chromosomes of course. And with those chromosomes we need to be able to form all three children, otherwise you would have had another father or another mother.

The fragment [2^1:4.G.38] illustrates that Yvonne, Renske and Emma discovered that their chromosome and gene division was incorrect, because all the offspring would get blue eyes and blond hair. In order to detect their mistake, the students verified the allele division on the parents' pairs of chromosomes, with the parents' hereditary features: '*Well your mother is not blond, is she? So that becomes aa'*.
Besides, Yvonne's misinterpretation of '*dominant*' as synonymous to 'frequent', Emma guides them again to the essence '*but we have a father ánd a mother*'. In

order to solve their allele division problem (cellular level) she links father and mother (organismic level) with '*cells of father and cells of mother*' (cellular level), and that all three children have to originate from a chromosome combination of these parents' cells. So, in solving problems on the cellular level students ascended to the organismic level and linked hereditary phenomena on the cellular and organismic level.
In the first trial (section 4.3.3) one of the most important findings was that students were not very successful in ascending the levels of biological organisation when explaining a hereditary phenomenon. That students were able to interrelate the levels of biological organisation in this second trial was also confirmed by the written test, and is illustrated by Jack's and Daisy's answer on the written test.
The answer of Jack (fragment [2^2:7.T.39]) shows that he is able to relate a hereditary feature on the organismic level, albinism, with a mutation (in the cell) '*in the genes that are responsible for the pigment production*'. Moreover, he links the two recessive alleles (resulting in no pigment production) to the possibility that a person becomes an albino. Daisy (fragment [2^2:7.T.40]) specified that albinism is caused by a mutation in DNA whereby the pigment production is reduced and the person will have the disorder (albinism). She also links the molecular level (mutation in DNA) and cellular level (two recessive alleles resulting in less pigment production) with the hereditary feature albinism on the organismic level.

[2^2:7.T.39]
Jack: Albinism is caused by a mutation in the cell, in the genes that are responsible for the production of pigment. When a person (organism), does not produce pigment, it has two recessive alleles. Only with those two alleles someone can become albino.

[2^2:7.T.40]
Daisy: Albinism is caused by a mutation in DNA by which the production of pigment substances is highly reduced. The allel for the deviance is recessive, you need to have two recessive alleles in order to have the disorder [*Albinism*].

In contrast to the majority of the students of the first case study, the students in this second case study were able to link alleles with the (lack of) production of a substance (pigment) that has a certain effect in the organism (hereditary trait of pigmented skin). The phenotype of an individual will be albino when it has two recessive alleles. Or when both alleles produce the pigment (or actually code for the protein, enzyme, that enables the cell to produce pigment), the individual will have a pigmented skin. So we may conclude that these students are quite able to ascend from (the molecular level via) the cellular to the organismic level.

Analysis question 1c and 1d: *Are students able to ascend the levels of biological organisation (1d) and to interrelate the different genetics concepts on these levels (1c)?,* can be largely affirmed. Most students were well able to ascend from the cellular to the organismic level (e.g. LA 10) and to interrelate the genetics concepts on these levels. The previous section already demonstrated that students were able ascend meaningfully to the population level (LA 2). The (relationship between the) organismic and cellular level had the focus of attention in the scenario.

Consequently, students' descriptions of the relationships with the molecular level and the genetic concepts on this level were less detailed and less accurate.

Cross-referring to central question and explicating the levels of biological organisation (1a)

In order to make the steps in descending the levels of biological organisation more meaningful and explicit, two main revisions were made in the second LT strategy and the scenarios: 1) emphasis on and cross-references to the central steering question, and 2) emphasis on and explicit mentioning of the levels in the scenario and teacher's manual.

The previous section 'organismic level' already showed that the teachers explicitly introduced the central starting question. In lesson 3 the teacher referred to the organismic level and the central question. She repeated the first step taken in the genetics course: started on the organismic level by looking at external features of organisms, hereditary and non-hereditary traits, influence of environment, which leaded to the observation that you resemble your parents but are not identical to them. This observation was connected with students' daily life experiences with remarks such as '*you look like your father*' and '*you have your mothers' nose'*. Subsequently, the connection with the cellular level was explicitly made, in order to answer the (partial) question. The teacher referred to the descending (zooming in) of levels, and indicated that they are going *'to look at another level to see what is happening inside the organism'*. Moreover, she repeated the partial problem raised in the previous lesson that *'the difference in the two reproduction mechanism has to be associated with differences in the cell division process'*. Subsequently, they had a look inside the cell, and studied the hereditary material, chromosomes (LA 4 to LA 6), and the teacher connected this again with the partial problem of difference in offspring of sexual and asexual reproduction. The next step taken was to look *inside* the cells, '*inside the nucleus at the chromosomes'*, and to indicate that the chromosomes are to be observed at that moment. In the last lesson before the written test, the teacher again cross-refers to the central question and the organismic and cellular level.

It can be concluded that the scenario was carried out as intended in this respect. The teacher(s) explicitly mentioned the biological levels of organisation, and cross-referred to the central question during the genetics course. Also at the end of the course the central question was repeated in order to return to the starting point of the course.

The question remains whether the students themselves were able to distinguish these levels and apply them meaningfully in solving genetics problems. The succeeding meta-reflection phase, LA 16 to LA 18 (revision 4 in the second LT strategy, section 4.3.3) was built in in the second LT strategy and its scenarios in order to make the levels of biological organisation more explicit for the students. Moreover, it should enable students a) to distinguish the different levels of biological organisation, and to b) position the different hereditary phenomena on the different levels of biological organisation.

In the meta-reflection phase, the steps that had been taken in the previous lesson and the levels of biological organisation they referred to, were explicated in a whole class discussion. Besides, the need and the advantage of distinguishing the levels of biological organisation was indicated.

[2[1]:7.C.41], T is teacher

T: What's important is that you realise that you are going backward and forward between those levels. Biologists try to make a division in those levels, and look what is happening on a certain level, e.g. what is happening on the population level. And what is important to you, you have to become conscious of the fact that textbooks are not always dealing accurate with those levels, so they can jump up and down very often and do not adequately finish one level. We hope that you can indeed go backward and forward between these levels, while you also know, 'I am at this point, I'm talking about an individual' or oh yes 'wait we are talking about a population here, so we are talking about a group of people', 'and now we are going to look at the cells in that body, so I am on the cellular level'. Thus that you become conscious when you are reading a text what level they are talking about, what does that imply?

In addition, the levels of biological organisation were depicted on a handout (figure 4.12) and the students had to distinguish the levels in a text on sickle cell anaemia (LA 17, table 4.5).
In the written test students needed to distinguish the different levels of biological organisation in a text that dealt with the hereditary trait of albinism. The relative scores (%) per question per trial class are depicted in table 4.8. Question 1 stated: '*Divide the text on albinism according to the different levels of biological organisation'*. Question 2 stated: '*Explain why the chosen text fragments belong to that particular level'*.

Table 4.8 ***Relative number of correct answers to question 1 and 2 of the written test, measuring understanding of the concept 'levels of biological organisation'****. n is the number of students involved in the written test.*

		2nd case study		3rd case study	Total
	Class	4V1 (n=16)	4V2 (n=11)	4H (n=11)	(n= 38)
Question		(%)	(%)	(%)	(%)
1		70	80	70	73
2		70	70	50	63

Table 4.8 shows satisfactory understanding of 'levels of biological organisation'. Students were well able to distinguish the levels of biological organisation in a text on a hereditary trait and also knew why certain text fragments belong to a particular level of organisation. However, 4H students under-performed in explaining why the text fragments belonged to a certain level (i.e. 50% vs. 70%).

Levels of biological organisation

The levels of biological organisation are built of parts that can be considered as autonomous entities. For example: an organism is built of cells. Cells are built of molecules. A population consists of organisms.

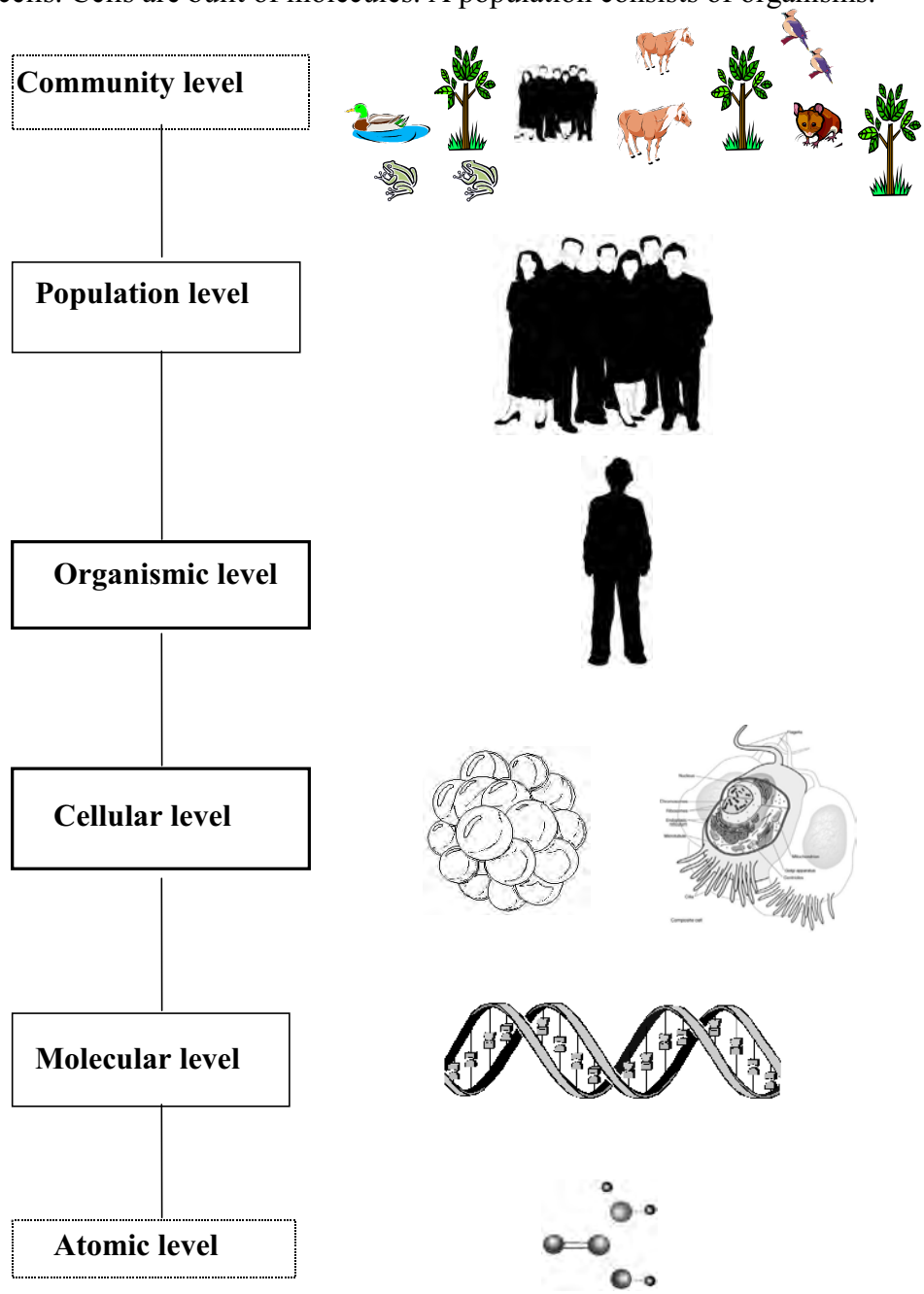


Figure 4.12 ***Handout students received on levels of biological organisation.***

So, analysis question 1a *Are students able to distinguish the levels of biological organisation*? can be affirmed. It was shown that students could distinguish the levels of biological organisation during learning activities in the genetics course as well as in the written test at the end of the course.
However, in retrospect we became aware of a shortcoming in the meta-reflection phase. The teacher did not explicitly answer the central question, nor invited the students to finally answer the central question. Besides, the central question was not part of the final written test. This is therefore a point of improvement.

Key concepts (2)

In the subsequent part of sections 4.4.3 we will discuss the learning and teaching processes and outcomes concerning the second key theme: key concepts. For the corresponding analysis questions the reader is referred to section 4.3.3, pages 76-77.

The somatic and germ cell line and the position of mitosis and meiosis in a life cycle (2a & 2b)

The learning and teaching strategy comprised different learning activities and situations through which the somatic and germ cell line and the position of mitosis and meiosis were explored.
A first move towards distinguishing the somatic and germ cell line and the related process of mitosis and meiosis was made in LA 2 (see section 1b 'organismic level' and 'descending to the cellular level'). LA 7 was designed to link the organismic and cellular level and to distinguish the somatic cell line and germ cell line in a new situation, i.e. within an individual's life cycle. Students had to solve the following problem concerning the relationship between sexual reproduction and gamete formation (meiosis): *How will the offspring be affected when a mutation occurs a) in the hereditary material of an individual's colon cell, and b) in the hereditary material of an individual's gamete?* Analysis of the audio-taped group discussions and written answers on the worksheet showed firstly that the discussions in the 4H class were less in-depth than in the 4V classes. The discussion of the 4H students focused on the problem whether the genetic material of a colon cell could be passed on to the offspring. For example they were reasoning *'it says 'hereditary material' of the colon cell, so it is passed on to the offspring, it is hereditary'* Also phrases like *'the gamete contains more hereditary information than a colon cell'* or even *'a colon cell contains only one hereditary characteristic, because it is a specialised cell'*.
The 4V students on the other hand agreed rapidly that the colon cell is not involved in the reproduction process, and that a mutation in the genetic material of an individual's colon cell would never be passed on to the offspring, in contrast to the gamete. All eight groups of students had reasoned this difference correctly. That the students were well able to reason the somatic cell line and germ cell line and that their explanations were more in-depth is illustrated by the written answer of Bob and Mart.

[2^1:3.W.42]

Bob: Gamete is 'yes', for the child that originates from this gamete. Colon cell is 'no', because that is not passed on to the child. Because the zygote goes through mitosis, the deviation is passed on through the whole body of the offspring, except for the reproductive cells, because there meiosis takes place. Therefore, the possibility on the deviation in the reproductive cells is 50%.

[2^1:3.W.43]

Mart: Colon cell is 'no', because it is not passed on to the children. Gamete is 'yes', it is a reproductive cell. Only passed on to one child, if the gamete is fertilised. The other gametes will not pass on the mutation.
Because the zygote goes through mitosis, the deviation is passed on to all the cells in the offspring, except for the reproductive cells. In the reproductive cells, the damaged chromosome does not have to be in all the cells; by means of meiosis only two of the four cells that originate can have it. So, there is a 50% chance that the child will not have the chromosome.

----- = Chromosome of Mieke [*offspring*] with a deviation

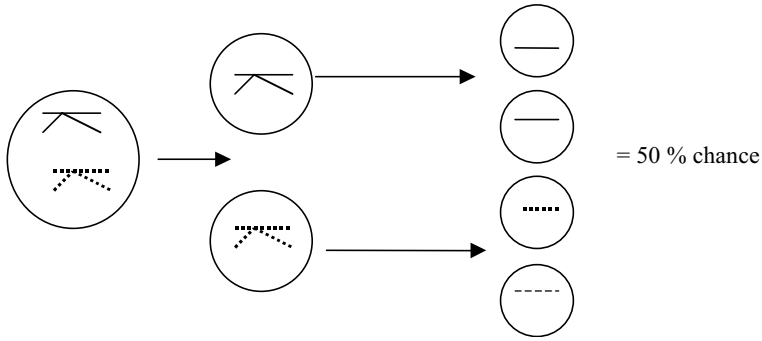


Figure 4.13 ***Accompanying drawing on Marks' worksheet to clarify his written answer.***

The quotations of Bob and Mart show that they reasoned and explained that the mutation in the gamete will only be passed on to the offspring when that particular gamete is fertilised, and consequently the mutation will be in every cell of the offspring's body because the zygote divides by means of mitosis. Besides, they indicated that the *offspring* could pass on the mutation to her offspring, but that the chance would be 50% because the gamete is formed by means of meiosis. So, they were even reasoning one extra generation ahead. We may conclude that the life cycle concept seems clear to these students and that they are well able to distinguish and describe the biological meaning of the somatic and the germ cell line in a life cycle. Moreover, they were able to explain the position of mitosis and meiosis in the life cycle (analysis question 2b).

A homework assignment (LA 7A) according to a questionnaire designed by Lewis *et al.* (2000; 2000a), invited students to indicate in four tasks in which different cell types of one person were compared, whether the genetic information in these cells was the same or different and why. The situations were: 1) two cheek cells of Robert; 2) one cheek cell and one nerve cell of Robert; 3) One cheek cell and one sperm cell of Robert; 4) two sperm cells of Robert. A fifth task was the comparison between a cheek cell of Robert and a cheek cell of John. The results of this

assignment in the second case study are depicted in table 4.9 (in the third case study only three students had made this homework assignment).

Table 4.9 ***Response frequencies in two classes regarding the homework assignment on the comparison of the genetic information in somatic cells and germ cells in different combinations (T1-T5)**.*** *The correct answers are depicted in bold.*

Class 4V1 (n=17)	*T1*	*T2*	*T3*	*T4*	*T5*
The same	**16**	**14**	2	3	0
Different	1	3	**14**	**13**	**17**
I do not know	0	0	1	1	0
Class 4V2 (n=12)					
The same	**12**	**8**	0	2	0
Different	0	4	**12**	**9**	**12**
I do not know	0	0	0	1	0
Total correct answers	**28** (97%)	**22** (76%)	**26** (90%)	**22** (76%)	**29**(100%)

***** Comparing tasks:
T1: two somatic cells of the same type (cheek cells)
T2: two somatic cells of different types (cheek cell and nerve cell)
T3: one somatic cell and one germ cell (cheek cell an sperm cell)
T4: two germ cells (sperm cells)
T5: two somatic cells of the same type of different individuals (cheek cells).

