Learning and teaching ecosystem behaviour in secondary education

Systems thinking and modelling in authentic practices

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Leren en onderwijzen van ecosysteemgedrag in het voortgezet onderwijs.
Systeemdenken en modelleren in authentieke praktijken

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor
aan de Universiteit van Utrecht
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ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen
op maandag 18 februari 2008 des middags te 14:30 uur

door

Regnerus Henricus Vitus Westra

geboren op 19 februari 1950, te Leeuwarden

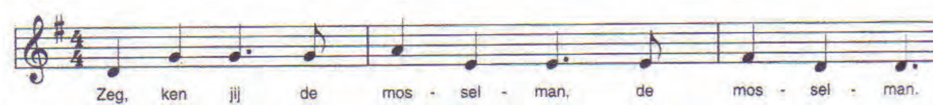
Promotoren: Prof.dr. K. Th. Boersma

Prof. dr. A. J. Waarlo

Co-promotor: Dr. E. R. Savelsbergh

Voor Ellen

Hey, do you know the mussel man? (Zeg, ken jij de mosselman?)



(traditional Dutch children's song, which was frequently sung by students when the researcher entered the classroom)

"The World is chaos. Blind is its path (…) Whither shall we wander? Where shall we go?"

Translated from the Danish book of poetry 'Fribytterdrømme' from Tom Kristensen.

"Annies doctrine: 'There is nothing which is not nature. We are all nature. Even the big cities will be broken down to rubble where eagles will breed and lizards will sunbath on the walls. To jungle or spruce forest with mysterious formations.'"

Translated from the Swedish novel 'Händelser vid vatten' from Kerstin Ekman.

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1 Introduction

1.1 A study on learning and teaching ecosystem behaviour by a teacher-ecologist

This thesis is about learning and teaching ecosystem behaviour.

Ecology is a fascinating field of science. It is about relations between living organisms, as well as between these organisms and their non-living environment. As there are so many organisms (conspecifics as well as representatives of different species) and so many different abiotic factors, constantly changing over time, the course of events is very complex and dynamic in most cases. I always wanted to know what could possibly happen and was amazed by the fact that one problem often had more than one solution in ecology, leading to a variation in possible outcomes. This all makes it difficult, sometimes even impossible to predict developments. By the end of my upper secondary school period, I had become fascinated by the phenomenon of relations, giving rise to a vast number of possible outcomes of processes. I could not decide to go for sociology, about relations between humans, or for ecology, about relations between organisms. Ultimately I did choose for biological relations. I have never regretted this choice. In my further career, there have been different periods with a different focus, respectively my development as an ecologist, as a teacher and as a curriculum developer.

Ecologist

During my university studies in biology I chose ecology in my masters. In this period I met Hans Reddingius, who was a mathematical biologist. I read his dissertation (Reddingius, 1972) and became a life-long convert to a mathematical approach in ecology. Under his leadership I carried out a mathematical modelling study on the effects of epidemic outbreaks on an animal population of the field vole (*Microtus agrestis L.*), by means of computer simulations. In those days such simulations were written in the computer language ALGOL-60, and run on a Telefunken TR4 computer. I finished my work after 9 months, delivered my models and an essay (Westra, 1971) and continued working in the field and in a hospital lab. I adapted my models for a population of rabbits (*Oryctolagus cuniculus* L.) and assembled ecological and virological data from a real epidemic of myxomatosis that was threatening the rabbit population of the island Schiermonnikoog. This has always kept fascinating me: the combination of modelling nature and observing nature, resulting in the fitting of real data into the models to validate the outcomes of the model.

Three articles have been of great significance in my development as an ecologist. The first is 'What it is like to be a bat' by Thomas Nagel (1974), because it made clear to me that every investigation should start with an attempt to put oneself in the position of the only concrete level of organization in ecology, being the organism. The second is 'An equilibrium theory of insular zoogeography' by Robert MacArthur and Edward Wilson (1963), which opened my eyes to the importance of modelling and finding laws in ecology. I remember using their ideas in daily practice in an advice that I had to write about reallocation of land and the consequences for bird life in the remaining areas (Werkgroep Schagerkogge, 1980). Finally, the third is 'Biological Populations with Non-Overlapping Generations: Stable Points, Stable Cycles, and Chaos', by Robert May (1974), in which he showed that the dynamics of populations that could be described in simple mathematical formulas with a deterministic character, could still be very complicated. This article caused a resonance with my feelings that it was fascinating to follow developments in an ecosystem which were in most cases fairly predictable, but sometimes totally unpredictable. Besides these articles, I still have warm feelings when reading an 'ecologist avant-la-lettre', Carl Linnaeus, who in his travel accounts (for example 'Öländska och Gotländska Resa', 1745) showed a deep interest in the relations between the organisms he saw and their environment.

Teacher

In 1974, at the end of my scientific studies, I had to decide what to do. In those days there was a strong feeling that it was possible to 'construct' society, and education was 'the real thing'. I found a job as a biology teacher in secondary school. My drive was to improve the biological and especially ecological literacy of my students. After all, it was the time of 'The year of nature' (1970) and 'The International Biological Program' (1960-1974); the time seemed mature for bringing ecology to society. '*Suddenly, it seemed, ecology was everywhere. Becoming the catchword of the day, it sneaked into the everyday vocabulary, not only of scientists and their culture, but of government bodies, political parties and social movements as well.*' (Söderqvist, 1986, p.V). In the United States the Green Version of the BSCS schoolbooks had been written from an ecological perspective (BSCS, 1963). In the Netherlands the first ecological books entered school practice (Boucquet, 1971; Hopman-Rock, 1975). In those days, ecology was not part of the national written examination, which was introduced in the Netherlands in 1975, but it was part of the curriculum, to be tested in the school examination[1]. Only in 1989, was ecology incorporated in the syllabus for the national written examination. What has not changed until now is the situation that no clue to the complexity or dynamics of ecosystems is given in school ecology. One can not find anything about it in the different curriculum papers, although in ecology as a science, complexity and dynamics entered the centre of the attention. By the end of the 1980s, the first computer models entered the schools, but they did not offer students the possibility to grasp the complexity and dynamics of ecosystems. The (mathematically formulated) relations between the various components in the ecosystem were hidden for the students. For me this remained unsatisfactory. How to teach the complexity and dynamics I had seen as an ecologist, so as to improve the ecological literacy of my students? My field studies in Schiermonnikoog had inspired me to stimulate practical activities with the aim of 'reading nature'. This means developing the ability to recognise organisms and relate them to material cycling and energy flows in the specific habitat which is to be read. It means also developing the ability to understand the relationships between functional groups and how abiotic factors, such as light and speed of water influence the whole ecosystem (Magntorn & Helldén, 2005). My students were involved in measuring and evaluating pollution in pond life, performing capture-recapture experiments with woodlice and insects, measuring plant diversity in a transect on meadows, counting the distribution of the Eurasian coot (*Fulica atra L.*) in time and space, etcetera. Students from 12-18 got fascinated by the variety of life found at different places and in different seasons. However, this fascination did not, by itself, lead to any deep ecological insights. In order for students to gain such insights, they need a theoretical background, based on ways of modelling nature. Without modelling it is not really possible for students to structure their ecological knowledge, taking into account spatial and temporal dynamics. This was all the more pressing, because there seemed to be no real progress in students' understanding of ecological processes, when moving from primary school to lower and subsequently upper secondary school. Therefore I had many questions. Why is the complexity and dynamics of ecosystems not implemented into the curriculum and the schoolbooks? Is it too difficult for learning and teaching? Is it the difficulty in modelling and the accompanying mathematics that block the way to implementation? Are the curriculum developers and the teachers not aware of the changes in ecology as a science since the 1960s (Odum, 1959)? And why is

1 At the end of upper secondary education in the Netherlands, there is a final test to decide about success or failure for students. This test consists of a part which is organized by the schools themselves and a part which is organized centrally. This last part takes the form of a written examination with, for biology, a mixture of multiple choice and open questions. Both parts contribute equally to the final mark of the students.

there no link between upper secondary school education and the many ecosystem-related questions in 'real life' (like discussions about quota in fishery, management or development of nature reserves, and the decline of typical meadow birds like lapwing (*Vanellus vanellus* L.) and black tailed godwit (*Limosa limosa* L.) in the Netherlands)?

Curriculum innovator

In 2001 two new lines in my career developed. Firstly, I started working in a modelling project in Utrecht University, where the graphic modelling tool Powersim was being used to develop curriculum materials for science subjects like homeostasis, dynamics of a rabbit population, several types of movement in sport, and the chemistry of a swimming pool. Secondly, the institute that develops the national examination tests in the Netherlands (Cito, Arnhem[2]) started an experiment with (partially) computer based national examinations in biology. I participated in this project and developed models with the same tool I used in Utrecht. This tool seemed a very adequate aid for learning and teaching the complexity and dynamics of ecosystems. So, when the project ended after two years and I was asked to do a Ph.D.-research project in Utrecht on opportunities to implement complexity and dynamics in ecosystems in upper secondary school, using computer modelling, I felt that this was exactly what I had been looking for such a long time. I got the opportunity to do research in classrooms and to find ways to test my ideas about complexity and dynamics in ecosystems in upper secondary school and to get answers to at least some of my questions. Therefore, I will first have to describe in short what these personal ideas entail.

My view on ecology

In 'The Time Machine' (Wells, 1895) the main character is displaced to the future, to the year 802701, by means of a machine. In 'Kruistocht in spijkerbroek' ('Crusade in jeans') (Beckman, 1973) the main character goes back in time, till 1212, the year of the children's crusade. It will be clear that descriptions of a time leap can be more exact when going back than going forward. When you do not go back too far, there will be silent witnesses in the form of texts, buildings or fossils. Going back further will make it more difficult to describe what could be seen. Still, this description will be more easily to produce of than making a description of the future.
An ecologist has a comparable problem. If he wants to predict the developments in

2 This institute works under the supervision of Cevo, which is the responsible organization for the national examinations.

an ecosystem, there are certain rules he could use. These rules can be extrapolated from history and from experimental data. After all evolution theory gives the rule that populations of plants or animals change in a direction in which the average fitness within the population will increase, causing them become more adapted to their environment. But chance has a strong influence on what will eventually happen. The environment changes in a way we cannot always foresee. And the 'reaction' of the members of the population to this change (being based on unpredictable changes in their DNA, called mutations) is a stochastic process, of which we at best can know the probability of the next step being a certain event (Pennings, 2006).

Take the developments on the islands near the Krakatau volcano in the Indonesian archipelago around 1880, for example. These are lushly covered with tropical vegetation, full with all kinds of insects, lizards, birds, and mammals. An area in a natural equilibrium, a climax stadium, some people would say. However, in 1883 an unpredicted but serious eruption of the Krakatau volcano takes place and in one blow the complete ecosystems on the islands Rakata, Panjang and Sertung are annihilated through a catastrophe: the islands look 'sterilized'. In 1932 at the place of the sunken Krakatau, a small island rises: Anak Krakatau. It is completely left without vegetation. What will these islands look like after a hundred years? How after one thousand or one million years? We can make some predictions about the colonization. Certain species do have a greater chance to reach an island than others. Light seeds do have more chance to spread than heavy ones. Seeds with an air cavity will drift better on sea than seeds without it. Small animals could be blown into the direction of an island. Also there are good chances for animals that can fly or swim well. Some animals will arrive purely by chance, clinging to a tree trunk. Fish, jelly fish, or star fish will come near the island, but they will not actually be able to live on it. A spider arriving alone will die before having the opportunity to reproduce, unless by accident another spider from the same species, but from the opposite sex arrives also. A small feline clinging to a tree trunk and arriving on an island will die in the end, if there are no prey animals to eat. A plant species which is growing well on an island will disappear if the pollinating insect did not succeed in arriving there.

The size of the islands also plays a role. The bigger, the more room for invaders there will be, and also for their partners and food sources. An advantage for colonizing animals will be that there are no enemies or competing species in the beginning. Predators are in most cases bigger than their prey and they will arrive on an island less easily. Therefore, herbivore animals will have the time and the opportunity to try some food that they did not eat before.

There is also a variety in landscape. On Rakata, which is the biggest of the resulting islands, there are many different habitats: high or low areas, sunny or more shadowy places, it will be wet and salty in the periphery near the sea and dry and less salty in the centre. So there will be chances for different species. However, being successful does not depend only on the circumstances on the spot, but also on the presence of other living creatures. All animals need a partner to make it possible to reproduce. Some need a tree to create shadow, or a flower to support nectar, some plants need birds to spread their seeds. Evolution will take care of populations adapting better to the circumstances and to the other organisms. A network of relations will develop, scientifically described in the concept of the ecosystem. Such a concept is completely different from the concept of a country, which is in many cases an area with artificial boundaries. After a number of years, there will probably be more species. After all, if plants are growing, there will be food for animals and shadow for plants and animals that do not tolerate intense sunshine. A predator coming on land on the island will have more possibilities as his food will now be available. Will this process go on? Probably it will not, because newcomers are confronted with competition. It could be difficult to chase away an already adapted species. Equilibrium between colonization and competition could evolve, the ecosystem becoming 'stable.' But, there will always be small changes, for example in the climate. Or, by chance, a population will increase or decrease strongly in numbers. This could cause problems in linked populations, on the other hand giving colonizing new species chances to immigrate. There will always be dynamics in the development of the populations to be found together in an ecosystem. Besides, there will also be the threat of big changes like a new volcano eruption, fading away nearly all living creatures.

What happened on these Indonesian islands could happen everywhere in the world, in every ecosystem. In the Netherlands a catastrophe could take place by means of a flood, changing the environment drastically. In the fossil record we can see the influence of climate change: there were periods when monkey, sabre tooth tiger and hyena lived in the Netherlands, but also mammoth, wolf and woolly rhinoceros. The most important rule to be found is 'change', followed by 'chance'. In 1968 the polder area Southern Flevoland was drained completely. An area of 3600 hectares, which was left on the edge of this big polder, with an industrial destination, developed into a marsh where thousands of birds came for foraging and resting. Birds that had been very rare like the bearded tit (*Panurus biarmicus* L.) increased in numbers and many western marsh harriers (*Circus aeruginosus* L.) started breeding there. Totally unexpectedly, the area developed in thirty years into an internationally valued ecosystem: the Oostvaardersplassen. In most cases, however, the abovementioned rule can only be discovered by looking at long-term developments. Then it appears that 'every species starts as a foreigner' (Kroonenberg, 2000), only some species immigrating more easy than others. Eventually these species will also leave, sometimes gradually, sometimes in one blow. Besides time, also space is important. If you study a small area, everything could look the same, but moving around you could see changes. In making predictions, time and space have to be taken into account. For periods not too long and areas not too vast it will be possible to predict developments quite well. But as time and space expand, this will become more difficult, not only because it will get more complex but also because the margin of mistake will increase. On these scales changes (by chance and gradually as well as catastrophic) will play an important role. And these changes do not always stick to the abovementioned rules.

