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.

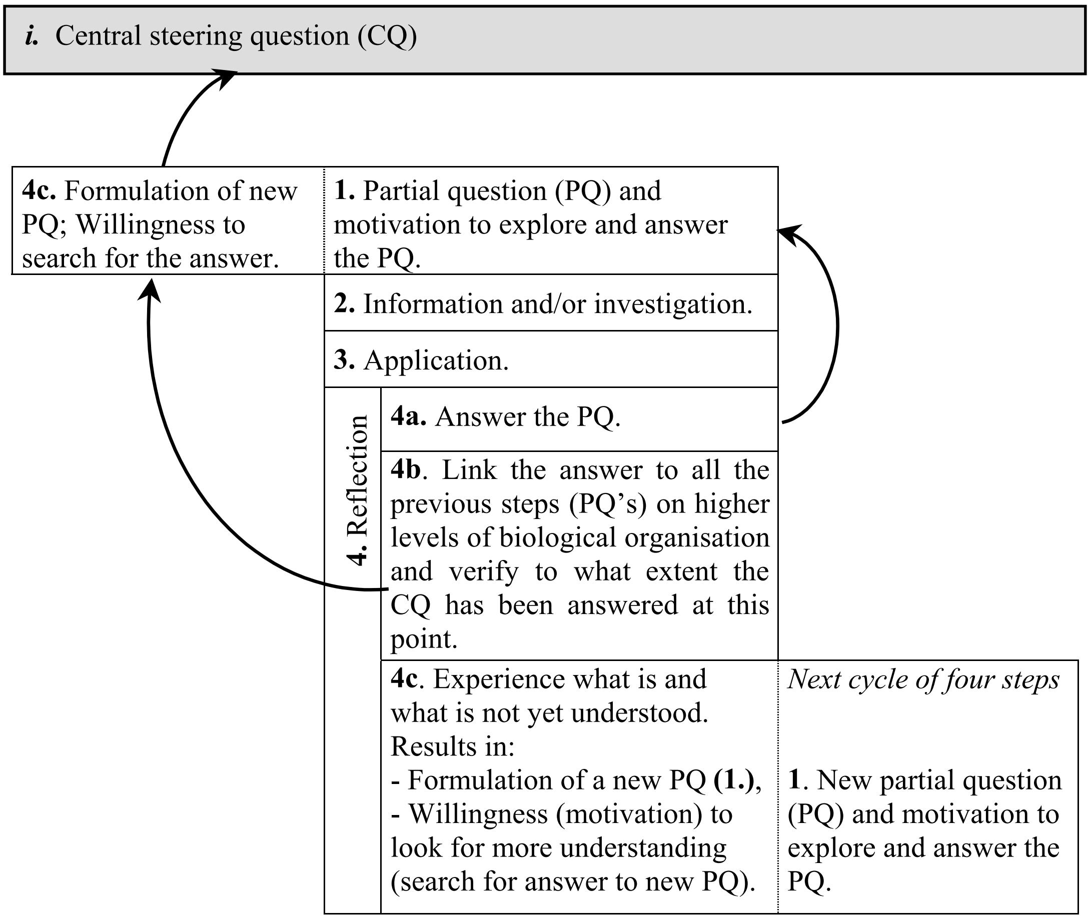

Figure 5.1 ***The structure of the reflection step and its position within the problem posing cycle.***