Table 4.9 shows that most students correctly answered these questions. In order to determine whether students' understanding of the continuity of genetic information within and between generations was adequate too, we need to consider their explanations next to their ticked responses. It proved that also the line of thinking of the majority was adequate. The students indicated that all somatic cells contain the same genetic information, because they all originated from one cell, the zygote, by mitosis. Some of them even explained that in different cell types different genes are activated. We may conclude that most students were aware of the continuity of genetic information between cells within one individual, and that they could correctly distinguish and explain the differences between the somatic cells and germ cells. Besides, all the students were aware that the genetic information in two cheek cells from different individuals are different (T5 has a 100% score).
Although most students solved these problems adequately some of them had difficulties at this stage in the learning and teaching sequence. Table 4.9 shows that T2 and T4 were the most troublesome (76%).
In T2 seven students answered that the genetic information in a cheek cell and a nerve cell of Robert are different. However, one of these students explained that '*there could be differences in the genetic information due to mutations that occurred' (Edwin, T1 and T2)*.
The line of thinking of the other six students was that the genetic information is related to the cell function. Although, they were well able to explain the difference

between a gamete and a somatic cell (*'the one has 23 chromosomes and the other has 46' (T3, Ilse*), they indicated that the genetic information in a cheek cell and nerve cell of Robert are different.

[2^1:3.W.44]
Pim: T2: Different it has another function so different information.

[2^2:3.W.45]
Maaike: T2: Different, because they are different type of cells, they have a different function.

In T4 five students answered that two germ cells of Robert would contain the same genetic information.

[2^1:3.W.46]
Gerda: T4: The same, because these are reproductive cells, both 23 chromosomes.

[2^1:3.W.47]
Wendy: T4: The same, they are cells that originated from the same zygote, they both have 23 chromosomes.

[2^1:3.W.48]
Emma: T4: The same, both reproductive cells.

Besides, these five students all correctly indicated that two different types of somatic cells would contain the same genetic information (T2) and moreover that a germ cell and a somatic cell would be different (T3). So, the students know that germ cells do not contain the same genetic information as somatic cells, and that all somatic cells in a person *have* the same genetic information. Overall we may conclude that these students don't know that homologue chromosomes are different.
Two students indicated that the genetic information in a sperm cell and cheek cell of Robert (T3) is the same (table 4.9). They explained this as follows.

[2^1:3.W.49]
Joost: T3: The same, merely this cell contains only 'n' and not the 2n of a cell. So, they contain the same information only the one 2n and the other n.

[2^1:3.W.50]
Renske: T3: The same, but in sperm cells you have 23 chromosomes, but with the same information as that of the cheek cell with 46.

These answers seem to indicate confusion on the homologue chromosome concept as 'identical'. Renske and Joost are both aware that gametes contain only half the number of chromosomes (i.e. '*23'* and *'n'*), but they think this half contains the same information as a diploid cell. However, in T4 they indicated that the genetic information in two sperm cells of Robert are different (T4).

[2^1:3.W.51]
Joost: T4: Different, both cells have 'n', only they do not have exactly the same.

[2^1:3.W.52]
Renske: T4: Different, for example one chromosome for blue eye colour and one for brown, but one is dominant and the other is recessive.

These answers show that Joost and Renske know that the chromosomes of a homologue pair are *not* identical, otherwise the gametes would be identical too. The term 'information' may be confusing, because the chromosomes of a homologue pair contain the same *genes*, but the content (alleles) of these genes can differ on the two chromosomes. When Renske says that '*the 23 chromosomes in the gamete contain the same information as the 46 chromosomes in the cheek cell'* she could mean that those 23 chromosomes also contain all the genes, because the 46 chromosomes contain all the genes in duplicate. Her answer in T4, in which she explains the occurrence of two different alleles in one homologue chromosome pair, underlines this thinking pattern.
The understanding that somatic cells in an organism contain exactly the same genetic information, because they all originated from the zygote through mitosis, was also probed in the written test. Students had to answer the next question (8):'*The needles on one limb of a pine tree differ in length. Does this difference depend on a difference in genotype? Explain your answer.* The relative scores in question 8 are depicted in table 4.10.
In total 33 students (87%) correctly answered that this difference in length did not depend on a difference in genotype. However, the students' explanation was not always complete or fully accurate, what explains the relative score of 60.
Hanna for instance wrote that *'all genes are the same in the whole tree'*. Probably she meant that the gene that codes for the length of the needles is the same in all the cells of the whole tree, but she did not explicitly say so. Her answer was therefore marked as wrong. Renske and Mart for example, both indicated that *'all the cells are the same'*, in fact all the genotypes in the (somatic) cells are the same, and Renske even confused 'mitosis' and asexual reproduction in which the mechanism is mitosis. Daisy correctly indicated that it is a difference in phenotype, but did not explain why the genotypes in the cells are the same. So, most students knew that all somatic cells have the same genotype, but they did not always explain this correctly in their written answer.
In a multiple-choice question (6) of the written test students had to position the processes that occurred between parents and offspring (translation of the arrow between P en F1 in a genetic cross) in the correct time order: meiosis, fertilisation, and mitosis. (The relative scores of the students in the second and third trial are depicted in table 4.10.) The answers to this question indicated that most students (70-80% in 4V classes) understood the position of meiosis and mitosis in the life cycle. That most students knew what processes take place in what time order in between parents and offspring (the link between two generations) also contributes to an affirmative answer to analysis question 2c: *Explain and reason the relationship between sexual reproduction, meiosis and inheritance*.

Overall the analysis questions 2a *Are students able to distinguish and describe the biological meaning of the somatic and the germ cell line in a life cycle?* and 2b *Are students able to explain the position of mitosis and meiosis in a life cycle?* have an affirmative answer too. Most students were able to adequately distinguish and position these biological concepts in the context of inheritance.

Table 4.10 ***Relative number of correct answers (%) to the questions of the written test at the end of the genetics course, per class***. *MC is a multiple choice question and O is an open question. n is the number of students that participated in the written test. Class 4V1 and 4V2 are part of the second case study, class 4H is part of the third case study. Only the questions that were posed in the written test of both case studies are depicted in this table.*

Question	Class	4V1 (*n*=16)	4V2 (*n*=11)	4H (*n*=11)	Total (*n*= 38)
1	O	70	80	70	73
2	O	70	70	50	63
3	O	90	90	50	77
4	O	60	60	30	50
5	O	90	80	70	80
6	MC	80	70	50	67
7	MC	80	50	50	60
8	O	60	50	70	60

Short clarification of the questions posed in the written test:

Question 1: Divide the text on albinism according to the different levels of biological organisation.

Question 2: Explain why the chosen text fragments (of question 1) belong to that particular level.

Question 3: Explain the relationship between reproduction, meiosis and inheritance.

Question 4: Give 4 differences and 2 similarities between the process of mitosis and meiosis.

Question 5: Point out a homologue chromosome pair in the schematic drawing of a cell and explain why it is a homologue pair.

Question 6: Position the processes that occurred between parents and offspring (translation of the arrow between P en F1 in a genetic cross) in the correct time order: meiosis-fertilisation - mitosis.

Question 7: A figure of a chromosome consisting of two chromatids was depicted. Students had to identify this figure as such.

Question 8: The needles on one limb of a pine tree differ in length. Does this difference depend on a difference in genotype? Explain your answer.

Relationship between sexual reproduction, meiosis, and inheritance (2C)

Whether students were able to explain and reason the relationship between sexual reproduction, meiosis and inheritance (analysis question 2c), was probed in different ways and at different points in the learning and teaching sequence. The chromosome practical (LA 10) was an important test and will be discussed in the subsequent section (2d).

Another source was the written test. Question 6 (table 4.10), discussed in the section 'The somatic and the germ cell line and the position of mitosis and meiosis in a life cycle', indicated that students knew that meiosis, fertilisation, and mitosis are the processes linking two generations. Moreover, an open question (3) in the written test explicitly asked: '*Explain the relationship between reproduction, meiose and inheritance'*. Particularly the students of the second case study were very well able to explain this relationship correctly. Like table 4.10 shows the relative score of

correct answers to question 3 was in both 4V classes 90%. The written answer of Silvia shows how well the students of the 4V classes were able to describe this relationship.

[2^2:7.T.53]
Silvia: *Reproduction* is generating offspring, this happens by means of sexual intercourse, an egg cell of the woman and a sperm cell of the man come together. These are both haploid cells and together they form a diploid cell. Haploid cells (that is reproduction cells) are formed through *meiosis*. [*She clarifies the process of meiosis by means of a drawing of cells with chromosomes during division*].
On the chromosomes that are in those cells are the genes of the parents. These are passed on to the child. The child inherits these features from the parents, that is *heredity*.

However, the students of the third case study (4H) scored considerably lower (50%, table 4.10). One of the reasons may be that the written answers of the 4H students were less univocal to interpret than the written answers of the 4V students. The answers of the 4H students were less extensive, and their wording was often ambiguous. It seems that these students had a lower linguistic competence than the 4V students, which is a disadvantage in a written test. In contrast to the 4V classes, the 4H class was a multicultural class (see table 4.1) in which a part of the students may have a bilingual upbringing. The written answer of Alfonso[3] illustrates the difficulties in univocally interpreting the written answers (it is translated with the same grammatical and verbal mistakes).

Chromosome behaviour and structure in the process of meiosis (2d)

The chromosome practical (LA 10 and LA 11) focused on highlighting and integrating key concepts (analysis question 2a to 2d inclusive). Because students had to simulate processes with coloured paper strips (chromosomes) this assignment gave much insight into students' understanding of the chromosome behaviour during meiosis and sexual reproduction (analysis question 2d).
The chromosome practical (see also section 'interrelating levels of biological organisation' and figure 4.11) incited students to reflection on their grasping of genetics concepts and to identifying gaps in their conceptual understanding. Especially misunderstandings on homologue chromosomes and the process of meiosis popped up, and students got to question these concepts in more detail. Most students were able to explore the solution themselves, because they could visualise and try out the cell division process and chromosome division behaviour, with the strips of paper.
Every step (see figure 4.11) in this practical might cause difficulties for students, and was designed among other things to expose the misunderstandings students still may have at this point in the learning and teaching sequence. Data analysis showed that in all three classes students encountered the same kind of difficulties and made the same mistakes, namely:

- The somatic cell of father and mother did not get the same lengths of chromosome pairs. Actually, students did make two different species.

[3] Alfonso: It connection is that for the making of child meiosis occurs and get the half of the features of the mother and the father to make the child about their heredity.

Mostly, students noticed their mistake, when they had to form the offspring out of the egg cell and sperm cell and they have a multitude of different lengths and colours of chromosomes.

- Traits (i.e. genes) got different locations on the chromosomes of father and mother. This shows that students did not know that genes have a fixed location on chromosomes, and that the genes are on the same locus on the same chromosome number.
- A hereditary trait visible in father (e.g. 'big nose') was only placed on a chromosome pair of father and was not placed in a different form (i.e. allele for 'small nose') on a chromosome in the cell of mother. They reason that father has a big nose and mother has not. So, there was a gap in their understanding of a gene for 'shape of the nose'. (Actually, it is a polygenic trait.)
- A trait is only marked on *one* chromosome of a homologue pair of chromosomes. This indicates that those students do not realise at this point that a hereditary trait is determined by the combination of genes (alleles), and that every gene exists two times, one on every chromosome of the homologue pair.
- The chromosomes of a homologue pair are glued together. This indicates the confusion with a chromosome that exists of two chromatids before a division, the characteristic 'X-shaped' chromosomes. So, students tended to think that the chromosomes of a pair are identical.

This confusion between homologue chromosomes and chromosomes that consist of two chromatids, emerged in all classes during the teaching sequence and showed to be very persistent (also indicated by the literature, section 3.2). This can be caused among other things, by the fact that chromosomes in textbooks are mainly depicted in the 'X-shaped' way.

This practical tried to overcome this problem by starting with two somatic cells of the parents. Students could see that in the process of gamete formation, one of the chromosomes of each homologue pair will be part of a reproductive cell. When the egg cell and sperm cell of these parents fuse, the homologue pairs of chromosomes in the child consist of one chromosome of father and one chromosome of mother (two strips of paper with the same length and different colour). Before the students got to the point of fertilisation, they first had to constitute the somatic cells of the parents.

The confusion concerning homologue chromosomes and a chromosome consisting of two chromatids is illustrated by the next quotation of a group discussion during the chromosome practical.

[2^1:4.G.54]
Renske: The essence is that we have three pairs. What did you say?
Yvonne: When you glue it together like this, is it than also a pair?
Renske: Officially they are connected like this.
Yvonne: Like this?
Renske: With such a thing [*referring to the centromere*].
Gerda: When are they connected like this?
Emma: When they …uh, when you have mitosis.

Yvonne: So, when they are duplicated.
Gerda: How does it… so what is a pair?
Renske: Like this.
Gerda: In reality they are twisted like this, or not*? [Probably referring to the DNA-helix]*
Yvonne: I think a chromosome consists of DNA.
Gerda: Oh yes, alright.
Renske: These are only three [*chromosomes*], you know, they are not three pairs.

In designing the practical it was decided to start with *three* pairs of chromosomes in the somatic cells. Besides, the students had to divide at least *four* hereditary traits over the three pairs of chromosomes. Consequently, they were forced to place at least two traits on one pair of chromosomes. In this way we could probe whether the students knew that one chromosome contains many genes. The next quotation of a group discussion shows its effectiveness.

[2^1:4.G.55]
Gerda: Oh, then it will be in the same sequence on every chromosome. Oh, so on every chromosome it is exactly the same.
Renske: No that is not the case. They are not the same. A man does also have an X and Y chromosome.
Gerda: Okay, but you divide four traits over three pairs of chromosomes, but we have four traits. How do you want to divide these?
Emma: So, one trait on one chromosome?
Renske: No, no.
Emma: But how…?
Renske: Because on this only will be, uh let me think, on this will be tongue rolling and here *[referring to one chromosome pair*] uh, will be blond and blue.
Emma: Is that possible?
Renske: Yes.

It should be noted that none of the groups placed all four traits on one pair of chromosomes. Some students 'solved' the problem of four traits and three pairs of chromosomes, by dividing two traits on the chromosomes of father and two traits on the chromosomes of mother. Most students realised that there was something wrong in their division of chromosomes and traits over the parents when they had to constitute the offspring. Out of the diploid cells of father and mother they had to form reproductive cells through meiosis (all groups of students knew that meiosis was the cell division process responsible for the gamete formation). At that point students needed to make a reasoned choice from the possible gamete combinations for the offspring. The new chromosome and allele combination in the zygote had to correspond with the hereditary traits of the child determined at the beginning of the assignment. This step made that the groups of students needed to reconsider and think-through their division of traits, like the next quotation illustrates.

[2^2:4.G.56]
Josien: Can you make all the descendants with the accompanying features? Do you know what that means! So, this is the father and this was the mother [*referring to the chromosomes that originated from father and mother*], your father and your mother, but they don't have unattached earlobes! So we have to change this into 'none' [*unattached earlobe*].
Loes: Yes indeed we have to do that for the father and the mother, because now we are just doing something without….

Josien: Okay. We are talking about the father and the mother, and they should be able to make all the descendants.
Loes: So 'none' 'none', this is mother, and that is also 'none' because curls and wave is from mother. *[The students are adjusting the alleles on the chromosomes of father and mother*]
Josien: Your father doesn't have curls.
Loes: No. Then I have also 'none'. And we are both right handed. Yes, like this it is alright!
Josien: Yes, but you need to be able to form everything [*all the children with the right hereditary features*]. But that, your brother can not carry that. It does depend on what is dominant.

The quotation shows that when Josien and Loes needed to form the offspring, they reconsidered their division of alleles on the homologue chromosomes of the parents. In order to form the children with the corresponding hereditary features determined at the beginning of the practical, Loes and Josien saw that they had to change some alleles of father and mother, e.g. 'attached earlobes' into 'unattached earlobes'. The fragment illustrates that the design of the practical made students encounter there own mistakes, and that they were able to solve most difficulties on their own, in co-operation with the group members.
In conclusion, this chromosome practical was a very successful learning activity, because students were enthusiastically discussing their genetics concepts and difficulties they encountered in simulating the processes. The visualisation of the genetic processes on the organismic and cellular level and the fact that they had to actively carry it out with strips of paper and genetic traits of a real family made them finally understand it much better. Mostly, students could solve the problems they encountered in the practical by consultation of and discussion with their group members, like quotation [2^2:4.G.56] illustrated. Moreover, the teacher could guide them when they got stuck, by asking questions that guided them to the 'higher' level of biological organisation (outlined in section 1d).
Finally, in the whole class discussion and reflection on the practical (LA11) the difficulties students encountered were discussed. The teacher used the strips of paper on the blackboard to accompany this discussion and reflection, and to rehearse the key concepts and processes (i.e. diploid cells, homologue chromosomes, position of genes and alleles, meiosis, gametes and fertilisation, new chromosome combination in the offspring).
The written test showed that finally most students were well able to distinguish between homologue chromosomes and a chromosome that consists of two chromatids. In an open question (5) of the written test students had to point out a homologue chromosome pair in a schematic drawing of a cell and had to explain why it was a pair. All the students (100%) had pointed out the homologue chromosome pair correctly, and most students were also able to explain adequately why it was a homologue pair (80% table 4.10) like the written answers of Hanna and Renske illustrates.

[2^2:7.T.57]
Hanna: They contain the same *kind* of hereditary information, the information itself may differ, but the gene for eye colour has to be on both chromosomes will they be a homologue pair.

[2^1:8.T.58]
Renske: They have the same length and shape and contain the same traits.

Moreover, question 7 (multiple choice) showed a figure of a chromosome consisting of two chromatids. Students had to identify this figure as such. The average scores on this question in the second and third trial are depicted in table 4.10. 24 out of 38 students (63%) indicated the figure as a chromosome. There were still 5 students (13%) who thought the figure represented a homologue chromosome pair, while they correctly identified the homologue chromosome pair in question 5. However we may conclude that the persistent confusion of a homologue chromosome pair and a chromosome that consists of two chromatids was effectively coped with at the end of the genetics course. The consistent emphasis on the parents that pass on a gamete to the next generation, which contain one chromosome of every homologue pair, which from the new homologue pairs in the offspring (a 'father chromosome' and a 'mother chromosome') showed to pay off.