1.2 Aim and scope of the research project

From ecology to ecological literacy

Traditionally ecology, like other parts of the biology curriculum in upper secondary school, aimed at preparing students for a scientific career. However, in my view secondary education should provide a basic understanding of ecology, not only as a preparation for further study but also for citizenship. From a citizenship perspective, ecological viewpoints play a role in the public debate about land use, large scale fishing, sustainability, climate change, and so forth (Carlsson, 1999). Informed decision making (Waarlo, 1998) is a theme which is considered as very important in science education nowadays. In many countries the main goal of science education is shifting from preparing scientists towards educating citizens (Ben-Zvi Assaraf & Orion, 2005). The traditional treatment of ecology has a strong focus on scientifically rather outdated static aspects. It provides a limited view of the dynamics of an ecosystem, being just reversible fluctuations around an equilibrium state, superimposed on the development towards a climax ecosystem. In the light of modern scientific views on ecosystem behaviour, this representation falls short as a basis for well-informed decision making about the issues mentioned above, which is an example of ecological literacy. Ecological literacy is an example of the more general term scientific literacy, which was introduced in the 1950s. In the document 'Science for All Americans'

(AAAS, 1990) a scientifically literate person is described as someone who is aware that science and technology are human enterprises with strengths and limitations, understands key concepts and principles of science, is familiar with the natural world and recognizes both its diversity and unity, and applies scientific knowledge and skills for individual and social purposes. In the literature about ecological literacy (e.g. Bateson, 1972; Orr, 1992; Sandell et al., 2005), there is a strong focus on environmental issues and sustainable development. Orr emphasises the understanding of the relation between humans and natural systems and how these systems could be preserved. In my view, understanding of the dynamics of natural systems should be developed first, before understanding in the sense of Orr can be developed.

In order to become *ecologically literate*, students must be aware of modern views on ecosystem behaviour. This is not only ontologically, but also epistemologically important, as far as it gives the students more insight into the way modern ecologists are looking at natural phenomena. To improve students' insight, I think it is important in teaching activities not to isolate ecological concepts from 'the real world' where they function in authentic scientific or applied practices, but to introduce these practices with their characteristic ways of thinking and activities into classroom.

Conceptualising ecosystem dynamics through systems thinking and modelling

Let us start with a citation from Sophie Rabouille, retrieved from the website of NIOO Yerseke. *'Complexity is one of the intriguing and fascinating aspects of nature. But to understand some observed phenomena, we need to make abstraction of part of this complexity and concentrate on the main processes. From my first contact with modelling, I learnt that complex behaviour can emerge from the combination of very simple processes. Since then, my emphasis has been on mathematical modelling as it helps in conceptualizing ideas and hypotheses; models are for me a second laboratory that gives access to the main mechanisms involved in the observed biological system… And this tight exchange between theory and experience is also an exciting way to test and validate hypotheses.'*

To introduce ecosystem dynamics as it is described above into upper secondary education, it is not enough to rewrite the chapter on ecology in biology schoolbooks. Many students appear to have problems in understanding complex and dynamic behaviour and in predicting the changes that will occur in an ecosystem, for example when some external factor 'disturbs' it. An ecosystem can be regarded as a complex adaptive system (Gell-Mann, 1995). Such a system behaves according to three key principles: order is emergent as opposed to predetermined, the system's history is irreversible, and the system's future is often unpredictable. These features result from the interaction of various components and processes at different levels of biological organization (organism, population, and ecosystem) (Holling, 1987). It has been claimed that explicit systems thinking and modelling could improve students' understanding of ecosystems (Boersma, 1997; Hogan & Thomas, 2001; Schaefer, 1989; Zaraza, 1995; Westra et al., 2005). Research also suggests that students learn more about systems behaviour by building or using dynamic (computer) models than by creating static depictions of systems relationships like food chains or food webs (Kurtz dos Santos & Ogborn, 1994; Louca et al., 2003).

Keeping students involved by using an approach with authentic practices
I plan to use a context-based approach. However, the approach I will use differs in some respects from more traditional context-based approaches. In biology education in the Netherlands, this approach was introduced in 1987, when a new curriculum was developed (Werkgroep Examenprogramma's Biologie, 1987). In traditional context-based approaches a context is defined as a situation, and used to relate certain concepts to prior knowledge which is acquired by students in their social environment. These approaches can be criticised. In considering concepts apart from context, and not as embedded in context, it emphasises only the didactical meaning of a context. If it is accepted that a concept is situated in a context (Henessy, 1993; Lave, 1993; Wenger, 1998) and that its meaning is at least to some extent determined by it, it makes no sense to select concepts and contexts independently. Therefore it is preferable to select concept-context combinations, as they function in authentic practices. In other words, a context is interpreted not as a situation, but as an authentic practice.

1.3 Research question

The challenge of this study was to select several ecosystem-related authentic practices to enable students to exercise meaningful systems thinking and modelling activities in order to grasp the dynamics and complexity of ecosystem behaviour. Consequently the following research question was articulated:

> *What are the characteristics of a valid, feasible and effective learning and teaching strategy about ecosystem behaviour using modelling and systems thinking in authentic practices?*

With valid, feasible and effective I mean respectively: in line with modern ecological ideas, having the possibilities to be used by teacher and students, and leading to measurable learning results.

In order to answer this question, I will have to determine the essential characteristics of the concept of the ecosystem and subordinate concepts like complexity and dynamics. I need also to find out which types of authentic practices are appropriate for my aim. It will be necessary to define the meaningfulness of understanding in the context of ecosystem behaviour. Linked to this definition I need a description of a pedagogical approach, based on a philosophy of learning and teaching which could be used as a base for a domain specific learning and teaching strategy. Also I will have to determine the main difficulties in learning and teaching the concept ecosystem, using systems thinking and modelling in authentic practices. And finally, a problem diagnosis, an inventory of solutions and reflections on the adequacy of the solutions are needed which could serve as a basis for defining criteria for an adequate learning and teaching strategy.

Therefore, our specific sub-questions will be:

1. *Which ecology-related authentic practices seem appropriate for enabling students to grasp and value the role of systems thinking and modelling?*
2. *What are the opportunities for systems theory to clarify complexity at various levels of biological organization such as organism, population and ecosystem?*
3. *What are the opportunities for computer modelling to clarify dynamics at various levels of biological organization such as organism, population and ecosystem?*
4. *Which pedagogical approach is helpful for students in using modelling and systems thinking?*
5. *Which pedagogical approach is helpful for students in developing scientific ecological concepts starting from concepts embedded in authentic practices?*

1.4 Outline of this thesis

My first concern is a pedagogical approach, based on a philosophy of learning and teaching which could be used as a base for a domain specific learning and teaching strategy. Therefore, chapter 2 discusses the Vygotskyan cultural historical approach as well as the activity theory that is based on Vygotsky's ideas. These justify and underpin the developed learning and teaching strategy, in which I make use of authentic practices. The advantages and also the problems I will meet using these practices, will be discussed. In addition, the problem posing approach that aims to involve students actively in the learning process will be discussed.

Chapter 3 elaborates the methodology of the developmental research approach, starting by legitimising this approach, followed by a description of the explorative phase and the cyclic empirical research phase.

In chapter 4 the concrete explorative phase starts by focussing on the concept 'ecosystem', as it is used by ecologists in different, sometimes side by side emerging views. The role of systems thinking and modelling in the science of ecology will be addressed as well.

Chapter 5 continues the explorative phase. Now the focus is the concept 'ecosystem' in upper secondary school education: views of teachers and learners, views in schoolbooks, in examination syllabi, and tests will be discussed, along with difficulties that students have with the concept 'ecosystem' and subordinate concepts and with systems thinking and modelling.

In chapter 6 the first outline of a learning and teaching strategy will be developed, leading to a scenario. This strategy will be based on design criteria which did arise from the explorative phase.

Chapter 7 concentrates on the methods being used in the concrete empirical research phase, where the adequacy of the scenario was tested in subsequent research cycles in classroom.

Chapter 8 describes the actual process of testing and improving the scenario in classroom. The chosen ecology related authentic practices will be accounted for. The final learning and teaching strategy arrived at, will be discussed and evaluated.

Finally, in chapter 9 the research question will be answered. I will also reflect on my investigations and on possibilities for further application of the use of authentic practices. I will give attention to problems in systems thinking and modelling. Some ideas about possibilities for further research will be dealt with. In an epilogue I will reflect on my special position as a researcher who is also an experienced teacher.

2 View on learning and teaching

2.1 Introduction

Any learning process will cause changes in the consciousness of the learner (Van Parreren, 1987). If specific learning outcomes are aimed at, it is not only important to determine *what* students should learn, but also *how* this learning could take place effectively. There are several types of learning. Every biologist knows the different types of animal learning: trial and error, classical and operant conditioning, habituation, imitation linked with imprinting, and insightful learning, where understanding plays an important role (Manning, 1967). These types can also be found in humans. In the context of formal education, we are most interested in insightful learning. Thus, what we need to find out is which conception of learning will be adequate to learn relevant concepts, how to guide students in finding motives to learn these concepts, and how to tune teaching to findings about learning.

In section 2.2 I will describe the search for an adequate conception of insightful learning, resulting in the selection of the cultural historical approach, rooted in the work of Vygotsky. I will also pay attention to the use of social practises which follows from this approach. In section 2.3 I will introduce the problem posing approach as a heuristic to provide the students domain specific learning motives and in section 2.4 I will conclude what should be implemented in a learning and teaching strategy aiming at adequate learning, taking into account the findings in the sections 2.2 and 2.3.

2.2 Conceptions of learning

Some developments in secondary education from 1975

Educational psychology investigates how students learn in multiple settings. The results of these studies are fundamental for a teacher. He must know how his students make sense of what they are taught and how various situations affect learning. In an interview (Shaughnessy, 2004, p.165) the educational psychologist Anita Woolfolk distinguishes three major categories of effective teaching. First, she emphasizes the importance of understanding students' understanding. '*No matter how you teach, no matter what the goal, no matter who the students are, as a teacher you must keep asking what* *sense the students are making of it. One of the most important things a teacher can do is to understand how students think about an idea or subject.*' Secondly, she stresses the point that students want to learn about things that are meaningful and relevant to them and belong to the real world. Thirdly, it is important to know the students and to know how they learn, and to apply this knowledge inventively in teaching.

There are many theories of learning, some being more effective than others when aiming at understanding. A strong relation exists between *what* you want students to learn and *how* this should be learned. Around 1975 emphasis was on Carl Rogers' 'Freedom to learn' (Rogers, 1969). However, the ideas of Rogers did not correspond with the actual teaching and learning methods in most schools. The prevailing learning psychology could be described as *connectionist*, founded on behaviourist ideas. Learning stimuli were provided by the teacher and the schoolbook; there was no attention for what stimuli brought about in the consciousness of a student. In teaching, focus was on an optimal connection between learning-stimuli and expected behavioural responses of the students. The content was fixed, there was no relation between the content and natural phenomena in the real world where the students are part of, and the focus in learning was on reproduction of the taught content. An implication was that teachers concentrated on the biological content, trying to extend their biological knowledge, not so much concentrating on the development of modern learning and teaching strategies.

The school system appeared to be very resistant to change. Sometimes I got inspired by reform pedagogues like Dewey (Dewey, 1897), Boeke (Freudenthal-Lutter, 1966), Korczak (Mortkowicz-Olczakowa, 1973) and Neill (Neill, 1996). They were all child-centered and made efforts to build, in Dewey's words a 'miniature community, an embryonic society' where idealized social relations could be practiced and lived. In Neill's school, Summerhill, he sought to create a living democracy in a school setting by balancing the rights of the individual and community. While these reformers wanted the learners in their schools to acquire skills and knowledge, they also wanted them to learn to think independently, take charge of their own lives, and become contributing members of their society. However actually, my inspiration did not lead to profound changes in the traditional teaching repertoire in the classroom.

But then, things changed. By the end of the past century there was an intense interest in how to learn and what to learn. Concerning science education, there were plans for a renewal of the science subjects in secondary school, because of the decrease in the number of science students in many European countries (Campbell, 2001). As European commissioner Janez Potočnik said in 2007 during a panel discussion at the Science on Stage Festival in Grenoble: *'Unfortunately we are seeing a decline in science subjects taken in schools. I find this a real pity. Europe can only become a knowledge society if we invest in the education of our future generations. This includes a good understanding of science.'* In 2006 one of the basic themes of PISA was the assessment of scientific literacy (OECD, 2006).

A cause for the decline in science subjects taken in schools was considered to be that science textbooks present science as a completed body of knowledge, detached from its contexts of discovery and application. Therefore students experience school science subjects not as meaningful for themselves; they can not link what they learned in school with natural phenomena in the real world. Thus, students do not grasp the meaning of science in society and the advancements in science research. *'School science education can only succeed when pupils believe that the science they are being taught is of personal worth to themselves.'* (Reiss, 2000, p.159)

A special European magazine (Science in School) was launched to promote inspiring science teaching by encouraging communication between teachers, scientists, science teachers and everyone else involved in European science education. The idea of learning important scientific knowledge in contexts, already popular in the Netherlands in the 1980s in physics education (Kortland, 2002) and biology education (Werkgroep Examenprogramma's Biologie, 1987) was picked up again. This happened not only in the Netherlands (project 'CVBO- Vernieuwd Biologie Onderwijs[1]), but also in Germany (project 'Biologie im Kontext[2]) and in the United Kingdom (project 'SNAB' by Salters-Nuffield[3]).

In the early attempts in the Netherlands and other countries (like in *Science: the Salters Approach,* University of York Science Education Group, 1990-1992) to implement a context-based approach in teaching and learning, it proved hard to tune contexts to be used with the conceptual requirements of the curricula (Bennett & Holman, 2002). There were discussions about what concepts had to be used. In these discussions no choices were made whether to focus on scientific literacy, having in

1 http://www.nibi.nl/
2 http://www.ipn.uni-kiel.de/projekte/bik/bik.html
3 http://www.heinemann.co.uk/library/series/index. aspx?d=s&skey= 98

mind the 'generalist students', or on deep and complete science, having in mind 'the future specialist students.'

A general renewal of upper secondary school education started in the same period in the Netherlands, entitled 'Studiehuis' (Study house). The main issues of this approach were encouraging the development of skills and autonomous (self regulated) learning. Learning to learn was one of the skills in focus. Students should be able to reflect on their learning. Coaching students rather than conveying knowledge and skills should be the teacher's role. The background of this renewal was the constructivist idea that abovementioned transmission learning is not very effective. Learning has to be done by oneself; teachers can only support this process. Imitation of what was learned by transmission will not prepare the student for new situations. This new way of learning is a never ending process, especially in a society, where knowledge and skills change very fast (Simons & Zuylen, 1995). When students learn by discovering things, finding solutions or making (re-)inventions, this will be more effective than by transmission of knowledge and skills. It was assumed that this would lead to students that were better motivated (Boekaerts & Simons, 1995). These ideas appealed to me. When I started this investigation in 2003, I decided this was the moment to take in a position in the discussion about this theme. That's to say, to formulate my view on teaching and learning, to look more extensively at the work of people like Dewey, who had very inspiring ideas about the interaction between the learner and the environment, and to indicate what kind of learning psychology seemed adequate to me for shaping teaching for understanding.

Constructivism

An alternative to transmission of knowledge is the active construction of knowledge by learners. In Dutch biology education, constructivism has been the dominant paradigm for educational scientists since the 1990s, although this did not always lead to a change in the dominant 'transmission situation' in classroom (Kuiper, 1993; Kamp, 2000). In constructivism, learning is conceived as an active construction of knowledge, starting from the knowledge which is already present in the learner (Driver et al., 1994). This *individual* view on learning traces back to the work of Dewey (1897), with the notion that 'education must be conceived as a continuing *reconstruction* of experience' and of Piaget (1937), with the notion that 'intelligence organises the world by organising itself'. So, contrary to behaviourist ideas, the centre of attention of constructivists is the learner himself as an active person. An implication is that the role of the teacher changes from 'transmitter of knowledge' to 'coach' of the learning process of the learners.