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),

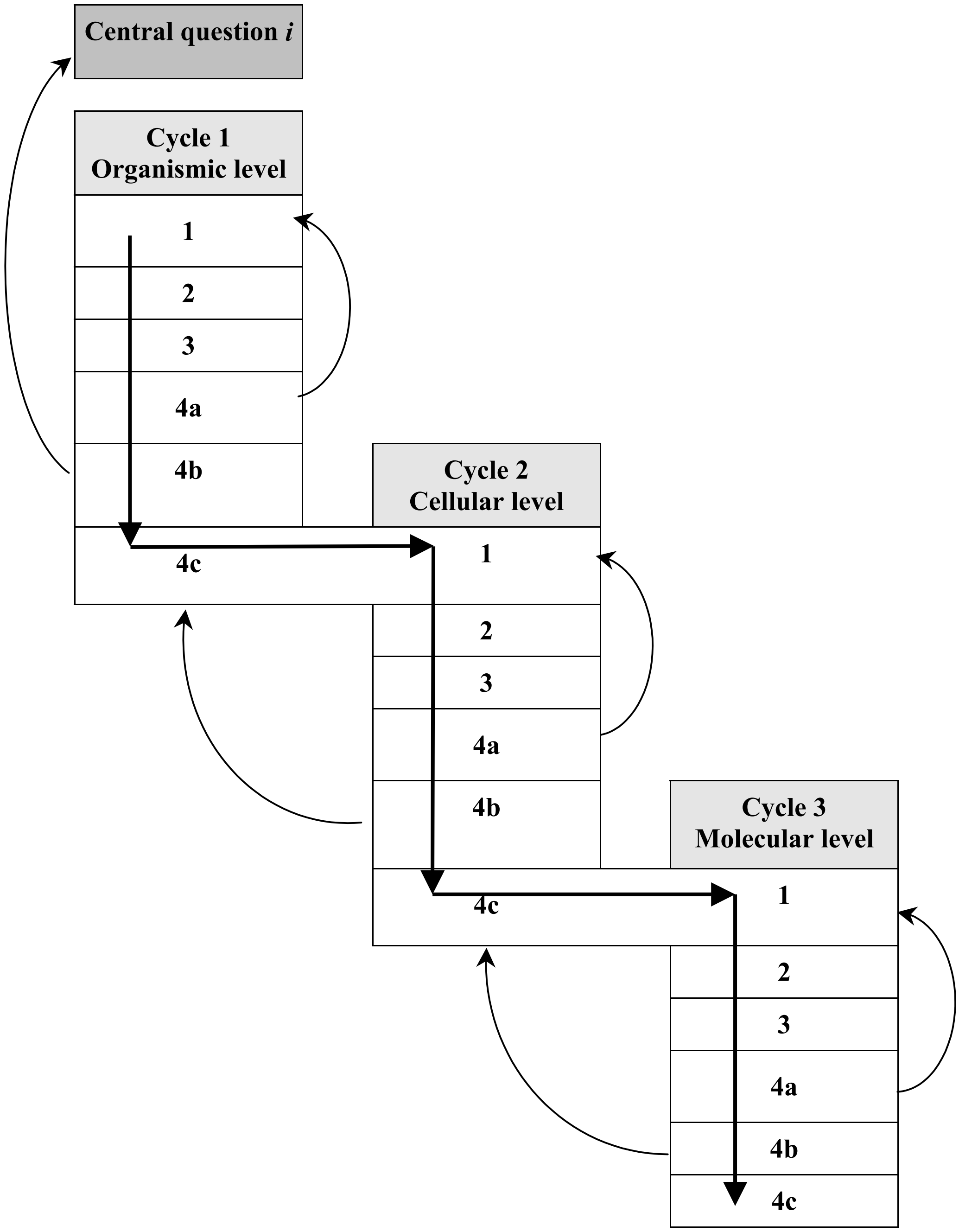

Figure 5.2 ***Schematic representation of the yo-yo LT strategy: descending and ascending the levels of biological organisation by means of the four problem posing steps****. 1. Partial question and motivation to answer the question in a next learning activity, 2. Information and/or investigation of 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.

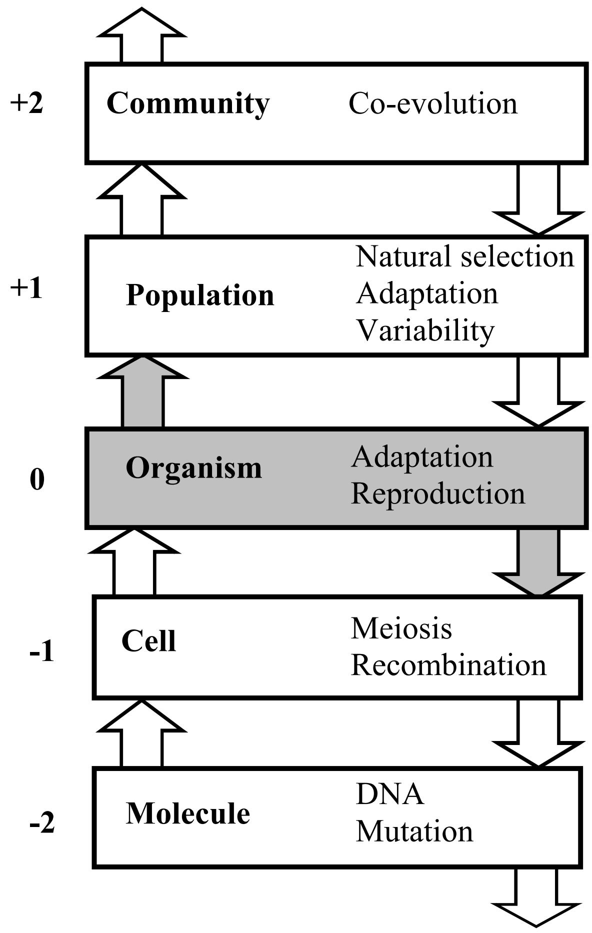

Figure 5.3 ***Preliminary arrangement of the key concepts on the different levels of biological organisation for the subject of evolution, according to the yo-yo LT strategy.***

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.