Genetic crosses

The insertion of genetic cross problems was an explicit request of the biology teachers of the case studies. It was our assumption that when students know and can reason the main relationships in inheritance, they should not find it hard to solve genetic crosses meaningfully. So teachers could dedicate two more lessons on genetic crosses after this trial, but they did not rely on it. We complied with their worries and inserted two activities in the chromosome practical (but not extra lessons to exercise all kind of genetic crosses). Firstly, students had to depict the family they used in the chromosome practical in a family tree, and to indicate the heredity of one genetic trait in the family tree. Secondly, the family tree was used by the teacher in the class discussion to demonstrate a first monohybrid cross as follows: a) the strips of papers (chromosomes) were attached next to the persons in the family tree to visualise the hereditary of the trait in this family, b) the family tree was erased, and only the chromosomes with the alleles (represented by a letter on the strips of papers) were left and used to demonstrate a monohybrid cross, c) the chromosomes (strips of paper) were left out and only the symbols (alleles) were used in the genetic cross. Subsequently, the students had to practice a few genetic crosses in a homework assignment. The attention paid to the genetic cross problems in the second and third trial was restricted to these two activities. Moreover, the teachers preferred to test the students' ability to solve genetic cross problems, after this limited exercise. This could help them to estimate the number of lessons they still had to dedicate to genetic crosses. Therefore, genetic cross problems were added to the written test and were selected by the teachers. Consequently these questions differed in the second and third trial. In the second trial the teacher selected two genetic cross problems, question 9 a to 9c and question 10 (table 4.11). In the third trial the teacher also selected two problems outlined in table 4.11.

It may considered strange that the focus of the learning and teaching sequence was not on exercising genetic cross problems, considering that most difficulties described in the literature on genetics education (see section 3.2) stem from the genetic cross problems, and were the reason to start this research project. However, the results of the written test show that the students were able to solve the genetic cross problems.

Table 4.11 ***Relative test scores (%) concerning genetic cross problem solving at the end of the genetic course, per class****. MC indicates a multiple-choice question and O an open question. N is the number of students that participated in the written test. Class 4V1 and 4V2 are part of the second case study; class 4H is part of the third case study.*

Question	Class	4V1 (*n*=16) (%)	4V2 (*n*=11) (%)	Total 4V (*n*=27) (%)	4H (*n*=11) (%)
9a	O	90	70	80	
9b	O	100	60	80	
9c	O	90	50	70	
10	MC	30	50	40	
9	MC				50
10	MC				70

4V, question:

9: A black cock is crossed with a white hen. All the descendants are fine spotted (illustration of the different chickens). They mutually reproduce.
9a: Draw up the Punnett square to the F2 including. Make use of Az and Aw.
9b: Which phenotypes occur in the F2 in what proportion?
9c: Which genotypes occur in the F2 in what proportion?

10: Chickens have different shapes of combs (illustration of the combs). The shape of the comb is determined by the dominant alleles P and Q and the recessive alleles p and q. These are not X-chromosomal. The table shows the relationship between genotype and phenotype for the shape of the comb. A man has a cock with a normal comb and a hen with a walnut-comb. From mating of this cock and hen five chicks originate: 2 with a normal comb and 3 with a walnut-comb. The man wants only chickens wit a rose-comb. Therefore he sells the 5 chickens, and wants to exchange his cock and hen. Is it better to exchange his cock for another cock, or to exchange his hen for another hen in order to get only chickens with a rose-comb? And what phenotype does the other cock or hen needs to have?

Presence of alleles	Type of comb
P and qq	Rose-comb
Q and pp	Pea-comb
P and Q	Walnut-comb
pp and qq	Normal-comb

A: A cock wit a pea-comb
B: A cock with a rose-comb
C: A hen with a pea-comb
D: A hen with a rose-comb

4H, question:

9: Some plants are not able to produce chlorophyll. This so-called albinism rests on the presence of one recessive allel. In tobacco plants that are heterozygotic for this feature self-fertilisation occurs. 600 seeds originate. After germination sprouts originate. How many of these sprouts will expected to be albino? A: 0, B: 150, C: 300, D: 600.

10: A homozygotic black-hairy guinea pig is crossed with a homozygotic white-hairy guinea pig. All the descendants (F1) have the phenotype of one of the parents. Two of these descendants are crossed with each other. The major part of their descendants (F2) will be expected to be, A: homozygotic, B: heterozygotic, C: have the phenotype determined by the dominant allel, D: have the phenotype determined by the recessive allel.

Even without the extra lessons to rehearse genetic cross problems students were already able to solve these problems rather well. The students of class 4V1 for scored extremely well on question 9 (90%, 100% and 90%, table 4.11) on a standard monohybrid cross. A complicated dihybrid cross (question 10) proved to be more troublesome at this point (30% and 50%, table 4.11). Our assumption that when

students understand the main line in inheritance and can reason the main relationships in heredity between parents and offspring would create the basis students needed to solve genetic problems, proved to be correct. It can be assumed that the students will be well able to solve the more difficult genetic crosses after one or two lessons of practising.

Analysis question 2c and 2d can both be largely affirmed. Students were *able to explain and reason the relationship between sexual reproduction, meiosis and inheritance*. The chromosome practical appeared to be very helpful. Besides, students could *explain and reason the process of meiosis and chromosome behaviour & structure (2d)*. Finally, students were able to insightfully solve monohybrid and simple dihybrid genetic cross problems without much training.

Conclusion second and third scenario in practice

The main results of the learning and teaching processes in practice have been outlined in accordance with the key themes (levels of biological organisation, key concepts) of the scenario and LT strategy. The executed second and third scenario have been discussed and reflected on in order to answer the corresponding research questions:

1. *To what extent could the nature and sequence of the learning activities in the second scenario be considered adequate?*
2. *What indications can be extracted from comparison of the observed learning and teaching processes and outcomes with the scenario, for revising the learning and teaching strategy?*

In general the nature and sequence of the learning activities (*research question 1)* of the second and third scenario can be considered adequate. We saw that several difficulties in genetics education described in the literature and indicated by Dutch biology teachers (section 3.2 and 3.3) were solved to a considerable degree.
Analysis questions 2a to 2d (*key concept theme*) could all be largely affirmed. It can be concluded that most students were able to understand and explain that growth and development, and sexual reproduction are linked with different cell division processes enabling genetics continuity and diversity. Students were able to distinguish the somatic and the germ cell line in a life cycle, and link these with the cell division processes mitosis and meiosis. Besides, students were well able to adequately connect sexual reproduction with the process of meiosis and inheritance.
So, the important general line in inheritance, the relationship between these key concepts, was clear to the students. They knew that meiosis is the linking process between generations, and that reproductive cells are the entities that build the offspring and contribute to the hereditary information of the offspring. Although, some students had difficulties in describing every single step that takes place during the meiosis in detail, the majority understood that this cell division process results in gametes that contain half the number of chromosomes, one of every homologue pair. So, the essence of meiosis is clear to most students. Moreover, the difficult and confusing homologue chromosome concept was clear to most of the students during or toward the end of the genetics course. The chromosome practical proved to be a

critical event in this case, as well as the overall sequence and outline of the learning and teaching sequence in which the origin of the homologue chromosomes are emphasised. Namely, starting with the parents on the organismic level followed by the SR mechanism and the cytological processes involved (cellular level). Emphasising the process of meiosis which forms the gametes (link between generations), containing half the number of chromosomes, resulting in a new combination of chromosomes (again homologue pairs: one of each parent) after fertilisation in the offspring.
Moreover, it was shown that our assumption that understanding the main line in inheritance and the main relationships in heredity between parents and offspring provides a knowledge base to solve all kind of genetics problems, proved to be correct.

The analysis question 1a to 1d of the key theme, *levels of biological organisation*, could all be largely affirmed. Thus, with respect to the sequence of the learning activities in the second and third scenario *(research question 1*) it can be concluded that the overall sequence to start on the organismic level and to gradually descend to the cellular and molecular level, turns out to be adequate. The steps in descending the levels of biological organisation were more gradual, more meaningful and more explicit than in the first trial.
The intended learning objectives on the organismic level were largely attained. In the introduction and orientation phase students' first notions on hereditary and non-hereditary traits were incited, and the central question was posed. Besides, in accordance with the central question a partial question was raised (*By means of what process did you receive features from your parents?*) and connected with students' knowledge on reproduction. This partial question was studied and explored by the students in comparing the SR and AR mechanism. Students' discussion and argumentation on the two reproduction mechanisms remained primarily on the organismic level, as the learning activity intended. Moreover, a functional question in which the population level was explicitly mentioned indeed made students ascend to that level. In the reflection activity the solution to the next partial problem (*What exactly is passed on that determines hereditary features and how is it passed on?*) was discussed. The transition from the organismic to the cellular level was made by connecting the cell division processes (mitoses, meiosis) to students' findings of identity and non-identity between parent(s) and offspring. Moreover, the comparison (analogy) of asexual reproduction with mitosis in human life cycle was made. A new partial question was incited: *What exactly are chromosomes (and genes) and how do they determine hereditary features?* Consequently, this question evoked the need for descending to the molecular level. Students were able to descend from the cellular level to molecular level and that the molecular structures were connected with the cellular processes.
The teacher explicitly mentioned the levels of biological organisation as well as the transition of levels during the whole teaching sequence. Moreover, the central starting question was explicitly introduced and cross-referred to during the learning and teaching sequence. It was shown that students were able to distinguish the levels

of biological organisation and could explain why certain text fragments belonged to a particular level of biological organisation.
However, there were still some points in the learning and teaching sequence that could be improved. The two identified weak points will subsequently discussed.

1. Explicit answer to the central question

Although the central question was explicitly introduced and cross-referred to during the learning and teaching sequence, it was noticed that it was not adequately answered at the end of the learning and teaching sequence. There should have been a distinct moment in which the teacher reflected with the students on the steps made in the previous lessons and the answers to the partial questions, which should enable students to finally answer the main question *How is it possible that you look like your parents but that you are not identical to them?*. The answer to this central question should contain all the concepts previously dealt with on the different levels of biological organisation and the interrelation between them. (Hereditary traits and sexual reproduction and asexual reproduction on the organismic level. Reproduction on the cellular level: cells, cell division, gametes, chromosomes, genes, new genetic combination in sexual reproduction, half the number of chromosomes of father and half of mother, zygote. Organismic level: new individual (mitosis), influence of environment and upbringing). Moreover, this question should have been part of the written test, in order to verify whether students were able to formulate the essence of inheritance in their own words. Although this was probed by all kinds of different questions on inheritance, the central question was not put forward again.

2. Diminishing the teacher's role in reflection

It turned out that the reflection activities in the LT strategy were mainly carried out by the teacher and not by the students. Although problems and questions had been expressed in small group discussions, most partial questions were formulated by the teacher. So, the scenario was not completely executed as intended. It is questionable whether the students familiarised with these teacher's questions, let alone that they were able to formulate these questions on their own. Yet, the students were quite able to investigate and answer the partial questions and they did not show signs of disconnection from the LT process. The learning outcomes of the 4V-classes in the second case study were quite satisfactory (e.g. average test mark 6,7), in contrast with the results of the 4H class (e.g. average test mark 5,5) with many weak students (only four out of thirteen students of the 4H class moved up to the fifth form by the end of the school year). Maybe these less satisfactory learning outcomes could be attributed partly to not performing the reflection activities on their own. On being asked, the teacher told that he experienced difficulties in executing the reflection activities with these students and therefore took the lead.
In the scenario it was described that the teacher's role was to guide the process of reflection while the students' role is to guide the reflection by content, by expressing their difficulties in a learning activity, and by discussing their answers. An alternative approach could have been to invite students to reflect individually on the learning activity by writing down their answer to the partial question and by indicating any lack of clarity. After collecting students' answers and questions a

whole class discussion could be started, in which the students may feel more confident to participate. The teacher should then structure the discussion in reflecting on a) the answers and problems in the learning activity, b) the answer to the partial question, c) to the extent the central question can be answered, and d) formulating a new partial question.

Accordingly the following revision will be made in order to optimise the LT strategy for genetics:

1. The central question will be explicitly answered and cross-referred to at the beginning of the meta-reflection phase (LA 16 third version, table 4.12), and the question will be integrated in the written test.
2. The teacher's role in the reflection activities will be diminished by integrating individual reflection time for the students (table 4.12). In the subsequent plenary discussion it is reflected on a) the answers and problems in the learning activity, b) the answer to the partial question, c) to the extent the central question can be answered, and d) formulating a new partial question.

So, in comparing the observed learning and teaching processes and outcomes with the scenario (*research question 2*), we can conclude that:

1. the overall sequence of the LT strategy for genetics (i.e. starting at the organismic level and gradually descending to the cellular level) seems adequate;
2. the steps in descending have become more gradual, more meaningful and more explicit than in the first trial. Although some transitions still can be improved, because the reflection activities were not fully carried out as intended;
3. students were able to ascend the levels of biological organisation, although the ascending from the molecular level to the cellular level remained less accurate. Maybe not surprisingly, because the core and focus of the LT strategy was on the organismic and cellular level, and not on the molecular level;
4. students were well able to distinguish the levels of biological organisation, and to (implicitly) yo-yo between the levels of biological organisation and the hereditary concepts of these levels.

Summarising, we can state that although we have established considerable improvement compared to the first LT strategy there are still some minor adjustments to be made in order to make the LT strategy for genetics more adequate. Consequently, we have not reached full maturation yet. The third and final yo-yo LT strategy for genetics will be outlined in section 4.5. So far we may state that the reshaped yo-yo strategy for genetics, can be graded as 'good enough'. The yo-yo strategy is an adequate way of dealing with the abstract and complex nature of genetics.

4.5 Reshaping the second learning and teaching strategy

The second and third scenario in practice resulted in the identification of two points of improvement. Accordingly, the second yo-yo LT strategy for genetics has been reshaped, resulting in the third and final yo-yo LT strategy for genetics (table 4.12).

The revisions made compared to the second outline of the LT strategy for genetics are highlighted in grey.

Table 4.12 ***Outline of the final yo-yo LT strategy for genetics.*** *Abbreviations: learning activity (LA), asexual (AR) and sexual reproduction (SR). Revisions are highlighted in grey.*

Sequence of problems	Sequence of learning activities
What does inheritance mean and how do hereditary traits look like?	**LA 1***: Introduction and orientation on the* ***organismic*** *level.* Globally orientating and motivating students in a class discussion by referring to their real life experiences of hereditary in humans, discussing their notions on (non)hereditary features, the influence of upbringing and environment on these personal features, which leads to students' amazement and questioning of what is experienced as obviously: • *How is it possible that you (offspring) look like your parents, but that you are not identical to them?* ***Central question(CQ)***
What are the mechanisms for passing on hereditary traits?	Referring to students' prior-knowledge: reproduction links parents and offspring (SR). There are also organisms with (almost) identical offspring (AR). • *What does SR distinguish from AR?*
	LA 2*:Group work, jigsaw method: Investigating SR and AR on the organismic level* by*:* Schematising and comparing the steps of AR and SR cycle. Comparing the advantages and disadvantages of AR & SR for the *population.* • Discovering AR offspring identical, SR offspring not identical to parents. • Discovering that in ***AR*** there is one parent and in ***SR*** a union of egg and sperm cell, originating from mother and father respectively, takes place. • Experience now (reflection in action) or in LA3 that they encounter a new question.
What are the structures that are passed on in the AR and SR mechanisms? By means of which processes are these structures formed?	**LA 3***: Individual reflection students on LA 2 followed by a plenary reflection: Towards the* ***C****ellular level.* Class discussion and comparison of the group answers of LA 2: Topics discussed: differences and similarities in AR and SR; advantages and disadvantages of the two reproduction mechanisms; schemas of the two reproduction cycles. For SR the concepts: egg cell, sperm cell, fertilisation, zygote, and new individual. • Answer to question posed in LA1 and link this to the CQ: difference is that in AR there is one parent. In SR a union of egg and sperm cell, originating from mother and father respectively, takes place. • Which evokes the need to explore: *What are the structures that are being passed on in SR and AR and how are they passed on?* Need for descending to the ***C****ellular level.*
What are the structures in the cell that account for passing on hereditary traits?	**LA 4**: *Whole class discussion and explanation (information) on the* ***cellular*** *level of cells and chromosomes*: By means of the schemas and knowledge about AR & SR it is established that ***cells***, which contain the hereditary information, are being passed on to the next generation. The cell division process ***mitosis*** is discovered in the discussion by referring to students' prior-knowledge on growth (i.e. zygote divides, grows, by mitosis). • Mitosis is linked to AR. In AR dividing cells, which contain chromosomes, are the vehicle. In AR offspring is (almost) identical to parent, so in mitosis chromosomes must be copied. In SR offspring differs from parents, due to a combination of gametes of both parents. The preceding cell division processes ***meiosis*** can be reasoned starting from the knowledge of mitosis in AR (offspring identical to parent) and the fixed number of chromosomes.
Where are chromosomes	**LA 5:** *Individual and group work investigating the cellular structures and cell*

located and what happens to chromosomes during cell division?	*division processes.* Looking at *real* cells and chromosomes under a microscope and at photographs of dividing cells with visible chromosomes. Looking at the cell division processes mitosis and meiosis on video. **LA 6***: Individual reflection students on LA 5 followed by a plenary reflection. Discussing what structures students have seen and recognised under the microscope and how these structures behave in the cell division processes.* • Resulting in the answer to question posed in LA3: Chromosomes are located in the cell nuclei. In AR the chromosomes are copied and divided equally among the daughter cells (*mitosis*). So the parent cell divides to form two identical cells. In SR two successive cell divisions result in four germ cells, each containing half the original number of chromosomes (*meiosis*). • This insight makes students wonder: *How do these cell division processes fit in the life cycle of multi-cellular organisms?*
How do mitosis and meiosis fit in the life cycle of multi-cellular organisms?	**LA 7**: *Group work*: *Application of previous genetics concepts to a new problem: relating the **organismic** level and the **cellular** level (yo-yo), by distinguishing the somatic and the germ line in an individual*: • Discussing the influence of a mutation in AR on the next generation. • Discussing the influence of a mutation in the hereditary material of a cell in SR (i.e. colon cell and gametes) on the next generation. Students relate in their own words: hereditary features of the offspring with the hereditary basis of the parents; mitosis and meiosis with the somatic line and the germ line respectively; AR with the somatic cell line, and SR with the germ line. Students realise what they (do not) understand yet and or where they get stuck in their reasoning pattern (reflection in action). **LA 7A:** *Homework assignment 'Cells of Robert': Application of the somatic and germ cell line concept to a new situation on the **cellular** level.* Comparison of the genetic information in different cell types of one person in different combinations (of somatic cells and germ cells). **LA 8**: *Individual reflection students on LA 7 followed by a whole class reflection, discussing and comparing students' group answers,* • Resulting in answering question posed in LA 6: AR is analogous to the ***somatic cell line***: from the zygote ongoing mitosis leads to growth and development. Any mutation in this cell line will not affect the next generation, contrary to a mutation in the ***germ cell line.*** • Formulate new partial question: *How exactly do chromosomes determine the different hereditary traits in an organism?*
What makes chromosomes determine the different hereditary traits in an organism?	**LA 9***: Plenary explanation (information) and discussion on:* Chromosomes, *genes and alleles*. Discussing students' first notions on genes (number of genes in humans). Chromosomes contain ***genes*** (and alleles) which instruct the cell to produce all kind of ***proteins***. The latter have different structural and functional roles, which are expressed in hereditary traits. Relationship gene and protein.
How do genetic traits on the organismic level relate to chromosome structure and behaviour on the cellular level?	**LA 10**: *Group work chromosome practical: application of gene, chromosome, cell, cell division, reproduction, hereditary trait -concepts, to a new situation (yo-yo): relating the **organismic** and **cellular** level.* Active integration and visualisation by means of coloured paper strips (chromosomes) of somatic line and germ line; process of meiosis and gamete formation; formation of a zygote; chromosome behaviour during these processes; gene arrangement; relationship gene location and genetic traits in the offspring. **LA 11***: Individual reflection students on LA 10 followed by a whole class discussion and reflection on the chromosome practical.* Comparing and discussing students' findings of the chromosome practical. Relating and discussing the concepts: genetic traits, genes, chromosomes, and homologue chromosomes. Inheritance, sexual reproduction, meiosis, gametes, zygote, mitosis,

- Resulting in answering the question posed in LA 8, and in a contextualised and integrated picture of the relationships between the genetics concepts on the cellular and organismic level.
- Following the genetic make-up of their own family makes them wonder: *how unique is a person's genetic basis?*

How unique is a person's genetic basis?