The cultural historical theory

Another approach starting from active construction of knowledge and until recently less prominently represented in Dutch secondary education has been the cultural historical activity theory, which is based on Russian learning psychology of the 1920s. The social form of constructivism and the cultural historical activity theory have a correspondence in stressing the role of the *social environment* in learning. Social constructivism starts from a socio-cultural view on learning, which has become more popular since a discursive turn in psychology has lead to a shift in focus away from cognitive processes in the individual towards individuals functioning in social contexts (Leach & Scott, 2003). Social constructivism as well as the cultural historical activity theory pay attention to the role of the teacher in terms of having to make a 'double move' (Van Parreren, 1983; Hedegaard, 2001): stepping down to investigate the level of the students, but also stepping up, by challenging them to develop more sophisticated concepts, which have to be reached in education. Construction of knowledge is not an individual process, but takes place in the interaction between the learner, his peers and the teacher. The cultural historical activity theory goes further on this point than social constructivism by emphasizing that the way in which this construction takes place can be described as a development and that this development is cultural historically determined (Van Oers, 1987). As a teacher who is very interested in enriching the ecological literacy of the students, focussing on understanding ecological activities rooted in social practices, the cultural historical activity theory seems appropriate to me. Especially the focus on activities of the students as an essential part of their learning and the prominent role of the teacher as a 'representative of human culture' in challenging the learners, appealed to me. By going more deeply into this theory, I tried to find out whether it would be possible to use it as a guide for a learning and teaching strategy.

The basic principles of cultural-historical theory are anchored in the ideas ofVygotsky (in collaboration with Luria and Leont'ev), that learning is not an autonomous process, but requires interaction between human beings as well as the use of tools (Vygotsky, 1978). This interaction and the use of tools can take place during play, work, education, and any other kind of activity. Learning requires a 'practice' that invites students to participate in all kinds of activities of a social nature. Students work together, talk, discuss, and reflect on their activities (Blanck, 1990). They use the tools that are used in society as instruments to construct their knowledge. One could say that their development leads to acquiring a toolbox, including the knowledge of when to use a specific tool.

In constructing their knowledge we find grounds for a negotiation of meaning between individuals: they learn how other (grown-up) people use this knowledge. At first, students are not able to perform all activities by themselves. It is the task of the teacher to investigate their *actual zone of development*, the area where they can perform all activities by themselves. After that he has to introduce them into their *proximal zone of development*, the area where they first will need their teacher, but will gradually take over to perform all activities autonomously. The knowledge of the students will arise from the performed activities by internalization, which means that this knowledge (material actions as well as societal signs like symbols or drawings) will be stored in the mind. Internalization requires the use of language, enabling communication between learner, teacher, and fellow students. There is a strong link between knowledge, language and activities. Language is the go-between between society and the individual, and reflections in the mind of students do not develop passively, but as a result of activities in the brain (Van Parreren & Carpay, 1972), which means that these reflections cannot be just a copied image of the world (Talyzina, 1981).

The Russian group, being influenced by their great predecessor Pavlov, used his scheme in an adapted form (see figure 2.1). The direct line between stimulus and response (in the left part of the figure, which is the classic Pavlov scheme) is characteristic for lower or primitive psychological functions (as studied by behaviourists as the only functions possible studying, like in rote learning). The triangle with X (in the right part of the figure, developed by Vygotsky) is characteristic for higher psychological functions, like in insightful learning.

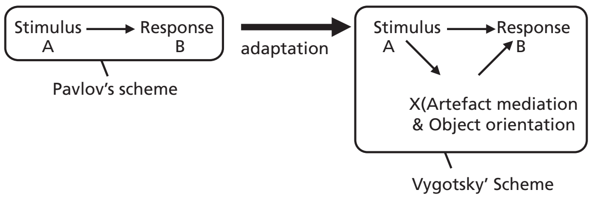


Figure 2.1 The 'Pavlov scheme' as adapted in the cultural historical approach (from Vygotsky, 1978, p. 40)

When the stimulus stands for some problem to be solved and the response is the answer to the problem after a learning effect (in the right part of the figure), activity plays a central role in linking stimulus and response by artefact mediation or object orientation. In animals this has been shown in an elegant study, where chimpanzees had to manipulate their environment by piling up boxes to reach and eat the bananas (which is the response) they could see (which is the stimulus), but which were too high to jump for (Köhler, 1927). In the activity theory (Engeström, 1987, 1991) this scheme has been elaborated far more extensively. In this theory, human activity is seen as developed in an evolutionary process. An activity is defined as an integrated series of physical and mental actions of a subject (being the human actor) with objects (being humans, other organisms or tools).

A distinction has been made between *scientific* and *spontaneous* concepts (Vygotsky, 1978). Scientific concepts, such as the scientific knowledge which is taught in formal education, are systemically organized bodies of knowledge. These concepts are flexible for scientists and can be generalized to contexts other than the one in which they are acquired. They are embedded in cultural systems and transmitted through formal schooling. Scientific concepts are acquired through verbal explanation, and they become 'contextualized' as they are applied to spontaneous objects and events. This is what we intend to reach in biology education when we want a transfer of ecological concepts learned in one practice to another practice.

Spontaneous concepts are acquired in the course of participation in the activities in which they are typically used. They are less flexible and are limited in their application to the situated context in which they are acquired. Spontaneous concepts begin with a grasp of concrete events and phenomena and develop as they are integrated into the formal knowledge systems as a scientific concept. In my view, the best way in teaching and learning is to start with these spontaneous concepts of the students. The teacher has a very important role, not only as an instructor showing *what* has to be learned, but also as a coach, helping and guiding *how* to do this, what tools could be used and how, to reach the level of the scientific concepts.

Since learning is a social activity, the learner has to be confronted with social practices whose authenticity could provide the learners, being interested in real world phenomena, with motives for learning (Blanck, 1990). In the learning situation, these practices should not be fragmented into isolated learning activities. They need to be adapted to a school practice for the learners, because these learners do not possess the knowledge and skills of the participants in the authentic practice. The learner should participate in coherent activities within the adapted practice, where every activity should be meaningful. By participating in all activities in such a practice, the learner will develop knowledge and skills. The teacher should, by choosing appropriate social practices and adequate learning activities, aim to widen the horizon of the learners.

Influences of Vygotsky on learning methods

It took some time before Vygotsky's ideas became popular in the Western world. His ideas differed strongly from the dominant behaviourist and constructivist approaches that took the learner as a 'natural agency' for learning for granted. Culture was seen by both approaches as an informative part of the curriculum, being external to the process of learning. Fierce discussions were held between behaviourists, who favoured the 'transmission' model of education, and constructivists who favoured the 'discovery learning' model. Both agreed that cognitive and learning skills are the preconditions in the learning process. They differed however in their perception of the role of the teacher being either the transmitter or the stimulator of an active construction of knowledge. Vygotsky emphasized that in the development of learning skills, the learning process is a source rather than a consequence. And his co-worker Gal'perin emphasized that socio-cultural and meaningful (tool-mediated) activity is essential in this process (Arievitch & Haenen, 2005). The tools being used in this process shape the experience and, consequently, the thinking of the students (Angeli & Valanides, 2004).

In the Netherlands, Vygotsky's work was introduced in the 1970s in the publication of 'Sovjet Psychologen aan het Woord' (Soviet psychologists speaking) (Van Parreren & Carpay, 1972). Van Parreren, who had already developed ideas of learning as a process of qualitative change of the structure of actions, integrated Vygotsky's ideas and developed a pedagogical concept, Developmental Education ('Ontwikkelend Onderwijs'), which has found a fruitful soil in primary education in the Netherlands, leading to about 125 so-called OGO-schools ('Ontwikkelings Gericht Onderwijs' or Development Aimed Education). In these schools the central aim is to provide opportunities for the children to participate in social practices (De Haan, 2005). One therefore needs to take into account societal needs, but also the needs of the children (Van Oers, 2005).

A concept-context approach

Until 2000, there was not much interest in Vygotsky's ideas in Dutch secondary education. There was a Ph.D.-study using the cultural historical approach in chemistry education (Van Aalsvoort, 2000), which however did not give empirical evidence for a successful use in classroom. In another Ph.D.-study (Westbroek, 2005), introducing simplified authentic practices into classroom appeared to be a promising possibility for creating meaningful learning.

In the Netherlands, in 2004 a large-scale innovation for chemistry was started, introducing a so-called concept-context approach. In the same year, the Biological Council of the Royal Academy of Science and Arts in the Netherlands published a report, pleading for the development of coherent education, amongst others by selecting key concepts related to specific contexts. In December 2004, the Minister of Education installed the Board for the Innovation of Biology Education, with the task to develop a 'learning line' for students from 4 to 18, and new examination programmes for upper secondary biology education. The Board elaborated the recommendations of the Academy into a concept-activity-context approach (Boersma et al., 2005a). Boersma (2004) explained that, in defining the role of contexts in science curricula we face the difficulty that the word 'context' has different meanings. A distinction can be made between a context as a situation, a social structure, a domain, and a cognitive structure or semantic network. Literature reveals that the meaning of 'context' is related to learning theory. Context as a situation is commonly found in publications from researchers working from a social constructivist perspective. Context as a social structure (or community of practice) is found in publications from authors working from a cultural historical perspective. Worth noticing is that the activity theory, which is linked to the cultural historical perspective emphasises not the social structure itself, but the *activity* performed in it.

The generally accepted meaning of a context as situation can be criticised. Since it considers concepts apart from contexts, and not embedded in contexts, it emphasises only the didactical meaning of contexts, i.e. to use them as a tool to motivate the learners. If it is accepted that a concept (defined as an important idea from biology structuring a relevant part of specific knowledge) is embedded in a context, and that the meaning of such a concept is determined by the context (Henessy, 1993; Lave, 1993; Wenger, 1998), it makes no sense to select concepts and contexts independently. Therefore according to the activity theory (Engeström, 1987; Hedegaard, 2001; Van Oers, 1987, 1998; Van Aalsvoort, 2004; Wenger, 1998), contexts are defined not as situations, but as social practices. In social practices participants perform goal-directed activities, using knowledge, symbols, language, tools, and sharing meanings and values. Furthermore, a situated perspective is accepted, which implies that a specific biological concept may have different meanings in different social practices. For example we look at the concept of 'herbivorous consumer' in two ecosystems. In an estuarine ecosystem we could find the mussel, feeding on algae and being sessile, which has implications for its competitive power in a period of food shortage. In a dune ecosystem we could find the rabbit, feeding on grass and being very mobile, which leads to greater differences in competitive power between individuals. Since knowledge and skills are often strongly situated, students have to adapt their acquired knowledge and skills when it is required to use them in another non-familiar social practice.

This process of adaptation is called re-contextualisation (Van Oers, 1998, 2001). In this process students have to transfer a spontaneous concept they already have into an abstracted scientific concept (as it is used in the social practice) and to adapt (re-contextualize) it, so that it can be used in another practice (see figure 2.2). This idea opened new perspectives to transfer in the learning process (Beach, 1999): the possibility to use newly gained knowledge in another, related area.

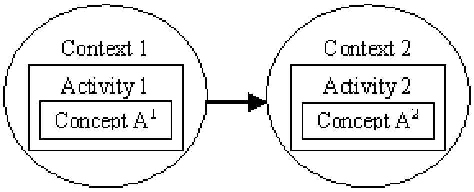


Figure 2.2. The relation between scientific concepts, activities and contexts according to a concept-activity-context approach; A^1 and A^2 refer to different conceptions of concept A (adapted from Boersma et al., 2005a, p. 9)

Social practices

Social practices have a number of common characteristics. In the activities which are performed by the participants, knowledge and rules are linked. People participating in a practice develop rules which contribute to maintaining of the practise. Rules can be distinguished in definition rules (what has to be done, the obligations inside the practice) and rules of experience (what should be done, the tactics, e.g. how to handle instruments smartly or how to handle problems smartly). Most practices are dynamic: there are impetuses for change from inside and from outside by communication with people participating in other practices (Jacobs, 2001). Based on the aims of a practise one could distinguish three types of practises (Boersma et al., 2005a):

- Life-world practices, like families or sport clubs
- Professional practices, like garden centres or health centres
- Scientific practices, like ecological research institutes or virological laboratories

Professional practices provide products or services with a meaning for people participating in other practices. So, practices are not completely autonomous, in professional practices there are always 'users' in the periphery, like customers or consumers.

Practitioners use knowledge in their activities that is relevant for their performance. Practices are situated (concrete, situation-specific), distributed (not confined to the individual, but spread to other persons), mediated (relevant cultural tools are used) and embodied (cognition, perception, tools, and activities all work together) (Hill & Smith, 2005). Although not every student will have an interest in the field of ecology as such, he is a member of society. As a member of society he will know that ecology matters in society, because man influences ecosystems, and is being influenced by ecosystems. Students like to relate what they learn to real world things (Osborne & Collins, 2001). Therefore I expect that starting with an authentic social practice (professional or scientific) in which ecology is involved, could help to make learning activities meaningful for students (Boersma, 2004; Bulte et al., 2004; Kattmann, 1977). Other implications will be that there will be a development in the learned concepts in the activities performed by the learners and that the teacher has, more than in constructivism, not only the role of a coach, but that he, with his content-based knowledge, will be also the go-between between culture and the learners, giving the opportunity to introduce culture-based knowledge.

2.3 Problem posing approach

For education to be effective, it is desirable that students are willing and enabled to take an active role in the complete series of learning activities. The use of an authentic practice will not be sufficient to meet this criterion. Therefore I adopted the problem posing approach (Klaassen, 1995). This is a didactical strategy that aims to actively involve students in the learning process. The problem posing approach claims that students participating in a learning and teaching (LT)-unit which is structured according to this approach, should always know what they are doing, why they are doing it, and how they are going to proceed. The student's global and local motives should therefore be evoked. The problem-posing character of this approach is reflected in the interrelation of the motives and knowledge that are to be developed. A general characteristic is the role of a domain-specific (that is specific to the content and goals being taught) 'global' motive, relating to the sequence as a whole, in connection with a series of 'local' motives that motivate its main phases.

The global motive concerns the desired learning outcomes; the local motives concern the participation in the next learning activity, with the aim to find answers to partial problems which connect students' already existing knowledge and skills with the goals that have to be attained during their learning process (Lijnse & Klaassen, 2004). *'As far as cognitive learning is concerned, we think that science learning should be considered as a process in which students, by drawing on their existing conceptual resources, experiential base and belief system, come to add to those (with accompanying changes of meaning). What should be added as a second starting point is that if this process is to make sense to them, students must also be made to want to add to those. Or, in other words, students should at any time during the process of teaching and learning see the point of what they are doing.'* (Lijnse & Klaassen, 2004, p.539)

In three Ph.D.-studies the global motive is expressed as a general steering question to be answered after completion of the learning and teaching (LT)-unit (Vollebregt, 1998; Kortland, 2001; Westbroek, 2005). The general steering question leads to a first learning activity or a sequence of learning activities. In general, a LT-unit consists of a number of problem posing cycles, each consisting of a questioning phase, a part in which students participate in one or a number of learning activities, and a reflection part phase (Knippels, 2001). In the reflection phase students reconsider what has been done, answer the partial question, make up their mind, and look forward to the next learning activity. These phases can be further divided, which results in six phases in the problem posing approach (Lijnse & Klaassen, 2004).

Questioning:

- Phase 1: orienting and evoking a broad interest in and motive for a study of the topic at hand.
- Phase 2: narrowing down this broad motive to a content-specific need for more knowledge.

Activity:
- Phase 3: extending the students' existing knowledge, in view of the global motive and the more specifically formulated knowledge need.
- Phase 4: applying this knowledge in situations the knowledge was extended for.

Reflection:
- Phase 5: creating, by reflecting on the developed knowledge, a need for a theoretical orientation
- Phase 6: developing further theoretical knowledge within this orientation.

The abovementioned Ph.D.-studies give empirical evidence that the problem posing approach can be a promising possibility for creating meaningful learning. There is much room for students' ideas, although in any case under the guidance of a skilled teacher.

2.4 Conclusions for a learning and teaching strategy

After orienting on conceptions of learning in 2.2 and 2.3, I sought to link a concept-context approach, where a context is interpreted from a cultural historical view, with a problem posing approach. This has been done by interpreting contexts as authentic social practices where activities become meaningful for students. These can be meaningful directly for themselves or indirectly, as interesting societal phenomena, combined with a design of learning activities. The activities are linked by a sequence of questions which can be solved by performing these activities, which could sustain students' motivation. In the end all answers contribute to answering the central problem. It should be stated that in my opinion the problem posing approach starts from the constructivist idea of learners that construct their knowledge, coached by a teacher who tries to foresee their way of solving a sequence of linked problems. In my opinion, the teacher should have the cultural historical role of being coach as well as go-between. He introduces culture based knowledge which will not be present yet in the consciousness of the learners. In chapter 6 I will elaborate on this point in the description of the learning and teaching strategy.

3 Developmental research approach

3.1 Introduction

After the justification and theoretical underpinning of an adequate learning and teaching (LT) strategy by linking the cultural historical activity theory with the problem posing approach, which was our subject in chapter 2, I first need to develop this adequate strategy and implement it into educational practice. Because it is unlikely that a first design will meet all criteria, I will take an iterative approach, where classroom evaluations are conducted to inform subsequent revisions of the design. In this 'developmental research' approach, the resulting teaching materials are not an aim in itself, but a means to gain insight into what works and why. In section 3.2 I justify my choice for a developmental research approach. Section 3.3 provides an outline of my research plan.

3.2 The choice for a developmental research approach

Traditional research approaches did help to identify and explore learning and teaching problems in classroom practice, e.g. students' perceived or expected difficulties in understanding scientific concepts and theories. In ecology teaching a lot of work has also been done on identifying problematic issues (e.g. Carlsson, 1999; Sander, 2002; Jelemenská, 2005). However, the description and analysis of problematic issues in learning and teaching does not tell us *how* they should be coped with in classrooms. Therefore follow-up research is needed to improve ecology education.

In developmental research, theory-driven, creative and practicable solutions to learning and teaching problems are designed in iterative consultation with experienced teachers and tested in classroom situation. The developmental research approach (or design research, e.g. Cobb et al., 2003) originated from the need to increase the relevance of research for educational policy and practice, the wish to develop empirically grounded theories about learning and the wish to increase the robustness of the design (Van den Akker et al., 2006). Many researchers contributed to the development of this kind of research, among others curriculum developers and researchers at the Freudenthal Institute for Science and Mathematics Education (former the Centre for Science and Mathematics Education) at Utrecht University (Gravemeijer, 1994; Lijnse, 1995).

One of the characteristics that favoured the choice for design research as the type of follow-up research I wanted to make use of, is that it is interventionist, which means that it aims at designing an intervention in the real world. Besides it is process oriented, which means that its focus is more on understanding and improving the interventions than on the 'end result'. It is also utility-oriented, which means that the resulting domain-specific learning and teaching theory should have practical value to real world users (Van den Akker et al., 2006). Developmental research outcomes are not limited to the 'instrumental' question of how a given learning aim can be attained. Rather this kind of research might also provide insight into which learning aims are feasible, how they fit together, and how they fit with students' interests. Therefore, one of the purposes of developmental research can be to adapt education in school to a changing society or to try to anticipate this change (Freudenthal, 1991). As I described in chapter 1, ecology as a science and ecology in upper secondary education do not keep pace, and it is not always clear which learning outcomes based on the scientific progress are attainable for students in secondary education. Therefore I expect that developmental research can be an adequate approach for my aims.

Very important in developmental research is the interconnectedness of learning and teaching (Lijnse, 1995). The objects of study are the domain specific learning processes and outcomes of the students who are taking part in the series of lessons and the impact of teaching on these learning processes and outcomes. Four basic questions have to be addressed for a specific domain (Boersma, 1998): 1) How can students attain a priori formulated learning aims? 2) How can teachers help students to attain these aims? 3) How can learning problems be prevented or solved? and 4) How can teachers help students to prevent or solve their learning problems? The answers are provided by a theory-based and empirically validated design of a domain-specific effective learning and teaching strategy.

Designing an effective strategy should only be done on the basis of a proper interpretation of students' prior knowledge and skills (Klaassen & Lijnse, 1996). During an explorative phase, which could be described as 'theory guided bricolage' (Gravemeijer, 1994), a supposedly effective learning and teaching strategy (LT-strategy) that extends students' prior knowledge and skills into the intended direction emerges. Subsequently, it is tested to which extent the intended and expected learning and teaching processes take place and why. This feedback of practical experience into the improvement of the strategy induces a cyclic process of development and research, which is the heart of developmental research (Gravemeijer, 1994). The more the actual teaching and learning process corresponds with the specific expectations, the better the didactical quality of the series of lessons.

The combination of the design part and the evaluation part of developmental research (and, if necessary, a re-design and re-evaluation part, etc.), should eventually lead to an empirically verified series of lessons of sufficient didactical quality, as well as to more generalized knowledge about the essential characteristics of the approach, e.g. a didactical structure (Lijnse & Klaassen, 2004).

The evaluation and empirical validation of the lessons are guided by the specific expectations that have been made explicit in the design part. The didactical structure serves as a framework for collecting data in classroom situation. Video- and audiotapes are used for observation of the teaching and learning processes. By analysis of various types of documents produced by the students (texts, drawings and computer models), I can monitor the learning processes and outcomes, to find out whether the learning aims are attained. Before and after the series of lessons students and teachers will be interviewed about their expectations and experiences concerning the activities performed in the series of lessons.

As developmental research is a mainly qualitative approach, the validity of the research outcomes must be corroborated in ways that are different from those in the 'hard' quantitative sciences. A classroom evaluation provides a case study: a unique field test in a naturalistic setting. Nevertheless, on the basis of this irreproducible event, I have to draw general conclusions about the functioning of my design. A useful instrument here seems triangulation, i.e. the combination of data and multiple methods corresponding with different points of view in the study of the same phenomenon, like classroom observations, video- or audio-taped fragments of the lessons, completed worksheets, drawings, computer models or questionnaires (Ghesquière & Staessens, 1999).

3.3 Outline of the research plan

The research plan can be structured in two phases: an explorative phase and a cyclic research phase (figure 3.1). Several research cycles are planned, until further development of the learning and teaching (LT)-strategy no longer results in improved learning outcomes, assuming that each next cycle leads to improvement, which unfortunately not always holds true (e.g. Boerwinkel, 2003). In practice, it has been found that two or three cycles result in a satisfactory final LT-strategy.

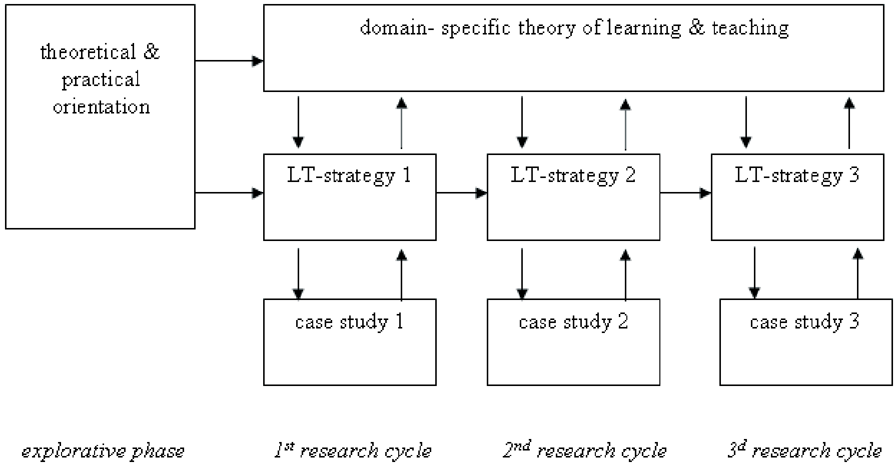


Figure 3.1 Design of developmental research (adapted from Boersma, Knippels & Waarlo, 2005b).

In the explorative phase, content analysis of schoolbooks, syllabuses as well as review of domain-specific science education literature and collection and sometimes reinterpretation of data (Riemeier, 2005) are aimed at defining the actual state of and the learning and teaching difficulties in ecology education in upper secondary school. Ecologists have to be consulted as well, for updated knowledge about ecology as a science and about how ecological research is done. With their help, also adequate ecology related authentic practices have to be selected and the performed activities and procedures studied thoroughly. In these practices complexity and dynamics have to be important concepts, available or to be made available so as to be comprehensible for students.

Based on the data and insights acquired in the explorative phase, two or more research cycles will be conducted. First a preliminary LT-strategy, based on data and literature collected in the explorative phase, is developed. In our strategy a sequence of problems (following the problem posing approach) and a sequence of corresponding learning activities are linked. The domain-specific content specifies the sequence of the problems, which are presented in a way that takes into account students' prior knowledge and skills.

The LT-strategy is elaborated into a scenario. In the scenario the LT-activities are described in detail by precisely working out a list of all intended and expected activities of the teacher and the students, making explicit the relation with the domain-specific content and learning aims. *'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)

After development of the actual LT-materials, based on the scenario, the LT-materials and the scenario are tested in classroom, with extensive data collection, including questionnaires, notes, sketches, and computer models of the students, transcription of all audio and video recordings, and analysis of all data.

With these data, it is possible to find discrepancies in LT-activities between the expectations described in the scenario and observations made in classroom, and to find explanations for them. This eventually leads to determining the required adaptations of the LT-materials, the scenario and LT-strategy, after which a new cycle starts. The domain-specific LT-strategy will evolve in a series of cyclical case studies in classroom, which is different from the multiple case study (Yin, 1984), where a phenomenon is investigated using multiple sources of evidence.

Both during development and testing of the learning activities and when the outcomes become available, *reflection* takes place on all activities and experiences in classroom, as well as on the development process itself. Reflection contributes to the development of theoretical notions about the learning and teaching problems of my specific subject. In the reflection there is a continuous going backward-and forward between the domain-specific theory of learning and teaching about ecosystems and the scenario.

In the end, after all adaptations I am left with a domain-specific theory for learning and teaching my specific topic.

4. The concept 'ecosystem'

4.1 Introduction

This chapter presents an overview of the meanings and uses of the concept 'ecosystem' in the science of ecology and the ways scientists use this concept. Section 4.2 describes the various views on ecosystems as they have developed in ecology, and the controversies about terms that arose between those views. In section 4.3 the role of modelling ecosystems comes to the fore, with special attention to systems thinking and levels of organization; to the role of mathematical modelling and computer usage and to interaction between different modelling approaches and the various views on ecosystems. Finally, section 4.4, presents implications for the teaching of ecology in secondary education.

4.2 The development of various views on ecosystems in science

The ecosystem

Ecology as a science, being defined as 'the scientific study of the distribution and abundance of organisms and the interactions that determine distribution and abundance' (Townsend et al., 2003, p.4), is one of the younger branches in biology. Most ecologists take the article 'The lake as a microcosm' (Forbes, 1887) as the actual beginning. Ecologists seek to grasp the processes that are responsible for distribution and abundance, so as to be able to make predictions, for example about the dynamics of parasite populations or the developments in a game reserve. There can be found three structural categories in these processes. In the first place, there is the structure of the abiotic factors with their distribution in time and space. Second, there is the structure of all populations with their distribution in time and space. And third, there is the trophic structure, which is about the flows of matter and energy in the ecosystem (Hjorth, 2002). To define the total of all these processes and their relations, ecologists use a number of terms, one of which is the term ecosystem. This term was first coined by Tansley in 1935 to refer to a biotic assemblage and its associated physical environment in a specific place (Tansley, 1935). He introduced the term to cover both living and non-living elements. This helped move ecology away from the more loosely defined, 'organismal-by-analogy' view (Clements, 1934) that was popular in this period, into the direction of today's view. The reference to a 'system' was a deliberate choice of Tansley to indicate that he had in mind a physical machine-like entity. By contrast, later scientists tended to reject the notion of an ecosystem as a concrete entity, but rather considered it as just a subdivision of a continuous gradation of local species assemblages. Moreover, the attribution of any organizing principle or design to nature above the level of the organism has been thoroughly debunked (Botkin, 1990; Golley, 1993). Nevertheless, most of the ecologists, although they hold different views on the concept, still consider the ecosystem as a useful concept in organizing their knowledge about the living part of the world and its relation with the non-living elements.

Historically, the first dominant view considered all individual organisms and species as being part of a 'complete whole'. Then another view came to the front, in which populations were considered as mechanistic dynamical units with characteristic ways of reacting to disturbance. Finally, the currently very fashionable view focuses on the 'motives and strategies of individual actors' on the ecological stage (May & Seger, 1986).

Each of these views brings its own types of models, be it static models with food chains and food webs, dynamic mathematical models where relations are described in formulas, or computer models to make complex and dynamic interactions more transparent. In modelling ecosystems, various ideas from systems thinking relating to the concept 'ecosystem' play an important role.

Views and perspectives on the ecosystem

The concept 'ecosystem' is a theoretical construct: one cannot actually *see* an ecosystem. One can take one or more photographs, or make a film. On the basis of a transformation in which selected information from the photographs or the film is combined with information that was already stored in the brain, one can make a model of an ecosystem (see figure 4.1 a-c).

However, the photo, or the film, has been taken from a certain perspective, and if it had been taken from a different perspective, the picture would be different. A *perspective* refers to the personal choice of taking a position from where one is observing, as well as to the direction into which one is looking. It also refers to the personal process of excluding information and introducing stored information. This implies making choices, which will eventually lead to a *view* of the world or a part of the world. And a view can eventually lead to a specific style in scientific activities,

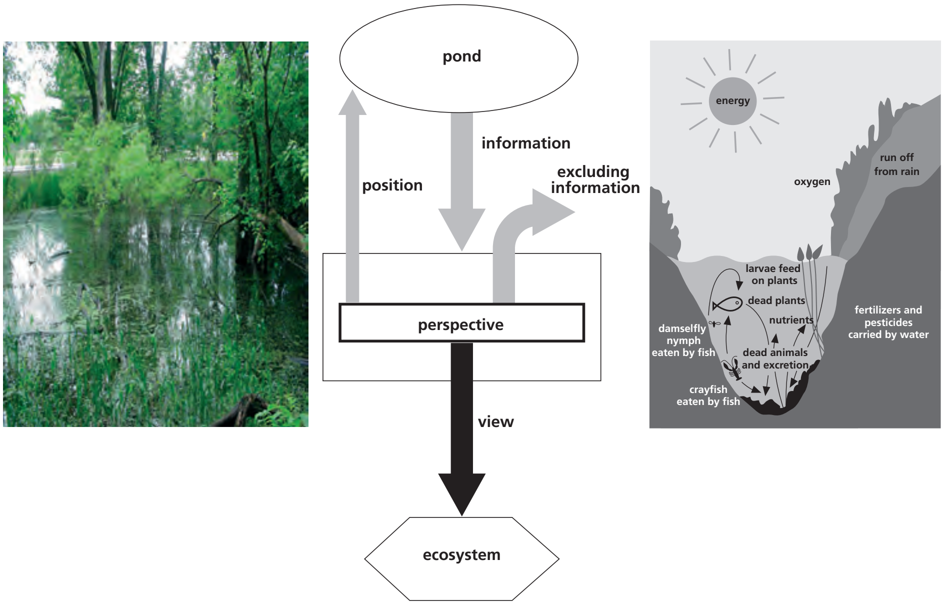


Figure 4.1 (a)A photograph of a pond. (b)Transformation of information into the concept 'ecosystem'. (c) A model of the pond as an ecosystem.

as the expression of a 'cultural ecology' of a group: its views, convictions, sacrosanct beliefs, and ways of solving problems (Kwa, 2005). Because the general definition of an ecosystem is applicable to any case where organisms and physical processes interact in some spatial area, it will cover an almost unimaginably broad array of instances, and there is plenty of room for people to make different choices (Jax, 2002), leading to different views.