LA 12: *Individual task calculating variety*.
Calculating how many genetic different gametes one individual can form and how many genetically different zygotes one parent-couple can form, to get an idea of the huge variety.

LA 13: *Individual reflection students on LA 12 followed by a whole class discussion and reflection.*
Comparing students' answers on LA 12. Notions on variety and biological meaning of SR are discussed: the forming and fusion of gametes in SR are random processes, which add to an enormous ***genetic diversity***, i.e. unique individuals.

- Students are wondering: *How do genes work?* → Need to descend to the molecular level.

How do genes work?

LA 14: *Individual investigation and application task. Transition from cellular structures (chromosomes) to the* ***molecular*** *level.*
Critical reflection on a newspaper article reporting on the identification of chromosome 22. Students identify the biological questions that arise when reading the article and students note how they picture chromosomes and genes and what they are built of.

LA 15: *Individual reflection students on LA 14 followed by a plenary reflection and providing additional information.*
Students' answers are compared and discussed. Additional explanation is provided on the chromosome, gene and DNA structure.
Answer to question posed in LA 13: The genes in the chromosomes are made of ***DNA***, which stores and faithfully transmits information. The information-carrying capacity of DNA comes from the 4 bases; they are 'read' as if they were letters, making up words of three bases long. These words give the information needed for building proteins, and for organising the activity of the cell.

Meta-reflection phase

Which levels of biological organisation has been transected in succession?

Which hereditary phenomena, features and processes are characteristic for the different levels?

LA 16: *Whole class reflection on the successive questions and answers in the genetic course and reflection on the related levels of biological organisation*.

- Explicit answer to the central question by integrating all the previous steps.
- Distinguishing the different levels of biological organisation.
- Relating different activities in the genetics course with the levels of biological organisation.

LA 17: *Individual task. Application of the levels of biological organisation to a different genetics context*.

- Distinguishing different levels of biological organisation in a text on a hereditary disease.
- Describing the main features and phenomena of the hereditary disease topic per level of biological organisation.

Students recognise the advantages of distinguishing the levels of biological organisation and yo-yo between them in grasping the hereditary topic.

LA 18: *Plenary reflection on LA 17:*
Discussing and comparing students' answers to LA 17.
In descending from organism to cells and molecules and ascending vice versa biological structures, processes and concepts can be interrelated enabling us to build up a coherent conceptual understanding of heredity. This ***backward-and-forward thinking*** is helpful in grasping hereditary phenomena.

Chapter 5

The yo-yo learning and teaching strategy

5.1 Introduction

The preceding chapters described and discussed the design, process, and outcomes of the developmental research study. Chapter 4 outlined the development, testing and reshaping of the LT strategy in three successive case studies, which finally resulted in the third and final version of the yo-yo LT strategy for genetics (section 4.5).
In this chapter we will reflect on the final version of the yo-yo LT strategy for genetics. In section 5.2 its didactical structure will be illuminated and the central research question of this thesis will be answered. This section will elucidate the essence of the yo-yo LT strategy. In section 5.4 focus is on the developmental research approach (chapter 2) and on the teacher's role in particular. The wider applicability of the yo-yo LT strategy will be discussed in section 5.3 and in section 5.5 future research directions will be suggested.

5.2 Reflection on the yo-yo learning and teaching strategy

In the introduction of this thesis we referred to recent developments in biological science and education, and to learning and teaching theories in order to define our position in the research field. We discussed the usefulness of the problem posing approach (Klaassen, 1995) and the importance of interrelating the levels of biological organisation due to the transecting character of genetics. The biological key concepts and the main line should be emphasised to enable students to obtain a coherent and meaningful insight into genetics. The central idea in the yo-yo strategy for genetics is descending and ascending the levels of biological organisation.
With these elements of our philosophy of learning and teaching genetics in mind, we can distinguish two components of the yo-yo LT strategy for genetics (table 4.11): 1) the *genetics content structure* embedded in a number of levels of biological organisation, and 2) the *problem posing structure*. Distinguishing these intertwined components is relevant for two reasons. Firstly, it allows us to present a more formal description of the yo-yo LT strategy for genetics, and secondly, this distinction makes it possible to discuss the wider applicability of the strategy.

The genetics content structure

Component 1, the genetics content structure in the yo-yo LT strategy is outlined in table 5.1. The outline comprises the genetics key concepts classified by the levels of biological organisation and presented as a sequence of relevant biological questions and answers: the conceptual thread.

The problem posing structure

Component 2, the problem posing approach takes care of arousing and maintaining learning motivation. By eliciting content-related meaningful questions and answers in a well thought out sequence a learning pathway is paved. Actually, the problem posing structure refines the content structure.

Table 5.1 ***Content structure of the yo-yo LT strategy for genetics.*** *Key concepts are depicted in italic bold. AR is asexual reproduction; SR is sexual reproduction.*

Questions	Answers
Organismic level	Everybody is familiar with hereditary phenomena in families.
What makes you look like your parents, without being identical to them? (**central question**)	
	Sex life links parents and offspring (sexual ***reproduction***), but this does not apply to organisms that produce identical progeny (asexual reproduction).
What distinguishes sexual from asexual reproduction?	
	In ***AR*** there is one parent and in ***SR*** there is fusion of an egg and a sperm cell, originating from mother and father respectively.
What structures are being passed on in AR and SR?	
Cellular level	In AR as well as in SR dividing ***cells***, which contain nuclei with ***chromosomes***, are the vehicle.
What happens to chromosomes during cell division?	
	In AR the chromosomes are copied and divided equally among the daughter cells (***mitosis***). So the parent cell divides to form two identical cells. In SR a cell divides by two divisions into four germ cells, each containing half the original number of chromosomes (***meiosis***).
How does mitosis fit in the life cycle of multi-cellular organisms?	
	AR is analogous to the ***somatic cell line***: from the zygote mitosis leads to growth and development. Any mutation in this cell line will not affect the next generation, contrary to a mutation in the ***germ cell line***.
How do chromosomes determine the different hereditary traits in an organism?	
	Chromosomes contain ***genes*** (and alleles) which instruct the cell to produce all kind of ***proteins***. The latter have different structural and functional roles, which are expressed in hereditary traits.
How do genetic traits on the organismic level relate to chromosome structure and behaviour on the cellular level?	
	Fusion of two gametes forms a zygote with a random ***recombination of homologue chromosomes*** (and their genes) from both parents.
How unique is an individual's genetic make-up?	
	The forming and fusion of gametes in SR are random processes, which add to an enormous ***genetic diversity***, i.e. unique individuals.
Molecular level	
How do genes work?	The genes in the chromosomes are made of ***DNA***,

	which stores and faithfully transmits information. The information-carrying capacity of DNA comes from the 4 bases; they are 'read' as if they were letters, making up words of three bases long. These words provide the information needed for building proteins, and for organising the activity of the cell.
Meta-reflection Which levels of biological organisation have been transected in succession and what is the added value of thinking backward-and-forward between these levels?	
	In descending from organism to cells and molecules and ascending vice versa, biological structures, processes and concepts can be interrelated, thus enabling us to build up a coherent conceptual understanding of heredity. This ***backward-and-forward thinking*** is helpful in grasping hereditary phenomena

By activating students' prior knowledge and relating to real life situations a central question is posed that could serve as a global motivation. The sequence of partial problems (questions) should then serve as a content related motivation to explore the next steps in the learning and teaching sequence.
The problem posing sequence that can be recognised in the successive learning activities of the yo-yo LT strategy for genetics (table 4.11), resembles the didactical phasing of Kortland (2001), and is in accordance with Klaassen (1995) and Vollebregt (1998). It consists of the following steps:

i. Central steering question (posed at the beginning of the LT sequence; global motivation)
1. Partial question (PQ) and local motivation to explore and answer the PQ: creating a need for extending knowledge.
2. Information and/or investigation: extending knowledge.
3. Application: using the extended knowledge in a new situation.
4. Reflection: reflecting on the extended knowledge.

This kind of didactical structures in accordance with the problem posing approach has been well described and reflected on by Lijnse & Klaassen (2002).

The structure of reflection step (4) differs from Kortland's reflection phase (2001). The structure of the reflection step and its position within the problem posing sequence is outlined in figure 5.1. In the reflection step (4) of the problem posing sequence, the partial question posed at the beginning of the learning activity will be answered, so there is a feedback to step 1 (4a, figure 5.1). Subsequently, the answer to this partial question is linked with all the previous steps (partial questions) on the higher levels of biological organisation, in order to verify to what extent the central question has been answered at that point and to co-guide the formulation of the next partial question (4b, figure 5.1) (this part differs from Kortland, 2001). In these reflection steps (or during the investigation and/or application step, i.e. reflection in action) students experience what they do and what they do *not* understand or know yet, which should motivate them to take the next step in the learning sequence (4c,

figure 5.1) by formulating a new partial question with the central question in mind. With this new partial question the next sequence of four steps starts (4c, figure 5.1). The problem posing structure consists of a number of successive sequences, cycles, each consisting of four steps. Each new cycle starts with the formulation of a partial question that needs to be explored and answered in the next set of learning activities.

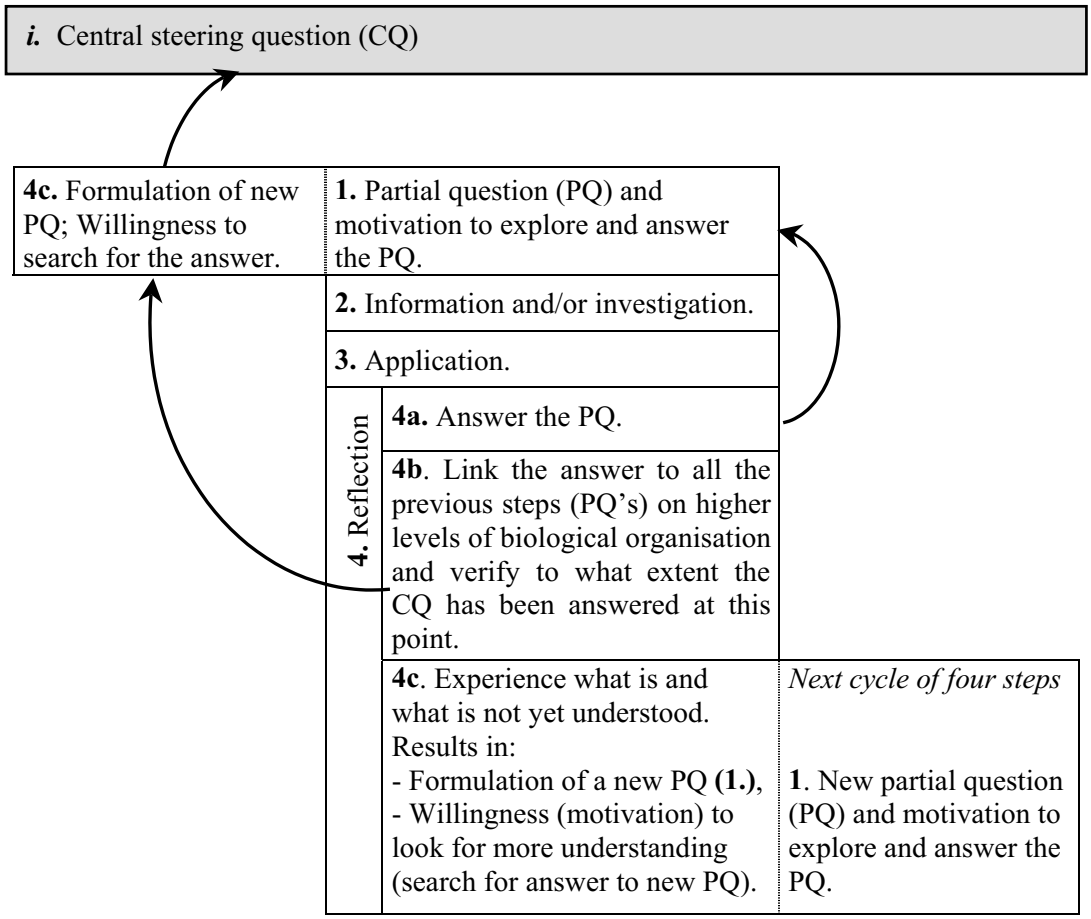


Figure 5.1 ***The structure of the reflection step and its position within the problem posing cycle.***

The heart of the yo-yo LT strategy

While going through these successive problem posing cycles in the yo-yo LT strategy for genetics, students gradually descend from the organismic level to the cellular level and finally to the molecular level. The feedback loops to the central question via the previous partial questions in the *reflection stage* correspond with ascending the levels of biological organisation that occurs. The essence of 'yo-yoing' is *not only* returning to the partial question that needs to be answered at that moment, but also coming back to the *previous partial question(s)* (on the higher level(s)), i.e. ascending (figure 5.2). In descending the levels of biological organisation none of the levels should be skipped. The same applies to the genetics key concepts, which can be considered steps in the conceptual structure.

This illustrates again the analogy with the toy 'yo-yo'. In handling the yo-yo it is impossible to skip part of the descending or ascending pathway. It is possible to yo-yo upwards and downwards, but the anchor and starting point is always the same: the hand that handles the yo-yo. In the yo-yo LT strategy for genetics the starting and anchor point is the organismic level, from where the levels can be descended and ascended (yo-yo downwards) but also ascended to the population and community level and descended (yo-yo upwards).
In the yo-yo LT strategy it is essential to go through, and complete, at least one problem posing cycle per level of biological organisation.

Summarising, the essence of the yo-yo LT strategy for genetics is descending and ascending the levels of biological organisation by means of the two intertwined components of 1) the genetics content structure, and 2) the problem posing structure, consisting of a number of cycles, each including four steps. Per level of biological organisation several complete problem posing cycles can be executed, depending on the number of key concepts and questions per level. At least one complete cycle has to be executed, however.
The general didactical outline of the yo-yo LT strategy is shown in figure 5.2.

Description of the yo-yo LT strategy according to the two components

In reflecting on the yo-yo LT strategy for genetics we illuminated the components in the strategy and described the essence of the yo-yo LT strategy on a more formal level (figure 5.2). This formalised description can be considered the domain-specific learning and teaching theory for genetics. In the yo-yo LT strategy for genetics five contents related problem posing cycles can be distinguished.