In the daily ecological practice, and in related areas of policy making (nature conservation, – management and – development) elements from multiple views recur. This sometimes causes fierce discussions about for example management measures in cockle fishery (Woestenburg, 2004), nature development in river forelands (Van der Windt, 1995) or management of large herbivores in the Oostvaardersplassen (Aarden, 2005). Quite often the participants in such debates base their arguments on ecological viewpoints that remain implicit, leading to unfruitful discussions (De Jong, 2002).

The use of various views on the concept 'ecosystem' and linked subordinate concepts might even pose a threat to the scientific reputation of ecology itself. *'It [ecology] was* *sometimes described as only a point of view, not a science at all. It now suffers the hazard of being transformed back to a point of view, a socio-political position, or even a guide to ethics and philosophy, sometimes by ignoring its accumulating scientific insight.'* (MacIntosh, 1985, p.323)

Four views on the concept 'ecosystem'

Over time, four major views on the concept 'ecosystem' did evolve: a holistic, cybernetic, dynamic, and chaotic view (De Jong, 2002). Among these four, the first and the second form a pair, as well as the third and the fourth, with a sharp divide between these two pairs. Many ecologists and science historians assume a shift of paradigm around 1970. Before that time, the dominant (holistic or cybernetic) views held that an ecosystem maintains a stable equilibrium. The system was considered self-regulating, deviations from equilibrium were considered of minor interest. In line with this view *nature* is still often defined as 'all that maintains itself, independent of human aims' (Van Wesenbeeck, 2006, p.37). After the 1970s, the dynamic and chaotic views came to the fore, which regard nature as always being in flux, being the product of unique events and histories. Non-equilibrium was the rule, equilibrium was considered as just a special case. The processes were emphasized, not the 'end points' (Pickett et al., 1992). Along with this shift in thinking about the dynamics of the ecosystem, a shift occurred in the perception of the concept itself (Budiansky, 1996; Kwa, 2002). First there was a 'romantic' perception, where people recognized a really existing unity in the diversity of species. A leading ecologist like Elton took it that the 'behaviour' of an ecosystem was determined by the complexity of the system and that the 'behaviour' of all populations was determined by this whole (Maynard Smith, 1974). This also led to ideas like 'functions' of groups of organisms and 'regulation', by which 'natural equilibrium' is reached and maintained: the homeostasis of an ecosystem. In this sense even a materialist view like in cybernetics is romantic (Kwa, 2002).

With the shift of paradigm a more 'baroque' perception developed. Here the idea is that organisms that share a certain area are just 'table companions' that influence each other. This influence takes place at an individual level. It was indicated that a food web shows individual relations, which can vary in space and time (Pimm, 1991). Not *every* rabbit is at *every* moment eaten by a fox. In the baroque perception the direction of thinking is bottom up with much attention for individual detail, where in the romantic view it was top down, the whole was in the centre of attention. The study on the level of the organism (autecology) was also stimulated by the cooperation of population dynamics and population genetics after 1950 (Kingsland, 1985). The development of fast personal computers, which made it possible to trace the adventures of groups that were heterogeneous in genetic composition, age and spatial distribution, further stimulated this approach. I will now describe the four views in chronological order of appearance.

The holistic view

In the early days of ecology, from the 1920s onwards, a holistic view dominated: a community (the term ecosystem was not yet in use) was considered an organic unity in which an irresistible development takes place towards a 'natural equilibrium' that maintains itself in the absence of disturbance (Smuts, 1973).

Later on, also *general systems theory* stressed the wholeness of the community, which was in open contact with the environment. The term ecosystem was used for the community and its environment. The roots of the general systems theory (GST) can be traced back to Vienna in the early twentieth century. Biologist Paul Weiss agreed with the vitalist[1] Hans Driesch, that activity in living organisms cannot be completely reduced to physical and chemical characteristics. However he did not want to incorporate the unobservable entelechistic[2] principle of Driesch. Weiss talked about an organism as a system with a hierarchical order, where new characteristics would appear with each higher organisation level that could not be described simply by the lower levels alone. *'As a system we want to define each complex that, when parts of it are modified, displays an effort to stay constant with regard to its outside.'* (Weiss, 1925, p.183) Ludwig Von Bertalanffy, also a biologist, further developed Weiss' organismic viewpoint, stating that cells, organisms, populations or ecosystems are complex, but highly organized entities, meticulously embedded in their environment. These entities (levels of biological organisation) can be considered as *open* (thermodynamic) systems, which continuously take up energy from their environment, compensating for the loss of energy in the form of warmth. Thus, in this way there is an intensive and

1 Vitalism is a school of thought which postulates that life cannot be fully explained in physical material terms. According to vitalists, life, which in the material world is manifested as a physical process, emerges as a result of an immaterial impulse.

2 Entelechy is a philosophical concept of Aristotle. The term traces to the Ancient Greek word entelecheia, from the combination of the Greek words enteles (complete), telos (end, purpose, completion) and echein (to have). Aristotle coined the word, which could possibly be translated in English as, "having the end within itself." To Aristotle, entelecheia referred to a certain state or sort of being, in which a thing was actively working to be itself.

constant interaction with the environment through the boundaries of these systems. There will be no fixed balance, with maximum entropy, but the system creates a 'steady state' at an entropy value far from thermodynamic equilibrium. Von Bertalanffy was motivated by a trend towards reductionism and specialization in biology to stress the value of studying organization and order in 'wholes' (Von Bertalanffy, 1968). The third Viennese, Arthur Koestler, described the ideas of the GST in a metaphor of the Roman god Janus, having two faces. He called the Janus-like entities that are on one hand a whole and on the other hand part of a bigger whole, holons: these are auto-regulating entities with independent properties, but also properties that are dependent of other parts (Koestler, 1978). This holon idea proved to be fruitful for studying levels of organisation such as the organism or the population as wholes, but also as components in a larger complex. Later Laszlo (1972) added the idea that not only new properties emerge at each higher level, but that also the lower level (subsystem) finds constraints imposed on its behaviour by the higher.

The cybernetic view

In the 1940s, the cybernetic view developed that was derived from an interdisciplinary study connecting the fields of control systems, electrical network theory, logic modelling, and neuroscience. The term cybernetics was introduced by the mathematician Norbert Wiener. Important in his theory are control and communication within biological or mechanical systems and their environment. Control is realized by means of feedback loops, which enable the flow of information. Wiener was the first to propose a connection between information and feedback mechanisms (first used as a term by Anokhin in 1935). Otherwise than in GST, the cybernetic view is much more mechanistic, to the extent that the same theory applies to engines as well as organisms (Wiener, 1948). The focus is not on the components in the system, but on relations between these components: regulation and homeostasis are key concepts (Cannon, 1932). Neural networks, cellular automata, and artificial intelligence have been developed from cybernetics. A famous example of a cybernetic approach to studying an ecosystem is the study of the Cedar Bog Lake in Minnesota, where Lindeman (1942) introduced terms such as functional organization and ecological energy efficiency ratios of an ecosystem. Scientists with a cybernetic view were also the first to use computer models on a large scale. In 1970s computer modelling became a popular approach in the International Biological Program (IBP) under the direction of Van Dyne. He was the first to use terms like 'components' (for organisms), 'forces' (for matter flows) and 'coupling' (for ecological relations) (Golley, 1993). Knowledge of the components of the system and the relations between them offers the possibility for man to restore equilibrium. The Odum brothers especially worked out this metaphor of a machine, stressing the fact that essential ecosystems behaviour is the balance of input and output of matter and energy (Odum, 1959).

The dynamic view

Under the influence of evolution theory, which grew in impact during the second half of the 20th century, a more dynamic view on ecosystems originated. In evolution theory, explanations for the properties or the behaviour of organisms are sought on two levels. One tries to find a proximate, physiological explanation, but also an ultimate explanation (Mayr, 1997). Take for an example the invasion of organisms of a spider species on an island. The proximate explanation is that a few spiders floated on a tree stump that drifted ashore on the beach, but the ultimate explanation is that these spiders have evolved to species that can survive for a long period at sea, capable of clinging on the stump. Form, function and behaviour of organisms develop in the course of an evolutionary process (which also causes special restrictions) by means of natural selection in an environment that is constantly changing. In this environment there can be fluctuations around equilibrium for a long period, but also changes, gradually or suddenly until a completely different scene has developed. Even without changes of the environment, the composition of the community can change, depending on the arrival of new species and the moment of their arrival (Pimm, 1991). A fruitful way to investigate such a composition proved a computer modelling approach, derived from mathematically founded networks. This means that equilibrium in a dynamic view is just a snapshot, a phenomenon which is only perceived when looking on a restricted time-scale (May, 1973). *Development* is in this view far more important than *equilibrium*.

The chaotic view

While the dynamic view already implied that equilibrium was a transient phenomenon, the chaotic view went one step further in claiming that forecasting was impossible beyond a certain time-scale. It had become clear that processes in an ecosystem are in most cases not deterministic, but stochastic (Botkin, 1990). As a consequence, the interactions between all components of the ecosystem are not determined beforehand, but chance is involved. Moreover, even deterministic processes with sufficient degrees of freedom, may lead to chaotic behaviour, as Poincaré had already proved in 1903. In an elegant study about flour beetles (*Tribolium castaneum* Herbst) this was proven to be also true for living organisms (Haefner, 1996).

According to the chaotic view, small changes in the initial state of an ecosystem can lead to completely different developments. This view put also the computer models, made by the cybernetics, under pressure. In most cybernetic models, which were made for complete ecosystems, many components were grouped in clusters, such as the cluster of the trophic level of second order consumers, or the cluster of decomposers. Relations were fixed in relative simple sets of differential equations. Therefore it is not surprising that the solutions of these equations had only little predictive value. However, when the cybernetic models were made more complex, trying to make them more realistic, their predictive value was even worse, because small changes in initial values had dramatic effects on the outcomes.

Backing to the chaotic view came from the dynamic systems theory (DST), which was originally developed by the chemist Ilya Prigogine (Prigogine & Stengers, 1985). As in GST, an organism or an ecosystem is regarded as an open system. However, in this theory, the complex system is not only open, but it also develops a dynamic order far from the (static and stable) thermodynamic equilibrium. To maintain order, there is a continuous dissipation of energy; therefore the orderly structure is also called a dissipative structure. There are abrupt and unpredictable transitions, which can be described by means of bifurcation diagrams (see figure 4.2). These transitions can result in temporary equilibria (attractors). It is fundamentally impossible to predict the further development of the system: going to an attractor (transition), going back to the original orderly structure (decomposition), or chaos. Dynamic order and chaos are neighbours. The described dynamic order, which can be maintained by taking up external energy, is created by self-organization or autopoiesis, which means that transitions can lead to a more complex structure (Maturana & Varela, 1980; Kaufman, 1995).

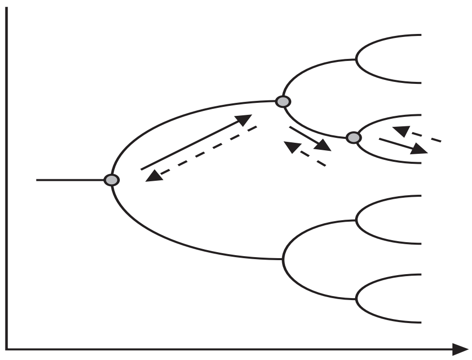


Figure 4.2. A bifurcation diagram with alternative equilibria.

The chaotic view triggered a reaction from the scientists, that's to say that from a broad systems approach they had to move to a more detailed one. Especially threshold conditions, where the system switches from one regime to another got much more attention in the chaotic view. For example, in recent work on aquatic ecosystems there has been a lot of attention for the precise course of water temperature and the age distribution of specific species of fish (De Roos et al., 2003; Mooij & DeAngelis, 2003). A minimal difference in a well-understood process, like the growth of young fish, may result in very different results on the level of the ecosystem. If small bream are just big enough to escape a predator like the pike-perch, this may result in a flourishing bream population. This may influence the whole ecosystem for years, by means of a high pressure on zooplankton by the bream. It appears that the growth of the bream is mainly dependent on the amount of warm days after the hatching of bream eggs, an amount that is difficult to predict in the Netherlands.

The position of the human species

In many ecology-related issues, the human species plays a crucial role, and it will not be surprising that the different views described above resulted in different ideas about the position of man in the ecosystem. Most ecologists agree on the position of man, as being a part of the ecosystem. However, man having a contemplating, creating and managing role, has a special position in the ecosystem. A term used here is 'Doppelstellung' (double position) (Kattmann, 1977): man is not an outsider in the biosphere, but he is a special creature with 'eigenartige Eigenschaften' (specific properties) as well as a species that is linked with the rest by descent and by interactions. Human influences often also have economical consequences. When influencing ecosystems, it is sensible for man to calculate the impact: economizing ecology. In general, the value of ecosystems can be divided into consumptive and non-consumptive uses. For example, consumptive uses for forests include logging and hunting; non-consumptive uses include bird watching, appreciation of the existence of an ecosystem, flood control, and soil conservation. While the value of consumptive uses can be directly based on market prices, it is harder to assign value to non-consumptive uses, which makes it difficult to present non-consumptive uses objectively in arguments about conservation of ecosystems (Daily, 1997). This economizing could be followed by a discussion about desirability in the light of sustainable development (Miller & Westra, 2002). Nevertheless, in modern dynamic or chaotic views it is clear that humans cannot foresee the full ecological impact of their behaviour, because the dynamic processes involved are not completely predictable. Moreover, these views stress that humanity cannot create ecosystems at will: a field or pasture can be laid out but a tropical rainforest or a coral-reef can not.

The characteristics of the four major views are summarized in table 4.1.

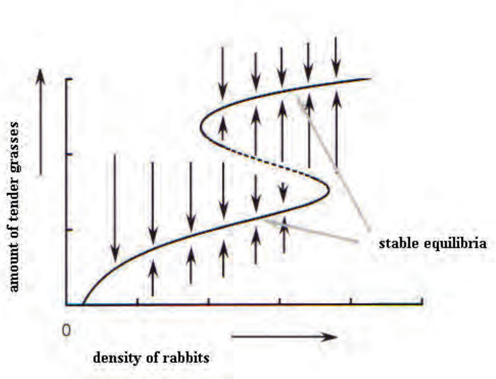
Table 4.1 A summary of the four views om the ecosystem and their characteristics.