Cycle 1. Organismic level: hereditary features and reproduction

In cycle 1 the genetics key concepts on the organismic level are explored by means of the four successive problem posing steps. The yo-yo strategy starts with raising a central question (*i*), which will finally be answered in the meta-reflection phase, after going through the five successive cycles of partial questions and answers. The introduction and orientation activity globally orientates and motivates students by referring to and questioning their real life experiences of hereditary in humans, which leads to students' amazement and questioning of what is obvious to them, i.e. *What makes you look like your parents, without being identical to them?* (the central question, step *i* in the problem posing approach sequence). By activating students' prior knowledge on reproduction, i.e. the linking process between parents and offspring, a first step in answering the central question is made and a partial question (PQ1) can be formulated. Sex life links parents and offspring (sexual reproduction), but this does not apply to organisms that produce identical progeny (asexual reproduction), i.e. *What distinguishes sexual from asexual reproduction?* (step 1 in the problem posing sequence). Students look for the answer to this partial question while engaging in a group learning activity: step 2 in the problem posing sequence. After discovering that there are also organisms that are almost identical to the parent and by verifying what process connects parents and offspring (reproduction),

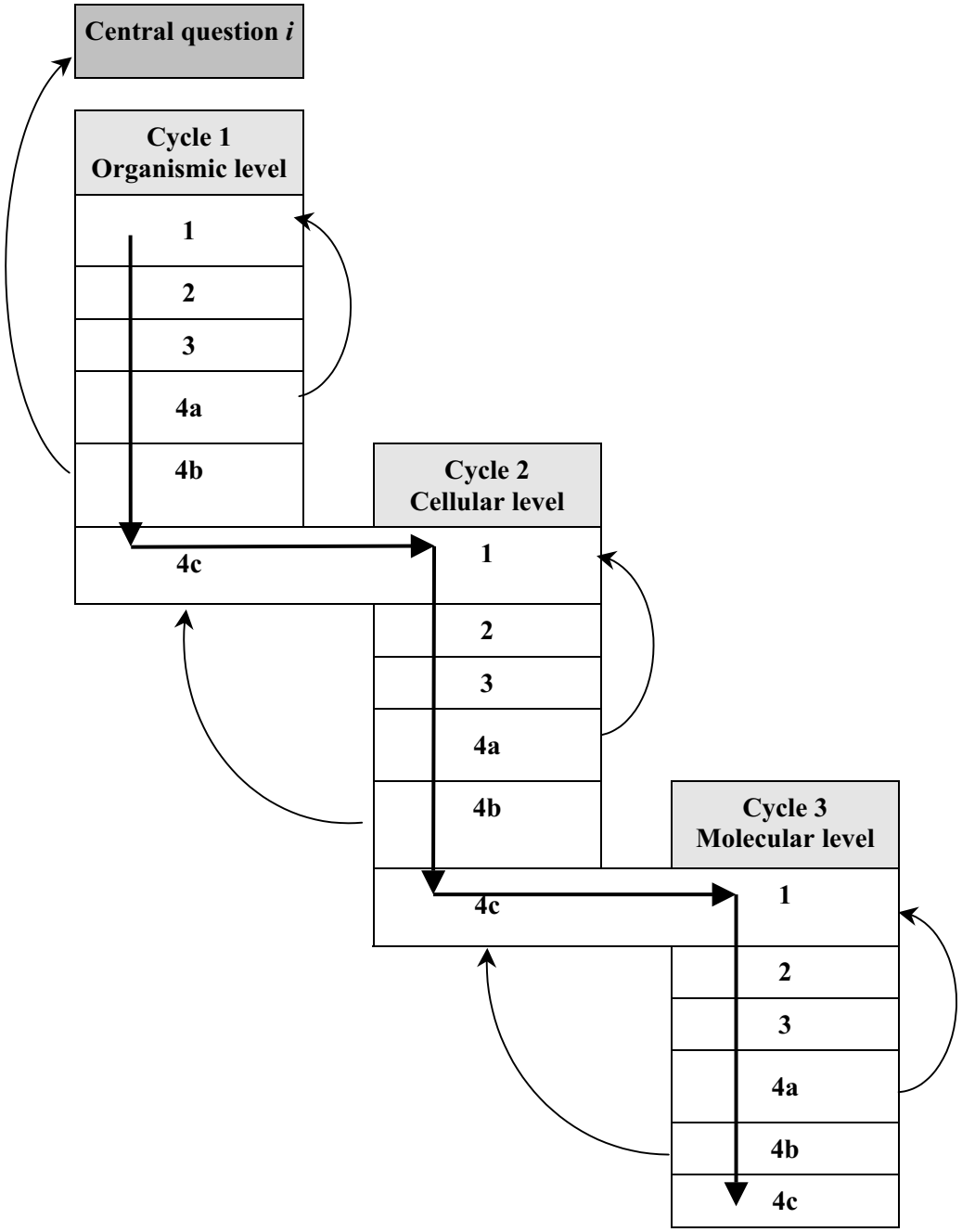


Figure 5.2 ***Schematic representation of the yo-yo LT strategy: descending and ascending the levels of biological organisation by means of the four problem posing steps****. 1. Partial question and motivation to answer the question in a next learning activity, 2. Information and/or investigation of the concepts, 3. Application of the concepts in a new situation, 4. Reflection: 4a. Answering the partial question, 4b. Linking the answer to previous partial questions (concepts on the higher levels of biological or ganisation) and verifying to what extent the central question (i) can be answered at this point, 4c. Formulating the new partial question that should serve as a motive to take the next step in the learning and teaching sequence.*

students want to investigate the differences and similarities between asexual and sexual reproduction. Subsequently, the learning activities will be individually *reflected on* by the students, succeeded by a whole class discussion and reflection (step 4 in the problem posing sequence), in order to:

4a) Answer PQ1,
4b) Verify to what extent the central question *i* can be answered at this point,
4c) Identify what they do not understand yet, or what part has not been answered yet in the previous learning activity. This will help students to formulate the next partial question (PQ2) and it will motivate them to answer this next question.

In the reflection phase students realise that they need more details on the reproduction process. Consequently, a new partial question (PQ2) is raised, i.e. *what structures are being passed on in the asexual and sexual reproduction mechanisms?* (Step 1 of the next problem posing cycle).

Cycle 2. Cellular level: cells, cell division and chromosomes

In order to answer partial question 2 students should search for structures and processes on a lower level of biological organisation, the *cellular* level. Students want to investigate (step 2) this by themselves in a practical, and they are supported by the teacher who provides additional information (step 2) on the cell division processes and the structures (chromosomes) that are passed on. Moreover, the teacher explicitly indicates that they are zooming in on the cellular level. Chromosomes and the cell division processes mitosis and meiosis are identified and linked with asexual and sexual reproduction (organismic level). Subsequently, the learning activities are individually reflected on and succeeded by a whole class discussion (step 4), in order to:

4a) Answer PQ2.
4b) Link the answer with PQ1 (asexual and sexual reproduction on the organismic level) and verify to what extent the central question *i* can be answered at this point.
4c) Identify what they do not understand yet, or what part has not been answered yet in the previous learning activity. This will help students to formulate the next partial question (PQ3): *How do mitosis and meiosis fit in the life cycle of multi-cellular organisms?* (step 1 in cycle 3), and it will motivate them to answer this question.

Roughly, students now know (and have studied) that chromosomes are the cellular structures that contain the hereditary information and that these chromosomes are passed on to the offspring by means of (reproductive) cells that originate from mitosis (AR) or meiosis (SR). In AR the chromosomes are copied and divided equally among the daughter cells (mitosis). So, the parent cell divides to form two identical cells. In SR a cell divides by two divisions into four germ cells, each containing only half the original number of chromosomes (meiosis).

Cycle 3. Embedding the cellular processes in the life cycle

The need arises to explore and specify the relationship between the cell division concepts and the concept of reproduction in more detail, and to position these

concepts within the life cycle of multi-cellular organisms (PQ3): i.e. somatic cell line and germ cell line of an individual. By applying the acquired genetics concepts (step 3), including cells, gametes, cell division processes and chromosomes, conceptual development goes on. The new concepts on the cellular level are interrelated with the concepts on the organismic level. The cell division processes mitosis (AR) and meiosis (SR) are linked with respectively the somatic cell line and germ cell line in an individual. AR is analogous to the somatic cell line: from the zygote ongoing mitosis leads to growth and development. A mutation in the somatic cell line will not affect the next generation, whereas a mutation in the germ cell line will. In an individual reflection on the learning activity and a reflection which involves all students:

4a) PQ3 is answered.

4b) The answer to PQ3 is linked with all the previous partial questions on the different levels of biological organisation, and it is verified to what extent the central question *i* can be answered at this point.

4c) Students realise that mitosis and meiosis are complicated processes asking for reconstruction of how hereditary traits are passed on via chromosomes. The need for additional information to explain the multiple different hereditary traits in an individual arises. A next partial question (PQ4) is formulated: *How do chromosomes determine the different hereditary trait in an organism?* (step 1 in cycle 4).

Cycle 4. Cellular level: linking genes, chromosomes and cell division processes

In order to be able to answer partial question 4, students' first notions on genes are discussed and the gene-protein relationship is explained (step 2). Besides the term 'hereditary' trait, the term 'genetic' trait could be introduced here.

Subsequently, in a chromosome practical students apply the new concepts to increase their knowledge and understanding of the mechanisms of reproduction (step 3). Hereditary phenomena and reproduction mechanisms on the organismic level are related to the cell division processes, chromosome structures and behaviour on the cellular level, and linked to the consequences for offspring (organismic level). Students have to think backward-and-forward between the organismic and the cellular level (yo-yo). Students become aware of the fact that the zygote represents a new, genetically unique combination of chromosomes. For the zygote contains a random recombination of homologue chromosomes (and their genes) from both parents, which add to an enormous genetic diversity, i.e. unique individuals.

By actively integrating the genetics concepts, students increase their understanding of inheritance and discover what they do and what they do not understand yet.

In a whole class reflection on the learning activities:

4a) PQ4 is answered.

4b) The answer to PQ4 is linked to all the previous steps (partial questions) on the different levels, and it is verified to what extent the central question *i* can be answered at this point.

4c) Students articulate what they do and what they do not understand yet, or what information they are still lacking after engaging in the previous learning

activity. This will guide them to formulate PQ5: *How do genes work? (What exactly are chromosomes and genes and how do they determine hereditary features?)* (step 1 of cycle 5).

Cycle 5. Molecular level

By posing partial question 5 the next step to the molecular level can be made. By means of the same sequence of steps, i.e. information or investigation, application, and reflecting on the PQ and central question *i*, the molecular level is explored. Genes in the chromosomes are made of DNA, which stores and faithfully transmits information. The information-carrying capacity of DNA comes from the four bases; they are 'read' as if they were letters, making up words of three bases long. These words provide the information needed for building proteins, and for organising the activity of the cell. The concept of DNA is linked to the hereditary phenomena and to concepts on the cellular and organismic level.
However, the molecular level was not the focus of our LT strategy for genetics. Therefore, we will not discuss the problem posing steps on this level in detail.

Meta-reflection phase

At last, students have descended (zoomed in) meaningfully from the organismic level to the cellular level and ascended (zoomed out) again, by means of content-related partial questions. Answering all these partial questions and linking them to the previous partial questions finally provides the answer to the central question (*i*). In SR the offspring looks like the parents, but is not identical to them because of a new and unique combination of homologue chromosomes (and their genes) originating from both parents. Chromosomes are the cellular structures that contain the hereditary information (genes) and that are passed on to the offspring by means of gametes that originate from meiosis (SR). The genes (and alleles) on the chromosomes instruct the cell to produce all kinds of proteins. These proteins have different structural and functional roles, which are expressed in hereditary traits.
The question that needs to be answered through meta-reflection is: *Which levels of biological organisation have been transected in succession and what is the added value of thinking backward-and-forward between these levels?*
In a whole class discussion students will reflect on the entire learning and teaching sequence by distinguishing all previous steps that have been taken in the genetics course and by relating the different activities with the various levels of biological organisation.
In addition, students use the levels of biological organisation in another genetics context, and describe the hereditary features that appear on these levels. They become aware of the 'yo-yoing' that appears in explaining hereditary phenomena and solving genetics (biological) problems. In descending from organism to cells and molecules and ascending vice versa, biological structures, processes and concepts can be interrelated, which enables them to build up a coherent conceptual understanding of heredity.

Answering the central research question of the thesis

At this point we can finally answer the central research question:

> *What is an adequate LT strategy for genetics in upper secondary biology education in order to cope with the main difficulties in learning and teaching genetics and to promote the acquisition of a meaningful and coherent understanding of hereditary phenomena?*

The explorative phase of this study disclosed that the main difficulties in learning and teaching genetics are related with the *complex and abstract* nature of genetics. The disconnection of inheritance and reproduction / meiosis leads to abstract subject matter. Manifestations of hereditary phenomena, processes, and structures on the different levels of biological organisation account for its complexity.

The yo-yo LT strategy for genetics copes with this complexity by explicitly distinguishing the levels of biological organisation, and by descending and ascending these levels, starting from the concrete organismic level. Explicating the levels makes the transect nature of genetics transparent to students, and provides an insight into what hereditary phenomena, processes, and structures occur on the different levels of biological organisation. The genetics vocabulary is tuned to the specific level students are dealing with at that moment, which helps to prevent confusion.

The educational difficulties that have been described in the literature (section 3.2) and that concern the cytological concepts (Kindfield, 1991; 1994a; 1994b, Lewis et al., 2000a, 2000b), the homologue chromosome concept and the chromosome structure (Stewart *et al*., 1989; 1990; 1994, Brown, 1990, Lewis, 2000a, 2000b) have been avoided to a great extent.

The yo-yo LT strategy emphasises the genetics key concepts per level of biological organisation and their interrelationships. The relationship between reproduction, meiosis, and inheritance on the organismic and cellular level is stressed and at the same time these key concepts are made concrete. This reduces the abstract nature of genetics. The yo-yo LT strategy for genetics enables students to explore the key concepts in hereditary in co-operative and active learning settings and to articulate what they do and what they do not understand yet. The problem posing structure of content-related partial questions and reflection activities motivates students to engage in the next learning activity, in which another related key concept on a specific level of biological organisation is explored.

By means of the yo-yo LT strategy the intended learning outcome has been attained, which means that students have acquired the competence of thinking backward-and-forward between the levels of biological organisation and that they are able to relate the genetics concepts on these different levels to each other.

Thus, the answer to the central research question is that the yo-yo learning and teaching strategy for genetics proved to be an adequate approach to cope with the abstract and complex nature of genetics in upper secondary biology education, and to promote the acquisition of a meaningful and coherent understanding of hereditary phenomena. It was beyond the scope of this developmental research project, however, to test the retention of the competence.

5.3 Further applications of the yo-yo LT strategy

In the optimal yo-yo LT strategy for genetics (figure 5.2) two intertwined components have been distinguished that are embedded in and linked to the levels of biological organisation. Since the levels of biological organisation play an important role in most biological topics, it can be argued that the yo-yo LT strategy is suitable for all biological topics that transect the different levels of organisation, e.g. evolution, ecology, and behaviour.
The domain-specific component in the yo-yo LT strategy for genetics consists of the genetics key concepts. Thus, when dealing with another topic, for example evolution, the key concepts have to be determined as well as the relevant levels of biological organisation. In the case of evolution, the population and community level would come in and the interconnectedness with genetics should be illuminated, comparable to the connection between genetics and reproduction. A preliminary arrangement of the key concepts for the subject of evolution, according to the yo-yo LT strategy, is shown in figure 5.3.

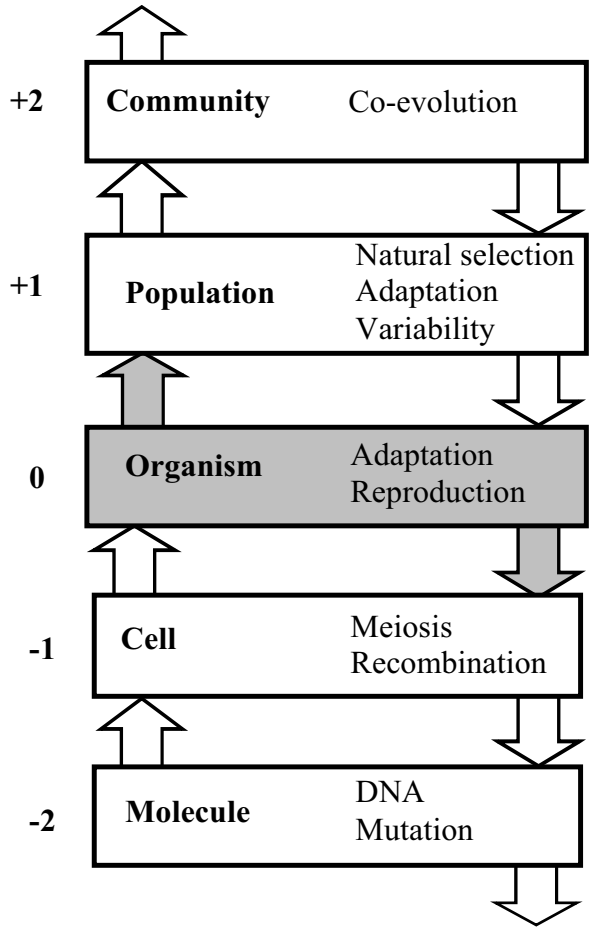


Figure 5.3 ***Preliminary arrangement of the key concepts on the different levels of biological organisation for the subject of evolution, according to the yo-yo LT strategy.***

It should be noted that it might not be easy to find an appropriate central problem that is both meaningful and motivating to students, and biologically relevant. In addition, the key concepts of the topic (content structure) and relevant students' prior knowledge should be identified in advance. Depending on the topic, the number of meaningful biological sub-questions per level may differ and accordingly the number of problem posing cycles will differ.
In Sweden Olander, Wallin and Hagman (personal communication) have experimented with the yo-yo LT strategy on the topic of evolution. Their positive experiences with the yo-yo strategy have not been published yet.

When reviewing the content structure of the school biology curriculum as it is reflected in biology textbooks, it is striking that, contrary to what the criteria of the yo-yo LT strategy set out, biology textbooks cover themes quite isolated from each other (see also section 3.5 'content analysis of school genetics'). According to the yo-yo LT strategy, it is important to first determine what the levels of biological organisation and the related key concepts that are essential for a good understanding are. Secondly, education should start at the organismic level, from which the levels of biological organisation are descended and ascended by means of at least one complete problem posing cycle per level. However, in most present secondary education biology textbooks themes are not linked to the organismic level (section 3.5). The organismic level of a particular topic is just briefly mentioned and then focus is mainly on the cellular and/or molecular level (e.g. metabolism, photosynthesis). Relationships between biological concepts and themes are not explicated (section 3.5).
Themes should be organised in such a way that their position and interrelationship in the biological systems are transparent for students. This implies that at least the lacking organismic level should be included, resulting in (slightly) reformulating the standard arrangement of topics in biology schoolbooks in order to promote students' acquisition of a coherent biological knowledge.
This way criteria of the yo-yo LT strategy can be helpful in restructuring the themes in the biological curriculum.

In this study the yo-yo strategy has been strongly related to the complexity of biological systems, but science education in general could benefit from this approach as well. The skill to relate macroscopic phenomena to microscopic particles has been identified as one of the main problems in secondary science education (Lijnse *et al*., 1990) both for students and teachers.