Characteristics	Holistic	Cybernetic	Dynamic	Chaotic
metaphor used for the concept ecosystem	(developing like) an organism	machine	accidental phenomenon, continuous movement	mobile; quiescence and then sudden movement
nature of the system	open system	closed system	open system	open system
development	directed: from simple (low diversity) to complex (high diversity):	an equilibrium (set point) is reached and maintained, feedback mechanisms play an important role	unpredictable, there is no direction in development	an apparently stable situation can disappear suddenly and unpredictably (chaotic regime), after which a new stable situation may generate
equilibrium	the complex situation is stable	limited fluctuations around equilibrium, resilience is strong by feedback	temporary, to be disturbed by evolutionary developments (long term), resilience weak	temporary, to be disturbed even without changes in the environment (short term), resilience weak
place of man	outsider	outsider	part of the ecosystem	part of the ecosystem
management and control	man is the cause of damage, but also able to restore and manage ecosystems (for example in the absence of predators)	man is able to stimulate and slow down the working of feedback mechanisms, which makes him responsible for maintaining equilibria	monitoring; man can create good conditions, but this is no guarantee for a special result	monitoring; man can create good conditions, but this is no guarantee for a special result

Ecological debate

Some terms that are used in the world of the ecosystem and the relation between these terms are still under discussion (Peters, 1991; Pimm, 1991). Let us look at a trio that is very important when we have complexity and dynamics of the ecosystem in mind: equilibrium, stability, and biodiversity. In ecosystems equilibrium never means *constancy,* there are always fluctuations; a possible equilibrium is always dynamic. If equilibrium is described as a situation in which the factors under study only show limited changes, one could ask how stable this equilibrium is. If a system easily loses its equilibrium when it is disturbed, we call the equilibrium *unstable*. When there is little change when disturbed, we say a system has a strong *resistance* and the equilibrium is *stable*. If a system, after disturbance, is unstable, but returns to the old situation rather quickly, we say the system has a strong *resilience*. Many shallow lakes have a strong resistance as well as a strong, but not infinite resilience. It was demonstrated that in a number of shallow lakes two stable equilibria can exist, with a *hysteresis* phenomenon: the development from the one equilibrium to another is different from the development in the opposite direction.

Suppose that an originally clear lake has become turbid by eutrophication. If people try to push this lake back from the turbid stable equilibrium to the clear one, they will have to reduce the amount of nutrients to values that are much lower than that which brought the lake from clear to turbid (Scheffer, 1999). The same could be found for the population density of rabbits in a dune area. When the density of rabbits declines (e.g. by an epidemic), the amount of tough grasses and reed will rise. It is difficult to lower this amount in favor of tender grasses, with the idea of stimulating the growth of the rabbit population. In figure 4.3 the two equilibria and the hysteresis effect are shown. For a long time it was believed that equilibrium is more stable when biodiversity and complexity are high. Some scientists think that there is a saturation level, where all niches are filled (redundancy hypothesis), while others think that the amount of niches keeps growing, but more slowly (rivet hypothesis). The idea is that high diversity is the result of a large number of different habitats and niches, which are maintained by feedback mechanisms. Here the term niche is somewhat diffuse (Tomlinson, 2000). A distinction can be made between a *fundamental niche* and a *realized niche*. The fundamental niche is determined by circumstances in which individuals of a species can survive, not bothered by intraspecific and interspecific competition or predation. The realized niche is much more limited, all circumstances that act on a special place are taken into consideration (Hutchinson, 1959) (figure 4.4).



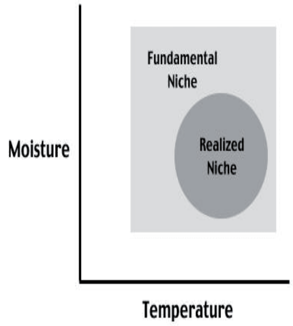


Figure 4.3. The relative amount of tender grasses as a function of the density of a population of rabbits. Figure 4.4. The relation between fundamental and realized niche.

The idea that equilibrium is maintained as long as the abiotic circumstances do not severely change is connected with holistic and cybernetic ideas. Opposing we find the dynamic and chaotic ideas that there are continuous changes in an ecosystem, in the abiotic factors (the weather, the composition of the soil) as well as in the populations (genetic composition, birth rates and death rates). '*An ecological community is like a market economy (filling with niches). Death is like going broke. The advent of a new business (species) will alter the fitness landscape of the others, so the landscape is constantly changing.*' (Gell-Mann, 1995, p.256) May (1973, 1979) put the cat among the pigeons when his investigations made clear that very complex ecosystems with great biodiversity are often less stable than rather simple ones. The complexity of an ecosystem, which can be indicated for example by connectance[3] (Klomp & Green, 1996), is, by the way, not identical with the biodiversity. Connectance refers to the extent of ramification of the relations between populations. For an example see figure 4.5.

In both cases the biodiversity (here defined as the number of populations in an ecosystem) is equal: five. However, the connectance of B is higher, because it possesses more relations. It is interesting to compare the connectance with the theoretical ideas of Kaufman (1995), who compares this structure with mathematic graphs. If

[3] Klomp and Greene actually use the word connectivity, but we stick to connectance (see also Pimm, 1991) because connectivity is used in recent publications as a measure for the connection between two nature reserves (see Soons, 2003).

Figure 4.5. Two food webs, differing in connectance. In B is found a higher connectance than in A.

the ratio of connecting lines to knots in an assemblage of graphs becomes higher than 0.5, there is a sudden transition from many loose chains into a giant cluster. In an ecosystem this would mean that many populations would influence each other in a complex nonlinear structure. In this view an ecosystem is a complex adaptive system. Otherwise than in an organism there are no homeostatic processes that result in the maintenance of equilibrium. When the circumstances change, the ecosystem changes too, leading in some cases to a completely new (temporary) equilibrium. In a categorization of complex systems (Weinberg, 1975) ecosystems are placed in the class of 'medium-number systems', having intermediate numbers of components and structured interrelationships among these components. The problem of the ecosystems scientist is not that the *object of study* is too complex. In large number systems (like a sample of millions of molecules in a gas, with unpredictable individual behaviour) the formalism of statistics can be used to predict systems behaviour as a result of the average of the motions of molecules. It is *the complexity of the organization* which makes such an approach impossible in an ecosystem (O'Neill et al., 1986).

4.3 Modelling ecosystems

Problems with dynamics

Several solutions have been proposed to prevent misunderstandings about the food web, which enables to grasp dynamics and complexity of the ecosystem. De Ruiter et al. (2005) suggest replacing the metaphor of a *static* structure like the food web by the metaphor of the structures to be built in the game of Jenga (see figure 4.6). This could contribute to visualizing the *dynamics* of a complex food web.

Figure 4.6. In the game of Jenga, each player successively takes away a block and places it on top of the tower, until the structure becomes unstable and crashes.

Each block in the game could be considered a potential keystone. It is hard to foresee which blocks will be essential to stability in a constantly changing Jenga structure. Comparably, the importance of extinct or imported populations for stability of the food web in an ecosystem can vary over time. In such a view, food webs are open and dynamic systems. This new idea could help in managing ecosystems that are changed by human influence, although the exact relation between the structure of a food web and the stability of an ecosystem appears to be very complicated. Small substructures play a key role in the stability of food webs. These substructures are loops of interactions, i.e. closed chains in the form of e.g. A eats B, B eats C, C is eaten by A. The strengths of interactions of these loops are important for food web stability. These strengths are a function of energy flow and biomass distribution, which in turn result from species characteristics. Thus, the stabilising organisation of a food web can be linked to certain patterns in species characteristics (Neutel, 2001).

Another way to grasp the complexity of an ecosystem is modelling. As concerns the dynamics of an ecosystem, models (especially computer models), contrary to the Jenga game, show three advantages. They enable one to 1. follow *quantitative* aspects of processes in time, 2. introduce various interacting factors, 3. study changes at the level of the individual, the population, and the ecosystem. Computer modelling is attractive since it may depict the changes occurring in a complex, dynamic ecosystem, caused by internal or external factors. A computer model can be started, stopped, examined, and restarted under new conditions, in ways that are impossible in the real setting (Holland, 2000).

Use of models

In biology we find a manifold use of models. For example, a torso of the human body, a scale model of the cell, or a model sketched on paper of the blood circulation. Modelling ecosystems has a long and rich tradition in ecological research. Modelling is one of the four mutually linked approaches that are used in ecosystem studies today (Likens, 1985):

1. Empirical studies: collecting data in the field, trying to integrate these into a complete picture;
2. Comparative studies: comparing a number of structural and functional components in a range of ecosystems;
3. Experimental studies: manipulating a complete ecosystem to identify specific mechanisms;
4. Modelling: trying to understand (pieces of) ecological reality and being able to forecast developments in an ecosystem.

By making a model, the ecologist tries to understand and be able to make predictions about developments in ecosystems. Such a model never contains all the features that are found in reality. It could be compared to a geographical map, which in fact is also a model. Different types of maps serve different purposes, i.e. they focus on different objects. They also differ in scale. In a similar way, an ecological model enables us to focus on those features that are essential in the context of the problem to be solved, for example on a specific level of organization, depending on the goals of the model. Thus, in a marine ecosystem the modeller concentrates on cod and its density (population level), because he wants to know what is causing the imminent extermination of this species. He is not interested in the exact weight of an individual cod, or in a complete survey of all species of fish in the area under study. As a consequence, a model is nothing more than an expression of the view (and sometimes the misconceptions) of the modeller (Reddingius, 1970). A model will necessarily not be better than the knowledge and assumptions it is based on.

Trust in the predictive power of models strongly varies across different views. A scientist with a chaotic view will be more reserved about the predictive power of his models than a scientist with a cybernetic view. In the International Biological Program, great sums were invested by the U.S. Government in ecosystems studies carried out by ecologists with a cybernetic view, who could convince the funding agency that they could actually manage and predict developments in ecosystems based on data collection and computer modelling (Golley, 1993; Kwa, 1989). Nowadays, it has become clear that such promises are doomed to fail: many ecosystems are so complex that it will be impossible to know all the details. Also, developments taking place in an ecosystem are historically irreversible, which means that there are ratchets that will block 'the way back'. For example, the history of species invasion in an area has great impact on further developments when new species arrive. As has been shown, when species were removed and afterwards reintroduced, they could not always occupy their old niche again, as it had been taken over and slightly changed by others. This so-called humpty-dumpty effect suggests that it will not be possible to put the same ecosystem back together again from its pieces, being the populations from various species (Pimm, 1984). Nevertheless, although models are sometimes maligned by field biologists, the impact of modelling in ecology is undisputed by nearly all ecologists.

Modelling and systems thinking

Levels of biological organization

Ecologists have always been interested in understanding the distribution and abundance of organisms and the interactions that determine distribution and abundance. However, there is more. *'Major challenges in ecology are to connect different levels of biological organisation, to deal scientifically with the enormous ecological complexity, to generalise from model systems, to up- and downscale in space and time.' (Vet, 2007)*

Organisms maintain relations with their environment: i.e. biotic factors like conspecifics, competitors from other species, food, predators, parasites, and abiotic factors like light, oxygen, temperature, availability of water, substrate, wind, et cetera. The study of individual organisms in interaction with their environment is the terrain of autoecology. However, ecology goes beyond the level of *concrete* organisms in interaction, to study also the interactions between *abstracted* classes, such as populations, communities, producers, consumers, course of temperature, et cetera. The pattern or the form of these relations will finally define the complete ecosystem (Lawson, 1977).

Systems thinking, based on the general systems theory (Von Bertalanffy, 1968), provides a framework with explicit attention for the hierarchical levels of organization and for the ways in which the parts (populations, or functional groups of populations, and all kinds of abiotic factors) exist in a mutual relationship and therefore influence each other in nonlinear, multi-causal ways, giving rise to dynamic patterns over time (Townsend et al., 2003). Systems thinking will focus on particular features of the ecosystem like the distinction of the levels of organization, feedback and temporal delay, which will cause dynamic, often cyclic but sometimes chaotic patterns (May, 1973; Booth Sweeney, 2000). Modelling in ecology is strongly linked with systems thinking. It enables us to encompass our knowledge about the components that interact in the system: how they interact, and how crucial these interactions are in light of the problem that is under study (Jørgensen & Bendoricchio, 2001).

Black box and glass box models

In dynamic system thinking multiple levels of organization are taken into consideration. Thus, the old discussion between reductionism and holism seems outdated. It became clear that when moving up to a higher level of organization, there are effects caused by a combination of scale (number of elements under study) and degree of complexity (dependent on the relations between all elements) that cannot be described using the properties at the lower level (Anderson, 1972; Gell-Mann, 1995; Holland, 2000). 'More is Different' was meant to say that for example one organism or a small number of organisms do not have all the properties that many of them possess together as a population. To put it differently, new properties *emerge* at higher levels. This is nicely illustrated in Hofstadter's dialogue between Achilles and the anteater. The anteater relates about his good friendship to an ant colony called Aunt Hillary. Achilles responds that an ant colony is just a bunch of organisms, crawling around to find food and building materials for their nest, upon which the anteater answers: *'You can put it like that if you want per se to see the trees and not the forest, Achilles. In fact ant colonies are, considered as wholes, well defined unities with their own properties.'* (Hofstadter, 1980, p.316) So, reductionism may break things apart and analyze the parts, but it fails to see the whole constructed from those parts (constructionism). On the other hand, holism sees the whole, but fails by trying to explain wholes without meticulously looking to the parts (Nørretranders, 1988).

Depending on the research questions in a concrete situation, the ecologist will choose a specific level to focus on. In a 'black box' model (figure 4.7a) there is no a priori information from inside included. One tries to establish a relation between input and output, based on outside information alone. In the specification of this relation the view of the ecologist plays a role. In a 'glass box' or clear box model (figure 4.7b), information about the inside of the system is included. As illustrated in the figure, a glass box model, at a lower level, will consist of an assemblage of black boxes again.

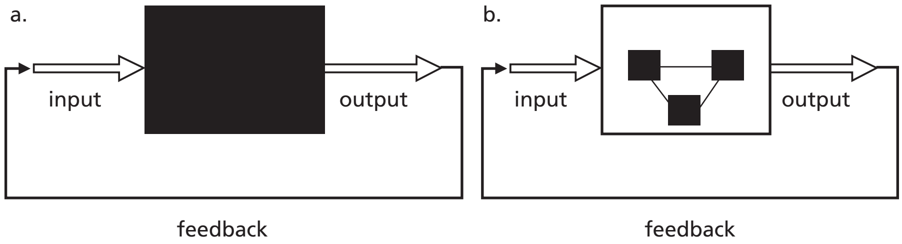


Figure 4.7 **(a)** Black box model. **(b)** Glass box model.

In table 4.2 the various levels of organization and the possibilities of performing investigations on these levels, using a 'black box' model or a 'glass box' model, are shown, using a lake ecosystem as an example.

Levels and the abiotic environment

There has been a lot of debate about the number and nature of the levels to study with regard to the ecosystem (Ringelberg, 1988). Historically, the four levels mentioned in table 4.2 have been studied separately. Some scientists doubt if an ecosystem is a system at all, or dispute the value of one or more levels above the organism (Engelberg & Boyarski, 1979; O'Neill, 2001). They suggest that the only real relations are at the level of concrete organisms; the rest is 'human construction' or modelling. While this may be true, other scientists keep it that formal classes are needed to grasp patterns in nature. A special problem is the position of the abiotic environment. At the level of organization of the organism, the abiotic environment is kept separate from the organism by the systems boundary, for example the skin of an animal. This division is also logical for another reason, because one organism does not have much influence on its environment. If we go up, all organisms from one species living together in a specific area form a population and subsequently, all populations living together in this area form a community. However, these collections do influence their environment, so it seems reasonable also to study a community together with its environment, i.e. the ecosystem. This will create a logical problem. A population can be considered as a set of organisms and a community as a set of populations, but an ecosystem can not be considered as a set of communities. As a way out, we could investigate organisms and populations together with their environment from the beginning, which would result in three system levels: 1. organism, 2. population and 3. community or ecosystem (which is in fact community + environment).

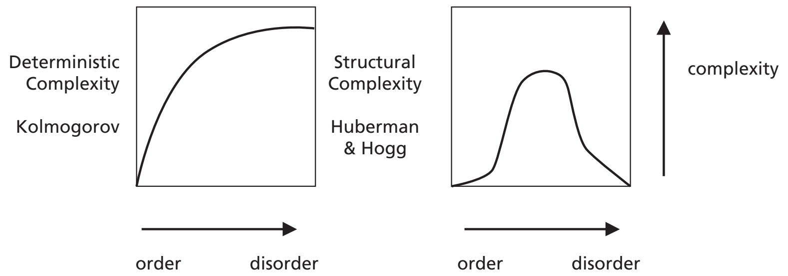
Table 4.2. The various levels of organization which are used in ecology.

level of organization	example	environment	black box	glass box
4 ecosystem	lake	other ecosystems	changes in stability, material flux, differentiation in niches	diversity of the community, relations with the biotope as exchange of nutrients with the soil
3 community	fish, insect larvae, zooplankton, phytoplankton, and macrophyta	biotope	changes in diversity, complexity, connectance	size of populations, relations such as interspecific competition, mutualism, or predation
2 population	daphnias	habitat	changes in size (density)	age distribution, sex ratio of organisms, relations such as in reproduction or intraspecific competition
1 organism	a daphnia	the water around it with a certain temperature, quantity of light, info-chemicals	age, sex, feeding behaviour	organs, relations between organs such as between heart and lungs

Similarities and differences in levels

Systems on various levels of organization have in common that they represent open and complex adaptive wholes with a systems boundary, in which the parts are influencing each other. However, there are also differences between hierarchical levels. In going from a lower to a higher level, one drops information about individual elements. For example, to regard organisms of the same species in a special area as a population, demands that individual differences between these organisms will be, at least partly, neglected. The same happens when populations of different species are clustered into a functional group of 'predators'. On the other hand, as has been made clear above, information is also added, as properties emerge at a higher systems level. Moving to a higher level means integration of lower levels, resulting in more complexity. In a first attempt to find a measure for the complexity of an object, Kolmogorov used 'the length in words of the shortest possible adequate description of the object under study' (Nørretranders, 2000). However, we are confronted with the problem that with this measure, highly random objects will turn out to be the most complex, because they need the longest description, where we want to take into account pattern, structure, correlation or organization. We want to define not *deterministic*, but *structural* complexity. An amendment was therefore suggested (Huberman & Hogg, 1986) that, like in an ecosystem, situated structural complexity between strict order, where everything is fixed and easy to describe and where it is quite easy to predict further developments, and disorder, where everything moves freely and is difficult to describe and where it is hardly possible to describe further development (see figure 4.8). This means that in an ecosystem an optimal complexity could be defined, where relations between the various components maintain a certain amount of order.

Figure 4.8. Patterns of complexity, according to Kolmogorov and Huberman & Hogg.



Mathematical models in ecology

Ecological models like food webs or flow diagrams of matter and energy are examples of static models. They are not helpful in grasping complex dynamic processes and components that change over time themselves. Here we need mathematical models, allowing us to calculate future developments. Looking at the use of these models, we could say that dynamic modelling of an ecosystem is the process in which ecological knowledge is expressed in mathematical formulas. Mathematical models enable us to explore in depth the complexity and dynamics of an ecosystem (Jørgensen & Bendoricchio, 2001; Townsend et al., 2003). They have the following characteristics:

1. They are valuable in summarizing our current state of knowledge;

2. They show which components interact with which others;
3. The processes are formulated as mathematical equations which have been proved to be valid;
4. The importance of the processes with reference to a specific problem is clear.

We are able to explore quantitatively scenarios and situations of which we do not (yet) have real data. However, caution is necessary. A model needs validation, which is necessary for predictions to be made. By collecting real sets of data, we can test the model in an empirical situation. This will give more confidence that the model can be used for predictions about developments in the future which is, for instance, important for nature conservation measures.

It is difficult to find the optimum level of complexity of a model. If it is too simple, it will neglect essential parts of the real system. If it is too complex, analysis will become very difficult and we will get stuck in detail. In both situations, the predictive power of the model is low. Thus, what is needed is the optimum zone of model complexity, the 'Medawar zone' (Grimm & Railsback, 2005, see figure 4.9), in which the essential elements are kept while complexity remains manageable. What parts are essential depends, at least partly, on the view of the modeller. For example, a long time scale is more important for a dynamic or chaotic modeller than for a cybernetic modeller.

The first mathematical models in ecology were at the very simple end of the spectrum: the Lotka-Volterra model of predator-prey relationships and the Streeter-Phelps model of the oxygen balance in a stream from the early 1920s show a clear cybernetic view. Relations between groups are described in strict deterministic equations.

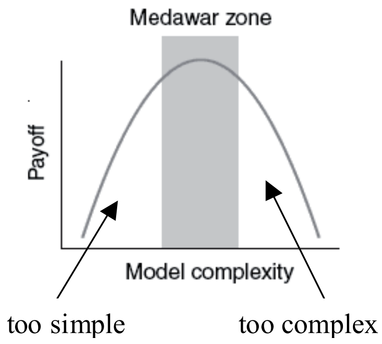
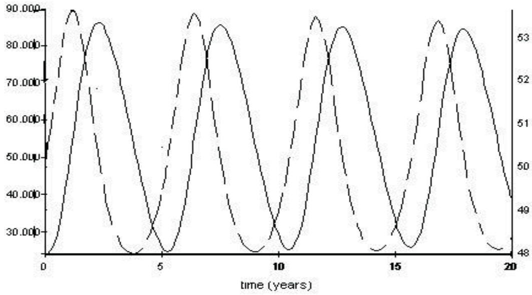


Figure 4.9. Payoff of bottom-up models versus their complexity. A model's payoff is determined not only by how useful it is for the problem it was developed for, but also by its structural realism; i.e., its ability to produce independent predictions that match observations (from Grimm & Railsback, 2005, p. 988)

Lotka (1925) and Volterra (1926) independently developed a mathematical model to explain the dynamics of prey and predator populations. Changes in the density of shark (being the predator) had been observed, derived from the percentage of shark in the fish catch in Fiume (Italy)[4] during the First World War. In two differential equations they wrote:

$$dN_1/dt = r_1.N_1 - p_1.N_1.N_2$$
$$dN_2/dt = p_2.N_1.N_2 - d_2.N_2$$

N_1 is prey density and N_2 is predator density, r_1 is the maximum rate of increase of the prey population, d_2 is the mortality rate of the predator and p_1 and p_2 are predation coefficients (for 'meeting' and 'conversion into meat'). This classical model can easily be run on a computer. The model output in figure 4.10 makes clear that both populations oscillate, with the phase of the predator oscillation lagging behind that of the prey population. When both populations are plotted against each other, a cyclic pattern is found (see figure 4.11).



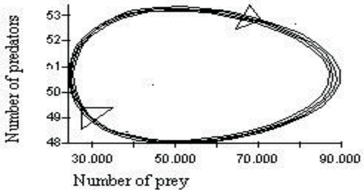


Figure 4.10. The development of the size of predator (_____: right Y-axis) and prey (_ _ _: left Y-axis) populations, according to Lotka and Volterra.

Figure 4.11. The relation between both populations according to Lotka and Volterra.

The Streeter-Phelps model (Streeter & Phelps, 1925) describes how a continuous influx of wastewater affects the O_2 concentration in an initially healthy river. Biochemical decomposition of the wastewater takes oxygen from the water, which is steadily compensated by aeration (transfer of oxygen from air to water). The resulting O_2 concentration in the river can be modelled by two differential equations:

4 Nowadays the city of Fiume is called Rijeka, situated in Croatia.

$$dO/dt = -k_B B + k_A(O_S - O)$$
$$dB/dt = B - k_B B$$

where O is the concentration of oxygen (g/L); O_S is the saturated oxygen concentration (g/L); B is the biological oxygen demand (g/L); k_A = aeration coefficient; k_B = degradation coefficient.

O_S depends on the water temperature; k_A and k_B are both dependent on the water temperature as well as on a reference temperature.

The output of this model, which is presented in figure 4.12, suggests a slow decrease in O_2, followed by a gradual increase.

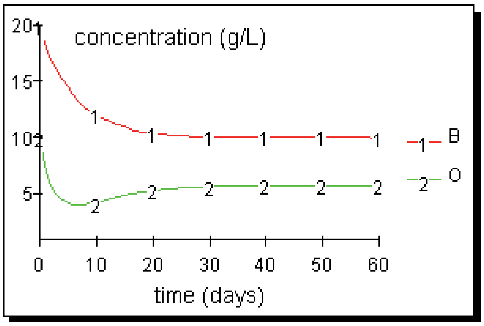


Figure 4.12. The development of the oxygen concentration (O) and the biological oxygen demand (B) in a river with a steady input of BOD-load.

In these models the differential equations are beautiful and transparent, but many ecologists questioned the assumptions behind them. For example, Lotka and Volterra supposed that the decline of the density of the prey population was only dependent on the predator density, and that the decline of the density of the predator was only dependent on natural mortality. Many field ecologists, having a dynamic view, doubted that this type of feed back loops would be sufficient to explain the fluctuations they observed in the field. Others questioned the assumption of Streeter and Phelps that there is a constant input of organic load and that the concentration of oxygen over the whole river reach remains relatively constant. There's a world of incomprehension between the assumptions in mathematics and ecology.

By contrast, at the too complex side of the spectrum are modelling efforts initiated in the 1970s, stimulated by the International Biological Program, which resulted in extensive funding for ecosystem studies, especially in the United States. Mathematical modelling became a widespread activity. Confidence in the calculating power of the computers gave rise to very complex models, the limiting factor being ecological knowledge. After a period of euphoria, criticism rose fast, stressing the point that the narrow deterministic details of the models did not mirror natural phenomena. Even more important, the models did not gain much predictive power. Other critics have pointed out that it is misleadingly simple to build complex computer-based simulations; that doing the mathematics by hand may provide deeper insight into the mathematical properties of the model; and that a modeller with insufficient background in mathematics may easily arrive at wrong conclusions (May, 2004). On the other hand, there is the inclination of mathematicians to 'bend reality' to relatively simple formulas with analytical solutions. An ecologist will doubt the validity of these formulas.

Slowly a balance emerged between the oversimplified and the unmanageably complex. Important factors were the inclusion of stochastic processes (where chance has influence) in the model and the availability of quantitative ecological data which could be used to calibrate and test the models. The resulting models were less complex, more transparent and realistic.

Once it became clear that ecosystems could not only behave in a dynamic, but even in a chaotic way, new mathematical tools came into use. In a chaotic process chance is important, but otherwhise than in a stochastic process, the possibility that a certain event will take place is not known. A renewed attention for individual differences led to a type of modelling in which one departed from individual organisms and made use of knowledge from artificial intelligence, because minimal individual differences at the start could lead to very different results. This created the risk of the complete system remaining outside the picture. By using powerful computers, it became possible to integrate insight in mechanistic detail with the functioning of the complete ecosystem (Grimm & Railsback, 2005; Mooij & DeAngelis, 2003). Therefore, it is time to pay some attention to computer modelling.

Computer modelling

Computer models enable to solve mathematical formulas that are difficult (or impossible) to solve analytically, by an iterative approach. Therefore computer models provide an adequate tool for studying complex and dynamic phenomena, which are phenomena where many factors interact, changing constantly in time. One needs to know the initial state, the relevant factors, and a possibility to calculate the changes in these factors over a set period of time (which could be seconds, hours, months, or years, depending on the situation). First however, a lot will have to be done before the computer can actually be used. As can be seen in figure 4.13, there is a parallel between ecological modelling and other types of scientific research. From the start, a model will be fed with data from 'the real world'. In the experimental testing phase, there is a continuous interaction between development of the model and the need for additional data. Once a model is ready, the work is still not done. New factors or complete sub-models are implemented into the model to get a better match with 'the real world', which gives better forecasts.

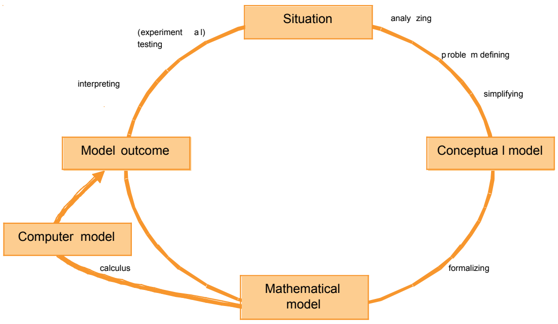


Figure 4.13. A modelling procedure (adapted from Savelsbergh, 2006, p. 5).

In modern scientific ecology, object-based tools[5] are most frequently used. The combined activities of the elements in the model are used to reflect the dynamics of the system. Thus, the progression of the system's dynamics emerges as the result of events occurring at the object level: 'bottom-up modelling' (Parrott & Kok, 2000). The rationale for this choice is that it is the organism that adapts. The properties

5 In an object based modelling tool each element is depicted separately as an object, and modelled as a discrete entity, the relations between entities are described by rules. This type of modelling can be sub-divided into:

a Individual based: an ecosystem is represented as a large collection of objects, the interacting organisms. The basic modelling unit is the organism. Examples are OSIRIS and EcoSwarm.

b Agent based: an ecosystem is again represented as a large collection of interacting organisms, but they have the ability to 'learn' about their environment and modify their behaviour accordingly. Examples are ECHO and Boids.

c Cellular automata: an ecosystem is divided into small spatial elements, where objects are arranged on a lattice and are influenced by special rules, leading to random walk mobility. Examples are EcoBeaker, Stagecast Creator and NetLogo.

of the ecosystem emerge from this adaptive behaviour of organisms. Therefore, to understand the relation between individual traits and systems behaviour, these tools seem adequate (Grimm & Railsback, 2005).

4.4 Implications for secondary education

In the previous sections, I have presented an overview of historical developments and the current status in research on ecosystems. Of course, not all of this could be covered in the secondary curriculum. In this section I will identify those crucial aspects that deserve attention in the upper secondary curriculum.

In line with my description in 4.2, it seems important to introduce the idea that different views on the same phenomena exist in ecology in secondary education, because this will clarify to a greater extent where the different positions in ecology related discussions come from. I could also say that extra attention must be paid to the views that are most central in modern ecology, being the dynamic and chaotic view, to make it possible for students to grasp the complexity and dynamics of ecosystems behaviour. Students should realize that there are not always clear-cut solutions in ecology, for example that there is no straightforward relation between biodiversity and stability and that predictions about ecosystems' behaviour will not always come true. As appears in 4.3, systems thinking and modelling (including the use of mathematical formulas, with or without a powerful computer used as a calculus supporting apparatus) seem helpful tools to grasp this complexity. In any situation students should learn to recognize the level of organization they are working at. They should be able to yo-yo (Knippels, 2002), meaning to go up and down between the various levels, knowing what characteristics are specific to each level. It also seems sensible for students to start at the level of the organism and then to proceed bottom up into the direction of the ecosystem, like ecologists do. The sophisticated object based modelling tools which are used in modern ecology seem too difficult for use in upper secondary school. Variable based modelling tools, in which the used entities are not discrete objects, but stocks and flows, showing relation specified behaviour, influenced by parameters and converters, seem to be more adequate here. There have been investigations which show that these tools can be very useful in upper secondary school (Ossimitz, 2000; Westra, 2002, Löhner, 2005). In chapter 5 (section 5.7), I will elaborate on this point.

5. Current educational practice: opportunities for change

5.1 Introduction

In the previous chapter, desirable learning objectives and promising approaches have been described from the viewpoint of ecological science. In this chapter, I will reconsider these objectives and approaches from the viewpoints of educational practice and educational research.

In the sections 5.2 and 5.3, I will discuss students' initial ideas about ecosystems and current approaches to teaching about ecosystems, as they emerge from the international research literature. In the sections 5.4 and 5.5, I will present empirical explorations to describe the situation in the Netherlands. My findings in these sections confirm that current educational practice is at odds with the views of practising ecologists and with the ecological insights that were described in chapter 4.