5.4 Reflection on the design of the study

In this section we will briefly reflect on the design of the study, and focus on the teacher's role in the developmental research design in particular. This reflection section is in part based on the final evaluation discussion with the three teachers who participated in this study. During this discussion their role in the study was explicitly evaluated and reflected on.

The developmental research design

Generally speaking, the developmental research design (see chapter 2) worked out successfully. The explorative phase was effective in providing sound design criteria, and the cyclic research phase resulted in an adequately tuned and research-based LT strategy for genetics. Furthermore, the distinction that had been made between a general LT strategy and a context specific scenario proved to be adequate in developing a domain-specific educational theory. In future use of the developmental research design, however, the teacher's role in the research design should be given more thought. The teacher is a very important actor in developmental research, because he/she is the person who carries out the scenario in practice. Even if the researcher has developed an excellent scenario, if the teacher does not carry it out as it was intended, no valid statements can be made about the adequacy of the scenario and the LT strategy. Although the teacher's role in developmental research is a crucial one (Kortland, 2001), it is still somewhat underexposed. Guidelines to assure adequate teacher preparation in developmental research have not been developed yet. In the next paragraph the teacher's role will be discussed in more detail.

The teacher's role in the design

Previous developmental research studies at the Centre for Science and Mathematics Education at Utrecht University have shown that there are different opinions on the most adequate preparation, and role of the teachers in the developmental research design.

The researcher as teacher

One option is that the researcher himself or herself carries out the scenario in practice, and fulfils the role of the teacher (e.g. Janssen, 1999). The advantage of this option is that the researcher can carry out the scenario fully to his or her ideas and intentions, and that he or she can respond adequately to unexpected incidents. This will improve the reliability of the scenario. There is no intermediary step of explaining the scenario and strategy and having it implemented by somebody else. The researcher has complete control over the teaching.

However, the advantage of this method is at the same time its disadvantage. For teaching interferes with data collection and having a detached view, it seems hard or almost impossible to objectively observe the learning and teaching sequence and one's own teaching, while teaching and carrying out the scenario in practice; let alone reflect on it. Moreover, the LT strategy should not only be adequate, but it should also be a plausible one. This implies that also a teacher, who was not involved in designing and developing activities, should be able to use the strategy. It will improve the validity of the LT strategy and it will be easier to convince potential users if the LT strategy has been shown to be manageable and adequate in regular teaching practices.

One teacher

A second option is to involve only one teacher in all case studies (e.g. Klaassen, 1995, Vollebregt, 1998, Kortland, 2001). The advantage is that the teacher will learn from experience and that he/she will get very familiar with the strategy.

Consequently, the teacher's adherence to the scenario will increase.
A disadvantage of this approach is that the successive trials will be taught in classes that are comparable or of the same grade, which will not be helpful to reveal the context specificity of the scenario. It may also be too much to ask from a teacher to participate for two or three years in the research project. In addition one teacher makes the empirical study vulnerable. Finally, the same argument as in 'the researcher as teacher-approach' applies here: the final strategy can be considered more valid when it has been successfully carried out by different teachers, who all have their own, that is different, backgrounds and teaching styles.

Several teachers

We decided to test the strategy in different case studies with different teachers. Two out of the three teachers who participated in our case studies also enrolled in the focus group interviews and indicated that they were willing to participate in further research. Our teacher-selection criteria were open-mindedness, teaching experience and favourable expectations concerning collaboration.
As discussed in the two previous paragraphs, having several teachers to test the scenario with has the disadvantage that the teachers will get less acquainted with the scenario and strategy. We tried to overcome this by choosing two classes in one case study, thus allowing the teacher to carry out the same scenario twice and to learn from experience. Consequently, the teacher can become more self-confident, and parts of the scenario that did not go as intended or that were not conform to our expectations in the first class, could be tested again or performed in another way in the second class. Of course our teachers were still far less familiar with the scenario than a teacher in the 'one teacher-approach' would have been. However, an important advantage for the teachers was that they did not have to commit themselves to time-consuming research for several years.
Moreover, the 'several teachers-approach' improves the validity of the strategy, since it is tried out in multiple schools, classes, and with different teachers with their different teaching styles. Besides, since the context specificity of the scenario is emphasised in this 'several teachers-approach', a clear distinction between the scenario and the LT strategy can be made. For every new teacher, school and form, the scenario has to be reshaped for the specific context, but the LT strategy remains intact. This forces the researcher to define the yield of the previous trial and to describe the essence of the LT strategy.
As it turned out, the teachers differed in perceived 'ownership' of the LT strategy, depending on the nature of their participation. Although they did not consider this as disadvantageous, this indicates that we had not thought through the learning process of the teachers well enough. We have outlined the importance of an active learning approach for the students before, but we did not transfer this approach to the situation of preparing the teachers. Apart from some preliminary discussions and consultations the teachers only critically commented on the feasibility of the scenario in a discussion with the researcher. Based on these critical remarks some last adjustments in the scenario were made, before it was put into practice. It was not recognised that for a good understanding of the first version of the LT strategy guided reinvention by the teacher might have been necessary. Although this would

have been time-consuming, we have to conclude that we did not fully 'practise as we teach'. Furthermore, in order to adequately reflect with the teacher on the strategy and on his/her actions, data analysis should have been performed in such a way that they could have seen the effect of their teaching and could have learnt from it (as in the 'one teacher-approach'). In the present study the teachers were only informed about the results of and experiences with the previous trial.
However, two out of three teachers who participated in our study indicated that they were content with participating in only one trial (with two classes) and that they would not have participated in a second trial, because they felt they had already learnt all there was to learn. A second case study would only have consumed more of their time and it would not have offered any additional learning value for them. The third teacher indicated that he would have been willing to participate in a second trial, because he felt he could have carried out the scenario more adequately the second time. This was the teacher who had only one class in the field-test.

Conclusion

We may conclude that all three options of the teacher's role in the design have their advantages and disadvantages, and that it is not at all easy to determine which option is to be preferred. All options reflect awareness of the importance of the teacher's role in developmental research. We should strive for balance between the teachers' wishes and the amount of time that they can put into this kind of studies on the one hand, and the requirements for an adequate research design on the other.
We may consider our choice for several teachers an adequate one that has balanced both the demands of the research and the teachers' needs.

5.5 Future research

This study has shown that the yo-yo LT strategy is an adequate and promising approach in order to cope with the abstract and complex nature of genetics and to promote meaningful biological thinking among the students in upper secondary biology education. The yo-yo LT strategy has been developed for the subject of inheritance, in which the organismic level and cellular level are crucial.
Considering the wider applicability of this didactical approach, it may be concluded that the yo-yo LT strategy deserves further study.

The molecular level

Although we have made a start with making a meaningful transition to the molecular level in the yo-yo LT strategy, it was not the focus of our research, nor of our yo-yo strategy. We may argue that the molecular level is not essential for a meaningful and coherent insight into inheritance. However, it would be for molecular genetics. New rapidly developing DNA-techniques and the ever-expanding knowledge of DNA are important topics in biology education. Molecular genetics would logically be the next subject in biology education after inheritance. However, the molecule concept has its specific difficulties (Vollebregt, 1998; Lijnse *et al*., 1990), due to the theoretical base of the molecule theory. Molecules are not perceptible, and this makes it difficult for students to grasp and handle concepts on the molecular level

(Lumer & Hesse, 1997a, 1997b; Fisher, 2000; Marbach-Ad & Stavy, 2000). It is advisable that students develop a proper concept of molecules in chemistry, before descending from the cellular to the molecular level in biology. Unfortunately this prerequisite will not always be met, since not all students in upper secondary education who take a biology course also take a chemistry course.
To tackle students' difficulties with the molecule concept it would be advisable to explore the transition to the molecular level in more detail in co-operation with researchers in chemistry education. Because molecules (e.g. DNA) are all part of a complex living system, we argue that also the molecular level should be explored and taught in the line of the yo-yo LT strategy, in order to promote the acquisition of a meaningful insight into the relationships between molecules (e.g. DNA, proteins), structures, and processes in the cell and in organisms. Isolated DNA and genes can do nothing without a cell; they need an ('living') environment that activates them. The way in which genes function in a cell, is highly dependent on the interrelationship of genes and conditions in the cell; they are part of a complex biological system. We suggest that the transition to and elaboration of the molecular level will be focus for further research.

Meta-cognitive tool

All biological topics can be viewed from the perspective of 'multiple levels of organisation'. Biology studies complex living systems and every area of specialisation (sub-discipline) studies parts of such systems, and is connected to other organisational levels. Researching biological problems is researching biological systems. Consequently, the systems theoretical perspective has acquired additional significance and has also been included in the attainment targets of secondary biology education.
It could be suggested to focus on a systems theoretical perspective in the meta-reflection phase of the yo-yo LT strategy and to introduce the yo-yo strategy as a meta-cognitive tool. So, our final suggestion for further research is to explore the possibility of introducing the yo-yo strategy (or thinking in levels of biological organisation, i.e. systems thinking) as a meta-cognitive tool and a starting point for new learning in biology. A promising start has been made by Verhoeff *et al*. (2001), who is developing a LT strategy for cell biology in which a systems theoretical perspective is explicated and explored.

5.6 Final conclusion

The idea and essence of the yo-yo learning and teaching strategy is actually very pure and simple, but holds great implications for learning and teaching biological subjects. In designing LT strategies in biology we should be aware of the different levels of biological organisation, and of the fact that biological concepts and terminology refer to these different levels. In learning and teaching a biological topic like genetics, we should start on the concrete, organismic level and gradually descend and ascend the levels of biological organisation through successive content related questions (a problem posing approach). The yo-yo LT strategy enables students to acquire a meaningful and coherent understanding of biological topics.

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Appendices

Appendix 1: Fragment of the first scenario.

Learning activity 2

<table>
<tr><td><u>LA 2</u>: Distinguishing the germ and the somatic cell line, and relating the cell division processes to these two lines.</td><td>Level: Transition from the organismic level to the cellular level</td></tr>
<tr><td colspan="2">Teaching method: Group work</td></tr>
<tr><td>Students activity
1. Solving a biological problem (Worksheet 1) in groups of 4 students: discuss and reason how a mutation in the hereditary material of a gamete and a colon cell affects the next generation.
2. Differentiate between the germ and somatic cell line and relate the cell division processes meiosis and mitosis to them.
3. Discuss and explain their insights into the two lines in their own words to the other students in the group.
4. Formulate an answer to the task (problem) they all agree upon.</td><td>Teacher activity
1. Guiding the students in their group work and discussion on request, but not giving the solution to the problem yet.
2. Signalling where students get stuck in their genetic reasoning pattern and what difficulties they encounter, in order to prepare the subsequent plenary discussion and reflection on this activity.</td></tr>
<tr><td colspan="2">Intended outcomes
1. Preliminary insight into the differences between the somatic cell line in a person and the germ cell line, and the relationship of the two cell division processes (mitosis & meiosis) with these two lines.
2. Most students will not be able yet to correctly connect the mitosis and meiosis with the somatic line and germ line.
3. Students realise what they do and do not understand yet or where they get stuck in their reasoning pattern, and get motivated to get more insight into the two main cell lines and the related cell division processes.</td></tr>
</table>

Learning activity 3

<table>
<tr><td><u>LA 3</u>: Whole class discussion and reflection on learning activity 2</td><td>Transition from organismic level to cellular level</td></tr>
<tr><td colspan="2">Teaching method: whole class discussion</td></tr>
<tr><td>Students activity
1. Explaining their answer to the assignment to the rest of the class.
2. Discussing the differences in answers and explanations of the groups.</td><td>Teacher activity
1. Noting the different group answers on the blackboard.
2. Guiding the classical discussion aiming at one answer to the assignment, by asking questions like:</td></tr>
</table>

3. Reasoning again, after getting new information and solutions of the other groups of students in the class, on the relationships between : - The somatic line, somatic cells, genetic basis in somatic cells and cell division process of somatic cells. - The germ line, gametes, genetic basis in gametes and the cell division process that forms gametes. 4. Articulating what they do and do not understand yet; Asking questions.	- Where in your body do you think this process take place? What is the function of that process? How do you picture that? - What is the difference between a gamete and a somatic cell? - How is a somatic cell resp. gamete formed? - To what extend are your somatic cells (resp. gametes) identical to one another? - What cells are involved in sexual reproduction (in producing offspring)? - What is passed on to the offspring? - What happens during fertilisation 3. Give a brief overview; present two drawings on the blackboard of the somatic and the germ cell line, the relationship with the cell division process, mitosis and meiosis, and the relationship wit the genetic basis of a next generation. 4. Discussing the aim of meiosis, the formation of gametes which contain half of the chromosome number. Provide additional information and explanation on the two cell division processes. After fertilisation, the zygote contains a new genetic combination, which is a combination of half the chromosomes of father and half the chromosomes of mother.
Intended outcome: 1. Students know and can explain the differences between the somatic and germ cell line in a life cycle, and can link the processes reproduction, meiosis, and mitosis to the cell lines. 2. Students realise that in a person all somatic cells contain the same hereditary basis. All chromosomes are copies of the first set of chromosomes in the zygote, by means of the cell division process mitosis. Any mutation in the somatic cell line will not affect the next generation, contrary to the germ cell line. 3. Students realise that all gametes in a person differ, they contain half the original number of chromosomes, one of every homologue pair. The cell division process responsible is meiosis. In sexual reproduction, the egg cell and sperm cell merge, and a new unique genetic combination (random recombination of homologue chromosomes from both parents) is formed.	

Accompanying worksheet 1 of LA 2

Discuss and solve the next problem with your group members:

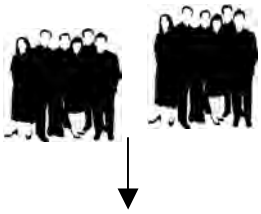
Anna is a healthy 28 year old woman.
A mutation occurs in the hereditary material of a gamete of Anna, and a mutation occurs in the hereditary material of a colon cell of Anna.

1. Will the mutation in the hereditary material of a) the colon cell, and b) the gamete be passed on to the children Anna will get?
2. Explain your answer.

Answer:

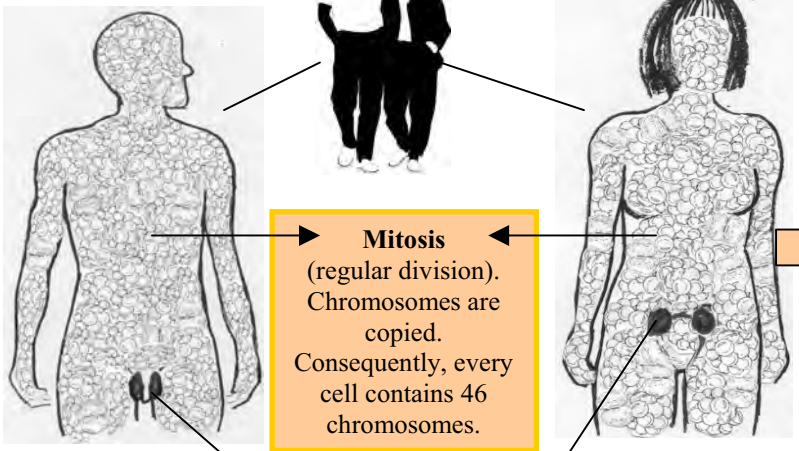
Appendix 2: Schematic representation to visualise the connection between the levels of organisation and the somatic and germ cell line.

Population humans. A population consists of organisms.



Organisms are built of cells.

Cellular level
The cells in our body are all specialised to fulfil a certain function. E.g. brain-kidney-, muscular-, bone-, colon cells.



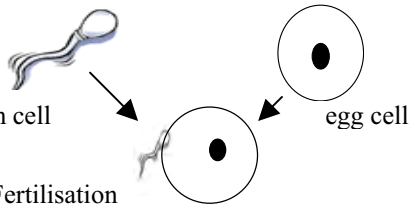
Mitosis (regular division). Chromosomes are copied. Consequently, every cell contains 46 chromosomes.

All cells in the body divide by **mitosis:** colon-, liver-, skin-, muscular cells. *Only*, gametes are produced by a special cell division process: meiosis.

Meiosis

Number of chromosomes halved (from 46 to 23). 1 chromosome of every pair in a reproduction cell.

Cellular level
Reproduction on the cellular level.



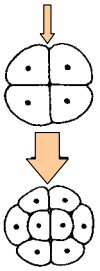
sperm cell

egg cell

Fertilisation

Chromosome-set of father in sperm cell melts with egg cell that contains chromosome set of mother. New nucleus is formed in which again 46 chromosomes are present, i.e. 23 homologue pairs. This is the new genetic combination (basis) of the offspring.

zygote



Mitosis

Offspring. **Organism**. new genetic combination of father and mother.

Summary

This thesis describes a research project that was carried out at the Centre for Science and Mathematics Education at Utrecht University between 1998 and 2002. The study addresses problems in learning and teaching genetics in upper secondary biology education. The aim of the study is to develop a theoretically founded and empirically tested learning and teaching strategy (LT strategy) to cope with these problems. The central research question to be answered is:
What is an adequate learning and teaching strategy for genetics in upper secondary biology education in order to cope with the main difficulties in learning and teaching genetics, and to promote the acquisition of a meaningful and coherent understanding of hereditary phenomena?

The design of this study according to the developmental research approach is outlined in **chapter 2**. The developmental research approach roughly entails two phases: 1) the explorative (orientation) phase, and 2) the cyclic research phase.
The *explorative phase* of this study (chapter 1 and 3) included theoretical and practical orientations and resulted in: 1) a definition of the position of this study in the research field and educational theories (chapter 1), and 2) the identification of the main difficulties in genetics education, more in-depth understanding of these learning and teaching difficulties, and the definition of the design criteria which an adequate LT strategy should meet (chapter 3).
In the second phase, *the cyclic research phase* (chapter 4), three case studies at different schools and at different school types (6 vwo, 4 vwo and 4 havo; table 2.1) were planned and conducted. Based on the results of the explorative phase a preliminary LT strategy for genetics was constructed and elaborated into the first *scenario*, which was then field-tested. When the scenario was carried out in practice various data sets were collected and analysed in order to evaluate the scenario and to reflect on the LT strategy. The outcomes provided information that helped to further improve the design. The revised LT strategy was converted into a second scenario, which was also field-tested. Thus, the LT strategy was developed in the process of cyclic empirical testing of scenarios in successive case studies.

Chapter 1 outlines the first part of the explorative phase. The developments in biological science and education are discussed, as well as current notions on learning and teaching, which served as a basis for a domain-specific philosophy of learning and teaching.
The latest scientific developments and insights have given rise to an increased attention for genetics, which stresses the importance of enhancing genetics literacy. Moreover, the developments in biological science and education underlined the importance of acquiring a coherent and integrative view on biology. An increased integration of research and knowledge on the different levels of biological organisation has taken place. Biological research is no longer merely reductionistic, instead it transects disciplines and levels of biological organisation.
The developments in the field of education have highlighted the importance of acquiring a 'learning to learn' competence that has become vital in our knowledge-based society. It seems that this approach has still not been adequately implemented in school practice. Focus should be on learning general biological insights and key

concepts that help to structure more specific knowledge in a domain. In our view it is important to emphasise the key concepts and their relationships in biological education, because it helps students to get a full and coherent picture and understanding of biology. This implies that when developing an adequate LT strategy for genetics, the key concepts and main lines in hereditary should be emphasised, and the overall learning goal should be the acquisition of competences. Moreover, students should be actively involved in their own learning process. The problem posing approach seems to be a fruitful and adequate way of motivating and actively involving students in content specific learning processes, and therefore this approach was used in designing a LT strategy for genetics.

In **chapter 3** the major part of the explorative phase is described. The main difficulties in learning and teaching genetics were identified by reviewing the international literature of the past two decades and by focus group interviews with Dutch biology teachers. Out of ten identified domain-specific difficulties two key difficulties were selected to focus on in the rest of this study: the *abstract* and *complex nature of genetics*. In order to acquire more in-depth data about these key difficulties an explorative case study was initiated in which a traditional genetics course in a 5 havo class was observed and audio-taped. The biology teacher was interviewed to clarify the rationale of his genetics education practice. The students kept logbooks during the genetics course and were interviewed to get more insight into their genetics reasoning skills and in the difficulties that they had reported in their logbooks, and to try out some first ideas for learning activities. Moreover, a content analysis of biology textbooks concerning the chapters on inheritance, reproduction and meiosis was carried out to determine in what way schoolbooks contribute to the abstract and complex nature of school genetics.
The explorative phase showed that it may very well be that a separation in time and space of the topics inheritance, reproduction and meiosis is responsible for the *abstract nature* of the subject. In addition, traditional genetics education focuses on solving genetic cross problems and a lot of students have difficulties with converting genetics texts into schemes and symbols and with interpreting these schemes and symbols. Moreover, students have to do mathematical calculations with those symbols in order to solve these problems, and they have to connect probabilities with biological phenomena. The Punnett square is often used routinely without relating it to real biological phenomena and processes such as meiosis.
The *complex nature* of genetics refers to the manifestation of heredity phenomena on different levels of biological organisation, and to the use of different corresponding vocabularies. Adequate understanding requires *backward-and-forward thinking* between the molecular, cellular, organismic, and population level, as well as interrelating the different structures and processes on the various levels. Biologists, including biology teachers, have interiorised this thinking skill and use it automatically. Students just starting to learn genetics get into trouble, because biology teachers and schoolbook authors often implicitly jump from one level to the other.
Based on interrelating the outcomes of the various research activities in this explorative phase, four design criteria for a LT strategy for genetics were extracted:

1. Genetics education should start on the concrete organismic level with which students are familiar , and should then gradually descend to the cellular level.
2. The relationship between meiosis and inheritance should be dealt with explicitly.
3. Two main cell lines, the somatic line (mitosis) and the germ line (meiosis) should be distinguished in the context of the life cycle.
4. Students should explore the relationships between the levels of organisation by themselves, guided by the structure of the learning activities (and/or teacher) that have been designed according to the problem posing approach.

In the *cyclic research phase*, presented and discussed in **chapter 4**, the four design criteria and ideas were converted into the **first LT strategy**, consisting of a sequence of problems and a sequence of corresponding learning activities.
Design criterion 1 directed that the levels of biological organisation should be dealt with step by step, starting from the organismic level that students are already familiar with, and then gradually zoom in on the cellular and molecular level. When students were supposed to descend a level it was important to show them why this was necessary, what the meaning of it was. This could be achieved by providing students with (genetics) problems on the organismic level that they could only solve by using genetics concepts of the cellular level (criterion 4). For the biological content structure of the LT strategy for genetics criterion 2 and criterion 3 were essential. Distinguishing explicitly between the somatic cell line and the germ cell line in a life cycle helped students to understand that growth and development on the one hand and sexual reproduction on the other are linked with different cell division processes (mitosis and meiosis) to ensure genetic continuity (cf. asexual reproduction) and diversity. Integrating these four criteria implicated that the learning activities should start on the organismic level and should refer to the reproduction processes. The key concepts in reproduction and inheritance should be explored in successive learning activities. Because the process of meiosis is a crucial link in inheritance and because especially 'homologue chromosomes' is a difficult concept for students, these topics received special attention and a chromosome practical was developed.
The outline of the first LT strategy for genetics (table 4.3) was converted into a scenario and accompanying teaching materials for the two 6 vwo classes. The scenario was field-tested to find out whether it met our expectations and to reflect on the adequacy of the underlying LT strategy for genetics. The overall goal of the first research cycle was to detect errors in the design and to consider modifications concerning the nature and sequence of the learning activities. Based on the results of the empirical test of the first scenario four revisions were made.
The most important revision had to do with the difficulties students had encountered in *ascending* the levels of biological organisation. After all, the idea was that students should not only be able and willing to descend a level of biological organisation, but they also should be able to ascend a level. The essence of the **second version of the LT strategy** for genetics was then described as *'yo-yo learning'* (analogous to the toy yo-yo), because students were invited to think up and down between the levels of biological organisation, and to relate the genetics concepts on these different levels. The overall intended learning outcome was characterised as a competence:

students should be willing and able to use genetics concepts meaningfully, i.e. they should be able to distinguish the levels of biological organisation, to see the relationships between those levels and to relate sexual reproduction and heredity in a life cycle, by means of thinking backward-and-forward between the levels of biological organisation.

The second version of the LT strategy for genetics (table 4.5) was converted into a second and third scenario and field-tested in two more case studies (two 4 vwo classes and one 4 havo class). The learning objectives provided evaluation criteria. These objectives referred to *levels of biological organisation* and to *key concepts.*

From this second research cycle it could be concluded that, in general, the nature and sequence of the learning activities of the second and third scenario could be considered adequate. We saw that several difficulties in genetics education described in the literature and indicated by Dutch biology teachers as 'difficult' were solved to a considerable degree. As to the evaluation theme *key concepts* it could be concluded that the most important general thread in inheritance, the relationship between the key concepts sexual reproduction, meiosis, and inheritance, was clear to most students. Moreover, it was shown that our assumption that understanding the main line in inheritance and the main relationships in heredity between parents and offspring provides a sound knowledge base to solve all kind of genetics problems, proved to be correct. As to the theme *levels of biological organisation* it could be concluded that with respect to the sequence of the learning activities the overall sequence to start on the organismic level and to gradually descend to the cellular and molecular level, turned out to be adequate. On each level biological meaningful questions were raised that evoked the need to descend a (sub)level of organisation and to connect these questions with the previous questions and genetics concepts.

In reflecting on the second LT strategy in order to indicate points for final revision, the observed learning and teaching processes and outcomes were compared with what was expected in the scenario. It could be concluded that:

1. the overall sequence of the LT strategy for genetics (i.e. starting at the organismic level and gradually descending to the cellular level) seemed adequate;
2. the steps in descending had become more gradual, more meaningful and more explicit than in the first trial. However, some transitions could still be improved, because the reflection activities were not fully carried out as intended;
3. students were able to ascend the levels of biological organisation, although there were still some difficulties with ascending from the molecular level to the cellular level (probably because the core and focus of the LT strategy was on the organismic and cellular level, and not on the molecular level);
4. students were well able to distinguish the levels of biological organisation, and to (implicitly) yo-yo between the levels of biological organisation and the hereditary concepts on these levels.

Besides some minor adjustments, we revised the final outline of the LT strategy (table 4.12) in such a way that students would have to answer the central question more explicitly, and that the teacher's role in reflection was diminished.

Finally, in **chapter 5** a formal description of the didactical structure of the final version of the yo-yo LT strategy for genetics is presented and the central research

question of this thesis is answered.
The essence of the yo-yo LT strategy for genetics is descending and ascending the levels of biological organisation by means of the two intertwined components of 1) the genetics content structure, and 2) the problem posing structure.
The *genetics content structure* in the yo-yo LT strategy for genetics (table 5.1) comprises the genetics key concepts classified by the levels of biological organisation, and is presented as a sequence of relevant questions and answers: the conceptual thread. The *problem posing structure* takes care of arousing and maintaining learning motivation. By eliciting content-related meaningful questions and answers in a carefully designed sequence learning is facilitated. The problem posing sequence that can be recognised in the successive learning activities of the yo-yo LT strategy for genetics consists of the following steps:

i. Central steering question (posed at the beginning of the LT sequence; global motivation)

1. Partial question and local motivation to explore and answer the partial question: creating a need for extending knowledge.
2. Information and/or investigation: extending knowledge.
3. Application: using the extended knowledge in new situation.
4. Reflection: reflecting on the extended knowledge.
   - 4a. Answer the partial question posed at the beginning of the learning activity (feedback to step 1).
   - 4b. Link the answer to this partial question to all the previous steps (partial questions) on the higher levels of biological organisation, in order to verify to what extent the central question has been answered at that point and to facilitate the formulation of the next partial question.
   - 4c. Students experience what they do and what they do *not* understand or know yet, which motivates them to take a next step in the learning sequence by formulating a new partial question (step 1) with the central question in mind. With this new partial question the next sequence of four steps starts.

Thus, the problem posing structure consists of a number of successive sequences or cycles, each consisting of four steps. Each new cycle starts with the formulation of a partial question that needs to be explored and answered in the next set of learning activities.

While going through the successive problem posing cycles in the yo-yo LT strategy for genetics, students gradually descend from the organismic level to the cellular level and finally to the molecular level. The feedback loops to the central question via the previous partial questions in the *reflection stage* correspond with ascending the levels of biological organisation that occurs. The **essence of 'yo-yoing'** is *not only* returning to the partial question that needs to be answered at that moment, but also coming back to the *previous partial question(s)* (on the higher level(s)), i.e. ascending. In descending the levels of biological organisation none of the levels should be skipped. The same applies to the genetics key concepts, which can be considered steps in the conceptual structure.

This illustrates the analogy with the toy 'yo-yo'. In handling the yo-yo it is impossible to skip part of the descending or ascending pathway. It is possible to yo-yo upwards and downwards, but the anchor and starting point is always the same: the hand that handles the yo-yo. In the yo-yo LT strategy for genetics the starting and anchor point is the organismic level, from where the levels can be descended and ascended (yo-yo downwards) but also ascended to the population and community level and descended (yo-yo upwards). In the yo-yo LT strategy it is essential to go through, and complete, at least one problem posing cycle per level of biological organisation.

The yo-yo LT strategy for genetics copes with the complex nature of inheritance by explicitly distinguishing the levels of biological organisation, and by descending and ascending these levels, starting from the concrete organismic level. Explicating the levels makes the transect nature of genetics transparent to students, and provides an understanding of what hereditary phenomena, processes, and structures occur on the different levels of biological organisation. The genetics vocabulary is tuned to the specific level students are dealing with at that particular moment, which helps to prevent confusion. In this way, the educational difficulties with cytological concepts, chromosome structure, and the homologue chromosome concept that have been described in the literature are avoided to a great extent.
The yo-yo LT strategy emphasises the genetics key concepts per level of biological organisation and their interrelationships. The relationships between reproduction, meiosis, and inheritance on the organismic and cellular level is stressed, and at the same time these key concepts are made concrete. This diminishes the abstract nature of genetics. The problem posing structure of content-related partial questions and reflection activities motivates students to engage in the next learning activity, in which another, related key concept on a subsequent level of biological organisation is explored.
By means of the yo-yo LT strategy the intended learning outcome has been attained, which means that students have acquired the competence of thinking backward-and-forward between the levels of biological organisation and that they are able to relate the genetics concepts on these different levels to each other.

Because the levels of biological organisation play an important role in most biological topics, we have argued that the yo-yo LT strategy could be suitable for all biological topics transecting different levels of organisation, e.g. behaviour, evolution, and ecology. When considering the wider applicability of this didactical approach, we may conclude that the yo-yo LT strategy deserves further study.

Samenvatting

Dit proefschrift beschrijft een onderzoek dat plaatsvond van 1998 tot 2002 bij het Centrum voor Didactiek van Wiskunde en Natuurwetenschappen aan de Universiteit Utrecht. Het onderzoek richtte zich op de aanpak van problemen bij het leren en onderwijzen van genetica in de bovenbouw van het havo en vwo. Het doel van het onderzoek was de ontwikkeling van een theoretisch gefundeerde en empirisch geteste onderwijsleerstrategie om deze problemen te kunnen hanteren. De centrale onderzoeksvraag luidt als volgt:
Wat is een adequate onderwijsleerstrategie voor genetica in de bovenbouw van het voortgezet biologieonderwijs om leerlingen een betekenisvol en samenhangend begrip van erfelijkheidsverschijnselen te doen verwerven.

In **hoofdstuk 2** wordt een overzicht gegeven van de opzet van het onderzoek. Gekozen is voor ontwikkelingsonderzoek, waarin twee fasen werden onderscheiden: de verkennende fase en de cyclische onderzoeksfase.
De *verkennende fase* (hoofdstuk 1 en 3) omvatte een theoretische en praktische oriëntatie en resulteerde in: *a)* een positionering van dit onderzoek in het onderzoeksveld en binnen leertheorieën (hoofdstuk 1) en *b)* de identificatie van de belangrijkste problemen met het leren en onderwijzen van genetica, een diepgaand inzicht in deze problemen en de formulering van ontwerpcriteria waaraan een adequate onderwijsleerstrategie zou moeten voldoen (hoofdstuk 3).
In de *cyclische onderzoeksfase* (hoofdstuk 4), werden drie casestudies in verschillende scholen en klassen (6 vwo, 4 vwo en 4 havo) gepland. Op basis van de resultaten en criteria uit de verkennende fase werd een eerste ontwerp van een onderwijsleerstrategie voor genetica gemaakt en vervolgens uitgewerkt tot het eerste contextspecifieke *scenario,* dat in de klas getoetst werd. Bij het uittesten daarvan in de praktijk werden verschillende datasets verzameld en geanalyseerd om het scenario te kunnen evalueren en te reflecteren op de onderwijsleerstrategie. De resultaten geven aanwijzingen om het ontwerp verder aan te passen. De herziene onderwijsleerstrategie werd omgezet in een tweede en derde scenario, die vervolgens ook in de praktijk werden getoetst. De onderwijsleerstrategie ontwikkelde zich verder tijdens het proces van cyclisch empirisch toetsen van scenario's in opeenvolgende casestudies.

Hoofdstuk 1 schetst het eerste deel van de *verkennende fase*, waarin de ontwikkelingen in het onderwijs en onderzoek in de biologie worden besproken, evenals de huidige ideeën over leren en onderwijzen. Op grond daarvan is een domeinspecifieke visie op het leren en onderwijzen geformuleerd.
De recente ontwikkelingen en inzichten in de *wetenschap* laten een toenemende aandacht voor genetica zien, wat het belang van het bevorderen van 'genetic literacy' benadrukt. De ontwikkelingen in het biologieonderwijs en onderzoek onderstrepen het belang van het verkrijgen van een samenhangend en geïntegreerd beeld van de biologie. Er vindt een toenemende integratie plaats van onderzoek en kennis op de verschillende biologische organisatieniveaus.
De ontwikkelingen in het *onderwijsveld* richten zich op het verwerven van een 'leren leren' competentie, die essentieel is geworden in onze huidige kennismaatschappij. Deze aanpak lijkt echter nog niet adequaat in de onderwijspraktijk te zijn geïmplementeerd.

In onze visie is het van belang om in het biologieonderwijs de sleutelbegrippen en hun onderlinge relatie te benadrukken. Ze kunnen een structurerende functie voor de meer specifieke kennis in een domein vervullen. Leerlingen worden zo in staat gesteld inzicht in, en een samenhangend beeld van, de biologie te verkrijgen. Voor het ontwikkelen van een adequate onderwijsleerstrategie voor genetica houdt dit in dat de sleutelbegrippen en hoofdlijnen in de erfelijkheid benadrukt moeten worden en dat leerlingen actief betrokken moeten worden bij hun leerproces. De probleemstellende aanpak kan een vruchtbare methode zijn om leerlingen te motiveren en actief te betrekken bij het inhoudelijk leerproces. Dit idee is gebruikt bij het ontwerpen van de onderwijsleerstrategie voor genetica.

Hoofdstuk 3 beschrijft vervolgens het grootste deel van de *verkennende fase*. De belangrijkste problemen met het leren en onderwijzen van de genetica werden middels bestudering van de internationale vakdidactische literatuur over genetica en focusgroep interviews met Nederlandse biologiedocenten geïdentificeerd. Dit resulteerde in tien domeinspecifieke problemen waaruit twee sleutelproblemen werden geselecteerd om het vervolgonderzoek op te richten: *de abstracte en complexe aard van genetica.* Om meer diepgaande kennis over deze twee sleutelproblemen te verkrijgen, werd een verkennende casestudy geïnitieerd, waarin een reguliere lessenserie genetica in een 5 havo klas werd geobserveerd (12 lessen). De biologiedocent werd geïnterviewd om de opzet van zijn geneticalessen te verhelderen. Leerlingen hielden tijdens de geneticalessen logboeken bij en zij werden geïnterviewd om meer inzicht in hun redeneerwijzen te verkrijgen. Ook werden enkele eerste ideeën voor leeractiviteiten uitgeprobeerd. Daarnaast werden de hoofdstukken over erfelijkheid, voortplanting en meiose van biologieschoolboeken geanalyseerd om vast te stellen wat schoolboeken bijdragen aan de abstracte en complexe aard van de genetica.
Uit deze verkennende fase bleek dat een scheiding in tijd en plaats van de onderwerpen erfelijkheid, voortplanting en meiose verantwoordelijk lijkt te zijn voor de *abstracte aard* van geneticaonderwijs. Het traditionele geneticaonderwijs richt zich voornamelijk op het oplossen van kruisingsvraagstukken. Leerlingen blijken problemen te ondervinden met het vertalen van teksten naar schema's en symbolen, en vice versa bij het lezen en interpreteren van schema's en symbolen. Daarbij moeten leerlingen wiskundige berekeningen met deze symbolen uitvoeren om deze vraagstukken op te lossen en ze moeten kansen relateren aan biologische verschijnselen. Het kruisingsschema wordt veelal routinematig gebruikt zonder dit te koppelen aan biologische verschijnselen en processen, zoals de meiose.
De *complexe aard* van de genetica verwijst er naar dat erfelijkheidsverschijnselen zich op verschillende biologische organisatieniveaus manifesteren, en dat elk organisatieniveau een eigen terminologie kent. Voor een betekenisvol begrip is het kunnen *heen-en-weer denken* tussen het moleculaire, cellulaire, organismale en populatieniveau vereist, alsook het verbinden van de verschillende structuren en processen op deze niveaus. Biologen, onder wie biologiedocenten, gebruiken deze 'denkvaardigheid' automatisch. Leerlingen die genetica proberen te begrijpen, komen in de problemen, omdat biologiedocenten en schoolboekauteurs vaak impliciet van het ene naar het ander niveau springen.
Op grond van de uitkomsten van de verschillende onderzoeksactiviteiten in deze

verkennende fase, konden vier ontwerpcriteria voor een onderwijsleerstrategie voor genetica worden gedefinieerd:

1. Het geneticaonderwijs moet beginnen op het organismale niveau waarmee leerlingen bekend zijn en dan geleidelijk afdalen naar het cellulaire niveau.
2. De relatie tussen meiose en erfelijkheid moet expliciet behandeld worden.
3. De twee belangrijke cellijnen, te weten de somatische lijn (mitose) en de kiemlijn (meiose) moeten in de context van de levenscyclus onderscheiden worden.
4. Leerlingen moeten de relaties tussen de biologische organisatieniveaus zelf ontdekken, daarbij begeleid door een zorgvuldig doordachte structuur van de leeractiviteiten (en/of door de docent) volgens de probleemstellende aanpak.

In de *cyclische onderzoeksfase*, beschreven in **hoofdstuk 4**, zijn de vier ontwerpcriteria en ideeën omgezet in een eerste onderwijsleerstrategie, bestaande uit een sequentie van vragen en een sequentie van daarmee samenhangende leeractiviteiten.
Uit criterium 1 vloeide voort dat de biologische organisatieniveaus stap voor stap behandeld moeten worden, te beginnen met het organismale niveau waarmee leerlingen al bekend zijn, waarna geleidelijk ingezoomd wordt op het cellulaire en moleculaire niveau. Wanneer leerlingen een niveau afdalen, moeten zij ook de noodzaak van het afdalen inzien; het moet betekenisvol voor hen zijn. Dit kon bereikt worden door leerlingen een (genetisch) probleem op het organismeniveau voor te leggen, dat zij alleen kunnen oplossen door gebruik te maken van geneticabegrippen op het cellulaire niveau (criterium 4). Wat betreft de biologisch-inhoudelijke structuur van de onderwijsleerstrategie voor genetica waren criteria 2 en 3 essentieel. Het expliciet onderscheiden van de somatische cellijn en de kiemcellijn in een levenscyclus hielp de leerlingen te begrijpen dat groei & ontwikkeling en geslachtelijke voortplanting, gekoppeld zijn aan verschillende celdelingprocessen (mitose en meiose), die genetische continuïteit (cf. ongeslachtelijke voortplanting) en diversiteit mogelijk maken. Leeractiviteiten moeten dus starten op het organismeniveau en er moet expliciet een relatie worden gelegd met de voortplantingsprocessen. De sleutelbegrippen betreffende voortplanting en erfelijkheid zouden verkend moeten worden in opeenvolgende leeractiviteiten. Daarnaast is het proces van meiose een cruciale schakel. ‘Homologe chromosomen’ is een moeilijk begrip voor leerlingen en dat gaf aanleiding tot de ontwikkeling van een chromosomenpracticum.
De **eerste onderwijsleerstrategie** voor genetica (tabel 4.3) werd uitgewerkt in een contextspecifiek scenario met bijbehorende lesmateriaal voor twee 6 vwo klassen. Het scenario werd vervolgens in de onderwijspraktijk getest om na te gaan of het feitelijke onderwijsleerproces in de klas en de leerresultaten overeenkwamen met de vooraf geformuleerde verwachtingen en om te reflecteren op de adequaatheid van de onderliggende onderwijsleerstrategie. Het algemene doel van deze eerste onderzoeksronde was het opsporen van ontwerpfouten en in het verlengde daarvan het opnieuw doordenken van de aard en volgorde van de leeractiviteiten. Op basis van de testresultaten werd het scenario op vier punten aangepast.
De belangrijkste aanpassing kwam voort uit het feit dat leerlingen moeilijkheden ondervonden met het *opstijgen* in de biologische organisatieniveaus. Leerlingen waren

in staat naar de lagere biologische organisatieniveaus af te dalen en de biologische processen en verschijnselen op de verschillende niveaus aan elkaar te relateren, maar ze bleken niet in staat om vanaf de lagere niveaus op te stijgen. Dit was het moment waarop het idee van de jojo-strategie werd geboren. De essentie van de tweede versie van de onderwijsleerstrategie voor genetica werd dus geduid met *'jojo-leren'* (analoog met het speelgoed jojo). Leerlingen worden uitgenodigd om heen-en-weer ('omhoog en omlaag') te denken tussen de biologische organisatieniveaus en om de erfelijkheidsbegrippen op deze niveaus met elkaar in verband te brengen. Het beoogde leerresultaat werd gekarakteriseerd als een competentie:

> Leerlingen zijn in staat om de biologische organisatieniveaus te onderscheiden, de relaties tussen deze niveaus te zien en geslachtelijke voortplanting en erfelijkheid binnen een levenscyclus aan elkaar te relateren door heen-en-weer te denken tussen de biologische organisatieniveaus.

De **tweede versie** van de **onderswijsleerstrategie** (tabel 4.5) werd uitgewerkt tot een tweede en derde scenario en in de praktijk getest in twee casestudies (twee 4 vwo klassen en een 4 havo klas). De leerdoelen leverden de evaluatiecriteria. Deze doelen verwijzen respectievelijk naar de *biologische organisatieniveaus* en naar de *sleutelbegrippen.*

Uit de tweede onderzoeksronde kon worden geconcludeerd dat in het algemeen de aard en sequentie van de leeractiviteiten in het tweede en derde scenario als adequaat beschouwd konden worden. De problemen zoals beschreven in de literatuur en aangegeven door de Nederlandse biologiedocenten, waren in aanzienlijke mate opgelost. Met betrekking tot *sleutelbegrippen* kon geconcludeerd worden dat de belangrijke inhoudelijke hoofdlijn van erfelijkheid, de relatie tussen geslachtelijke voortplanting, meiose en erfelijkheid, voor de meeste leerlingen duidelijk was. Daarnaast bleek dat met deze kennisbasis ook allerlei soorten kruisingsvraagstukken opgelost konden worden. Met betrekking tot *biologische organisatieniveaus* kon worden geconcludeerd dat de keuze om te beginnen op het organismale niveau en geleidelijk af te dalen naar het cellulaire en moleculaire niveau, adequaat bleek te zijn. Per biologisch organisatieniveau werden betekenisvolle vragen opgeroepen, die uitnodigden om af te dalen naar een lager organisatieniveau en om deze vragen te koppelen aan de voorafgaande vragen en aan (bijbehorende) erfelijkheidsbegrippen.

Door vergelijking van het geobserveerde onderwijsleerproces en de leerresultaten met de vooraf in het scenario geformuleerde verwachtingen, en reflectie op discrepanties, kon worden geconcludeerd dat:

1- de sequentie van de onderwijsleerstrategie voor genetica (beginnen op het organismeniveau en geleidelijk afdalen naar het celniveau) adequaat lijkt;
2- de stappen in het afdalen geleidelijker, betekenisvoller en explicieter zijn geworden dan in de eerste test. Toch zouden enkele overgangen nog steeds verbeterd kunnen worden, aangezien de reflectieactiviteiten niet geheel werden uitgevoerd zoals bedoeld;
3- leerlingen in staat waren de biologische organisatieniveaus op te stijgen, al bleef het opstijgen vanaf het moleculaire niveau naar het cellulaire niveau minder nauwkeurig (de onderwijsleerstrategie richtte zich vooral op het organismale en cellulaire niveau);
4- leerlingen in staat waren om de biologische organisatieniveaus te onderscheiden,

en om (impliciet) te jojo-en tussen de niveaus en de erfelijkheidsbegrippen op deze niveaus.

De onderwijsleerstrategie behoeft op twee punten verdere verbetering: het beantwoorden van de centrale vraag zou explicieter moeten, en de docent zou in de reflectieactiviteiten meer aan de leerlingen moeten overlaten. De laatste versie van de onderwijsleerstrategie (tabel 4.12) is op deze punten aangepast. Na deze aanpassingen beschouwen we de bijgeschaafde jojo-strategie voor genetica als 'goed genoeg'.

Tenslotte wordt in **hoofdstuk 5** een formele beschrijving van de didactische structuur van de laatste jojo-onderwijsleerstrategie voor genetica gepresenteerd. Tevens wordt de centrale onderzoeksvraag van dit proefschrift beantwoord.

De essentie van de jojo-strategie is het afdalen en opstijgen van de biologische organisatieniveaus door middel van de genetisch-inhoudelijke structuur en de probleemstellende structuur, die onderling verweven zijn.

De *genetisch-inhoudelijke structuur* in de jojo-strategie (tabel 5.1) bevat de genetische sleutelbegrippen, geordend naar biologisch organisatieniveau. Deze is gepresenteerd als een sequentie van relevante vragen en antwoorden: de conceptuele lijn. De *probleemstellende structuur* draagt zorg voor het opwekken en in stand houden van de leermotivatie. Door het ontlokken van inhoudsgerelateerde betekenisvolle vragen en antwoorden, wordt een leerweg geplaveid. De probleemstellende sequentie die in de opeenvolgende leeractiviteiten in de jojo-strategie kan worden herkend, bestaat uit de volgende stappen:

i. De centrale sturende vraag (gesteld aan het begin van de leersequentie) met als doel globale motivatie.

1. Deelvraag formuleren en lokaal motief om de deelvraag te beantwoorden: stimuleren van behoefte om kennis uit te breiden.
2. Informatie en/of onderzoek: uitbreiden van de kennis.
3. Toepassen: de uitgebreide kennis toepassen in een nieuwe situatie.
4. Reflectie: reflecteren op de uitgebreide kennis.
   - 4a. Beantwoorden van de deelvraag, gesteld aan het begin van de leeractiviteit (terugkoppeling naar stap 1).
   - 4b. Het antwoord op de deelvraag koppelen aan al de voorafgaande stappen (deelvragen) op de hogere biologische organisatieniveaus, om na te gaan in hoeverre de centrale vraag (*i*) nu beantwoord is en om de formulering van de volgende deelvraag te (bege)leiden.
   - 4c. Leerlingen beseffen wat ze nu wel en wat ze nu nog niet begrijpen of weten, wat hen een motief zou moeten verschaffen om een volgende stap in de leersequentie te nemen door het formuleren van een nieuwe deelvraag (stap 1) met de centrale vraag in gedachte. Met deze nieuwe deelvraag begint de volgende cyclus van vier stappen.

De probleemstellende structuur bestaat dus uit een aantal opeenvolgende cycli, elk bestaande uit vier stappen. Elke nieuwe cyclus begint met de formulering van een deelvraag die verkend (onderzocht) en beantwoord wordt middels de volgende leeractiviteiten.

Terwijl deze opeenvolgende probleemstellende cycli in de jojo-onderwijsleerstrategie worden doorlopen, dalen leerlingen geleidelijk af van het organsimale naar het

cellulaire en uiteindelijk naar het moleculaire niveau. De terugkoppelingslussen naar de centrale vraag via de voorafgaande deelvragen in de *reflectiefase,* komen overeen met het opstijgen qua biologisch organisatieniveau. De essentie van **'jojo-en'** is het *niet alleen* terugkomen op de deelvraag die op dat moment beantwoord moet worden, maar ook het terugkoppelen naar de *voorgaande deelvraag/-vragen* (op het/de hogere niveau(s)): het opstijgen. In het afdalen van de biologische organisatieniveaus mag geen niveau en ook geen genetisch sleutelbegrip worden overgeslagen (de conceptuele structuur).
Het voorgaande illustreert de analogie met het speelgoed 'jojo'. In het hanteren van een jojo is het onmogelijk om een deel van de neergaande of opgaande weg over te slaan. Het is ook mogelijk om omhoog te jojo-en en omlaag te jojo-en, maar het start- en ankerpunt blijft altijd gelijk: de hand die de jojo hanteert. In de jojo-onderwijsleerstrategie voor genetica is het begin- en ankerpunt het organismale niveau, vanwaar naar de niveaus kan worden afgedaald en weer opgestegen (neerwaarts jojo-en) maar ook kan worden opgestegen naar het populatie en levensgemeenschapniveau (opwaarts jojo-en) en weer afgedaald naar het organismeniveau. In de jojo-onderwijsleerstrategie is het essentieel om per biologisch organisatieniveau tenminste één complete probleemstellende cyclus te doorlopen.

De jojo-strategie reduceert de complexe aard van de genetica door de biologische organisatieniveaus expliciet te onderscheiden en door het afdalen en opstijgen met het organismale niveau als ankerpunt. Het expliciteren van de niveaus maakt het organisatieniveau-doorsnijdende karakter van de erfelijkheid voor leerlingen zichtbaar, en biedt inzicht in de erfelijkheidsverschijnselen, processen en structuren die zich op de verschillende organisatieniveaus voordoen. De genetische terminologie is afgestemd op het specifieke niveau waar leerlingen op dat moment mee bezig zijn. Dit voorkomt verwarring. De onderwijsleerproblemen, beschreven in de literatuur betreffende cytologische processen, het homologe-chromosoomconcept en chromosoomstructuur, zijn grotendeels verdwenen.
De jojo-strategie benadrukt de sleutelbegrippen in de genetica per organisatieniveau en hun onderlinge samenhang. De relatie tussen voortplanting, meiose en erfelijkheid op het organismale en cellulaire niveau wordt benadrukt. De sleutelbegrippen worden concreet gemaakt.
De probleemstellende structuur van de inhoudelijke deelvragen en reflectieactiviteiten is adequaat in het verschaffen van een motief aan leerlingen om een volgende leeractiviteit aan te pakken, waarin een aansluitend sleutelbegrip op een specifiek organisatieniveau wordt verkend.
Door middel van de jojo-onderwijsleerstrategie is het beoogde leerdoel behaald; leerlingen hebben zich de competentie van het heen-en-weer denken tussen de biologische organisatieniveaus en het relateren van de erfelijkheidsbegrippen op deze niveaus eigen gemaakt.

Aangezien de biologische organisatieniveaus een rol spelen in de meeste biologische onderwerpen, is betoogd dat de jojo-strategie ook toepasbaar kan zijn voor andere onderwerpen die verschillende organisatieniveaus doorsnijden, zoals gedrag, evolutie en ecologie. Gezien de bredere toepasbaarheid van deze didactische aanpak, mogen we concluderen dat de jojo-onderwijsleerstrategie verder onderzoek verdient.

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Curriculum Vitae

Marie-Christine Knippels werd geboren op 27 juli 1971 te Roermond. Haar Atheneum B diploma behaalde zij in 1990 aan het St.-Thomascollege te Venlo. In datzelfde jaar begon zij aan de Universiteit Utrecht met de studie Biologie, die in augustus 1996 succesvol werd afgerond door het behalen van het doctoraal examen. De specialisatiefase omvatte een tweetal stages: bij de Projectgroep Stofwisselingsfysiologie van de Vakgroep Experimentele Dierkunde, Universiteit Utrecht (onder leiding van Dr. Ir. W.J.A. van Marrewijk en A.Th.M. van den Broek) en bij de Afdeling Farmacologie van de Faculteit Farmacie, (onder leiding van Dr. F.A.M. Redegeld). Vervolgens volgde zij de wetenschappelijke beroepsopleiding Gezondheidsvoorlichting bij de Vakgroep Didactiek van de Biologie, waarin gedurende 5 maanden een duo-stage bij de Rode Kruis Bloedbank te Utrecht werd gelopen (onder leiding van Dr. C.L. van der Poel en Dr. A.J. Waarlo).
Na een aantal maanden op uitzendbasis werkzaam te zijn geweest als intercedent, werd zij in mei 1997 projectmedewerker bij de Vakgroep Didactiek van de Biologie. In opdracht van de Nederlandse Vereniging tot Bescherming van Dieren en de Wetenschapswinkel Biologie van de Universiteit Utrecht, werd vooronderzoek gedaan ten behoeve van de ontwikkeling van educatief materiaal over de relatie mens en dier voor het voortgezet biologieonderwijs.
In januari 1998 is zij als assistent in opleiding (AIO) in dienst getreden bij het Centrum voor Didactiek van Wiskunde en Natuurwetenschappen (CDβ) te Utrecht, Leerstoelgroep Didactiek van de Biologie. In deze functie is het onderzoek verricht waarover in dit proefschrift wordt gerapporteerd. Van september tot met december 2002 is zij als onderzoeker aangesteld bij CDβ voor het SLO-ontwikkelproject ‘De betekenis van science in het onderwijsaanbod van de basisschool’.

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