In the previous chapter, I have also argued that, from the viewpoint of ecological science, systems thinking and modelling might be suitable activities to gain insight into complex and dynamic ecosystems. However, it remains to be seen whether these activities are also feasible at the level of secondary education. I will review the evidence on these issues in the sections 5.6 and 5.7.

5.2 Students' initial ideas about ecosystems

Prior to any formal education, students will have developed some conceptions of ecological phenomena, based on their own perspectives. In a series of studies, ontological and epistemological differences between students' explanations of ecological phenomena and modern scientific ones were found.

For students the ontological status of an ecosystem is that it is concrete and real, where as for scientists it is conceptual and constructed. So, students tend to 'reificate' the ecosystem (Jelemenská, 2006): they define it by space and boundaries, making it a concrete unit of nature.

Many students hold holistic views, with a strong emphasis on equilibrium and the balance of nature (Sander, 2002). Just as holists and cyberneticists earlier, many students hold the idea that in an ecosystem there are checks and balances that maintain a 'natural equilibrium'. In their views, an ecosystem would work like an enormous teeter-totter, where balance should be maintained. If a population wanders too far to one side, another population must counter that move and adjust accordingly by moving to the other side. Thus, the components cooperate to serve the benefit of the whole, and balance persists, as long as man does not intervene.

In their reasoning about ecosystems, students tend to consider the components in the ecosystem in isolation (Ben-Zvi Assaraf & Orion 2004). Only the direct effects of a change tend to be recognised, while domino-like effects along a food chain, feedback mechanisms and reciprocal effects are poorly recognized (Grotzer & Bell-Basca, 2003; Stafford, n.d.).

With regard to the position of man, some students appear to have a biocentric or ecocentric view on the concept 'ecosystem' (with the perspective of 'me *in* nature'), where others have an anthropocentric view (with the perspective of 'me *and* nature'). These views seem to be purely idiosyncratic and do not change easily by teaching (Carlsson, 1999).

More generally, students' initial conceptions have been found robust to change, because they are grounded in alternative frameworks that students have constructed to interpret their experiences over an extended period of time; one or two classroom activities are not going to change those ideas. Students must be provided with time individually, in groups, and with the teacher to think and talk through the implications and possible explanations of what they are observing and this takes time (Driver et al., 1985).

5.3 Ecology teaching in the upper secondary curriculum

Both teachers and students tend to value ecology as an important issue. When asked about their main interests in biology, students most frequently mention ecology (Magro et al. 2001). Nevertheless, it seems that ecology as it is regularly taught remains disparate from the ecological issues students are interested in, as was found in France (Magro et al. 2001), and in Britain, among A-level students (Roberts, 1997).

For students, ecology, like most science matter, seems to be not important in real life (Johnstone, 1995).

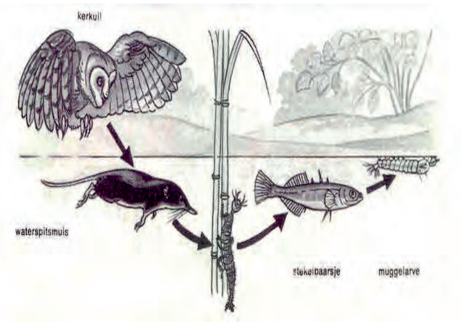
In addition, ecology appears to be a difficult subject. In an investigation among British A-level students, ecology took the second place (after energy & respiration) in the top five of difficult subjects in biology. Especially the pyramid of biomass, communities, energy flow, interrelationships and populations, got high marks in a difficulty scale (Openshaw & Whittle, 1993). Grasping the ecological concepts 'food chain' and 'ecosystem' that teachers want them to learn is also a problem for students. Only one out of 58 10th-grade biology class-students that had been taught about these concepts showed a sound understanding of the concept 'food chain' and not a single one showed a sound understanding of the concept 'ecosystem' in an assessment test (Marek, 1986).

In the traditional approach to ecology teaching, dependencies between populations are represented through 'food webs', energy flux schemes and cycles of matter. Arrows are used to represent the relations. Although these formats convey the idea of a network, these static representations do not seem to contribute much to students' insights into the dynamic interdependencies of populations in the web (Hogan, 2000)[1]. They also do not seem to realize that food webs describe relations at the level of populations, and not at the level of organisms. Moreover, many students do not realize that a food web is a representation developed to grasp the complexity of an ecosystem, rather than a fact of nature. This could be a consequence of the usual teaching approach, where the food web representation is presented as a fact, rather than constructed by the students themselves.

As a side issue, extra complications may arise if it is not clear what the meaning of the arrows is and in what direction they should go. Until about 1975 biology school schoolbooks used to represent a food chain like in figure 5.1a. The direction of the arrow represents the action taken by the consumer towards what is consumed. After that, under the influence of the ideas on the flow of matter in a food chain, the direction of the arrow changed, as can be seen in 5.1b. As any teacher knows, there will always be a few students who seem to adhere to the old-fashioned convention to draw their arrows. In the national written biology examinations in the Netherlands,

1 Besides, organisms of different species communicate with all sorts of signals, especially with chemical substances. This creates the possibility to represent an information web (Van Donk, 2002). This is not mentioned at all in school biology.

the scoring norms explicitly require a penalty for food webs with the arrows pointing in the wrong direction. Another obstacle in teaching ecology is that several concepts and terms can have different definitions, which is mirrored in schoolbooks where the same terms (e.g. equilibrium or niche) are sometimes used with different meanings (Sander et al., 2006).



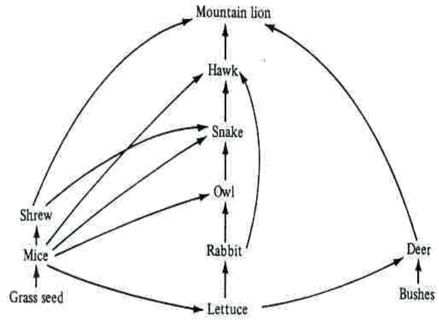


Figure 5.1a. A food chain (Brederveld & Payens, 1966).
waterspitsmuis = Eurasian water shrew; kerkuil = common barn owl; stekelbaarsje = stickle-back; muggelarve = mosquito larva.
Figure 5.1b A food web (Edwards, 1984).

In a food web, it appears to be difficult to find qualitative effects further than one link from the link that has been changed (Barman et al., 1995; Griffiths & Grant, 1985; Hogan, 2000; Webb & Boltt, 1990). A hypothesis stating that predators are the key to keeping the world green, because they keep the numbers of plant-eating herbivores under control (Hairston et al., 1960[2]) appears to be very strange for students. When a link in a food chain is removed, students are more likely to trace effects up through the trophic levels to predators than down to producers (Leach et al, 1996).

The metaphor of the teeter-totter, which is frequent in students' initial ideas, also recurs in biology schoolbooks (see figure 5.2). This metaphor may reinforce the idea of keeping balance through constant oscillations. With this metaphor, the current position of the human species could be characterised as 'being too fat for the teeter-totter' (Kauffman, 2003).

2 This hypothesis was recently supported by investigations on islands with and without predators in Venezuela (Terborgh et al., 2006).

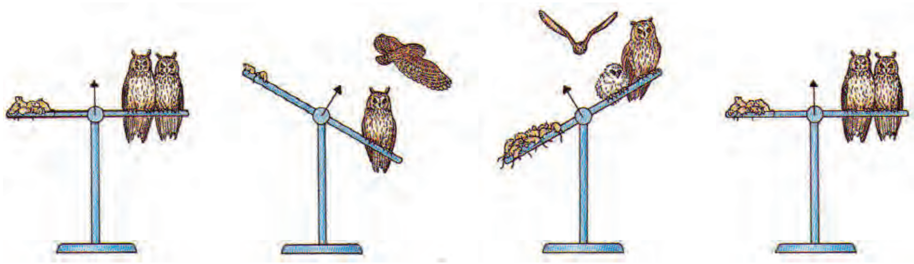


Figure 5.2. The teeter-totter with common voles and long-eared owls (from Smits & Waas, 2000a).

5.4 Dutch students' initial ideas about ecosystems

Interviews with students

To corroborate the literature findings on students' ideas, which were reported in section 5.2, I conducted 18 small-group open interviews with students from 5VWO (pre-university education, 16-17 years) from six different schools who were involved in ecology lessons. In these interviews students were confronted with questions about the changes that could be found when one of the elements of a food web has been taken away by culling and about the systems character of an ecosystem. As a general outcome, student responses to these interviews where in line with what could be expected on the basis of the literature.

In their reasoning about change in a food web, most students tended to neglect indirect effects of the change. For instance, when reasoning about the food web depicted in figure 5.3, many students did not realise how an operation like culling could have impact on elements in a food web which are further than one link from the population that has been culled:

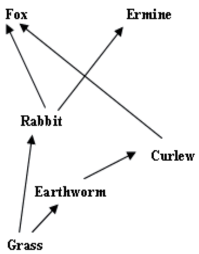


Figure 5.3. A food web used in an interview.

Interviewer: "Here is an illustration of a food web. Suppose that the foxes were culled. What does that mean for the earth worms in the area?"

Josh: "There will be more of them."

I: "Because?"

Josh: "The curlew eats fox, well no, the curlew eats the earth worms and the fox eats the curlew and if there are fewer foxes, there will be more curlews, no, wait, mm …. "

I: "And what will happen then?"

Josh: "Yes, there will not be more but fewer earth worms."

I: "And if the ermines, which are also predators, are increasing, what will that mean for the earth worms?"

Josh: "There will be fewer rabbits. Also fewer grass. The earth worm will have more to eat."

I: "You said, there will be fewer rabbits and fewer grass. Is that correct? Please look carefully."

Josh: "No, it is wrong. There will be more grass."

A specific point of concern appears to be that students are not familiar with the idea of an ecosystem or an organism being a system at all. Many of them are rather surprised by the systems idea being applied to themselves or to an ecosystem. A series of quotes on this point:

I: "In the word ecosystem you find the word system. What comes to your mind?"

Adinda: "I think more about something mechanic, some apparatus or so."

I: "Nina, would you describe yourself as a system?"

Nina: "Certainly not!" (she seems a little bit indignant)

I: "You don't like the idea, or do you think you are not a system?"

Nina: "I don't know."

The original conviction of these girls is that an organism or an ecosystem cannot be considered to be examples of a system. However, gradually they seem to discover the resemblance between their idea of a system and an ecosystem:

I: "And you, Milou?"

Milou: "But I am able to think!"

Adinda: "But that could be so in a certain system. I mean, in principle you have all kinds of electrical processes in your head, which make it possible … thinking processes, so in principle it is a system."

I: "Let's continue on this point. What do you think is characteristic for a system?"

Nina: "A system works automatically."

Milou: "A system is something on its own, without influences from outside."

I: "And does that apply to an ecosystem?"

Adinda: "The ecosystem needs light."

I: "Should a system be without influences?"

Adinda: "No, a machine needs an electricity supply."
I: "With what could you compare this supply in yourself or in an ecosystem?"
Adinda: "We need food."
Milou: "In an ecosystem it would be light and water."
I: "So, after this discussion, would you call an ecosystem a system or not?"
Adinda: "I think it is."
Milou: "In principle yes, it is on its own, but there are influences from outside."
Students tend to hold nuanced opinions about the position of man, who can be part of the ecosystem, or not. Again an example from the same three girls:
I: "Are we humans also part of the ecosystem?"
Nina: "Yes, we are animals and animals do belong in the ecosystem."
Milou: "Mm, we belong to the system, but not completely. We live so to say in a city and not in nature. We eat animals, but on the other hand we breed them ourselves."
Adinda: "We have a place in the ecosystem, but it is different than the other organisms, because we have more control. And by eating and breeding we tangle up the ecosystem."

So, the girls move between man being part of the system and being an outsider at the same time, which can be connected to the idea of Doppelstellung (Kattmann, 1977, see also page 49).

5.5 Teaching about ecosystems in the Netherlands

Based on the literature findings reported in section 5.4, I expected that the ecological views as they are embodied in secondary education diverge from current ideas in science. To verify this, I explored the Dutch ecology curriculum at different levels[3]. The following sub-questions were answered:

1. Which views can be found in the examination syllabus? (formal level)
2. Which views can be found in the national written examination tests? (attained level)
3. Which views can be found in schoolbooks? (written level)
4. Which views of teachers can be found in classroom practice? (executed level)

[3] The arrangement of levels is based on Goodlad (1979), with addition of attained and written curriculum.

5. Which personal views do teachers hold?
6. How do the personal views of research ecologists and those of teachers relate to each other?

An extensive description of the procedure and the results was published elsewhere (Westra et al., 2006). Here I only give a brief description of the results.

Views in the examination syllabus

In the examination syllabus (see Appendix 1) I counted 32 out of 216 (= 15%) ecology-linked attainment targets. The syllabus does not state any explicit ecological views but the terms used suggest that the cybernetic view dominates: maintaining equilibrium and succession are the central concepts whereas complexity, stability and (un)predictability are not mentioned.

Views in the national examination

In line with the syllabus, ecology forms a substantial part of the national written examination tests in the Netherlands: on average 22% of the total marks are used for ecology-related subjects, with values between 18% and 29% in the period 2000-2005.

Looking at ecology-related questions, two things are remarkable. First, it is not always possible to match a question with a view. Second, indications for a view are usually implicit. If there, they point specifically to a cybernetic view. When there are possibilities to test understanding of complex relations and dynamic processes, I find questions about linear effects, using 'flat' calculations. Keeping in mind that examinations have a strong feedback influence on the operational curriculum, teachers will not be stimulated to promote acquiring insights into dynamics and complexity in classroom.

Views in schoolbooks

I analysed three schoolbooks: 'Biologie voor jou' (Smits & Waas, 2000b, used in 39% of the schools), 'Nectar' (Maier & Van Wijk, 1999, used in 37% of the schools), and 'Synaps' (Pihlajamaa- Glimmerveen et al., 2000, used in only 2% of the schools, but investigated because it is an innovative method). The terms from the examination syllabus are well-covered in the schoolbooks. Again, a cybernetic view emerges (see table 5.1). At times, the content covered goes beyond the syllabus, but these extensions do not convey any more modern views. The dynamic or chaotic view are hardly represented, with the notable exception of the most recent edition of 'Nectar'(2004), which has a new paragraph 'Order or chaos' (p. 257-259). (In my systematic analysis I used the previous edition of Nectar.)

Table 5.1 Citations from the schoolbooks suggesting a cybernetic view.

Citation	Schoolbook
'The more or less predictable, relatively stable (end) situation of such a development is called ……'	Nectar, Maier & Van Wijk, 1999, p. 49
'In the climax of an ecosystem there is natural equilibrium: the biomass and the species composition hardly change'.	Nectar, p. 69
'The term ecosystem was introduced by biologists to indicate that such an area functions like a complete whole which makes it possible that over a long period a more or less fixed species composition can maintain itself.'	Synaps, Pihlajaama- Glimmerveen et al., 1999, p.273
'In a climax situation, the cycles of matter are closed and biological equilibrium is the rule. If not disturbed the composition of the ecosystem does not change over a long period of time.'	Synaps, p. 289
"Density-dependent factors are predation, parasitism, diseases and competition for food. These factors influence the density of the population by means of negative feedback. When the density increases, the factors which cause a decrease in density get more influence. And when the density decreases, the factors which stimulate the growth of the population are getting more important. This results in oscillations of the density of the population around equilibrium: the so-called biological equilibrium.'	Biologie voor jou, Smits & Waas, 2000b, p. 66

Teachers' views as revealed in teaching

My observations in ten ecology lessons on six different schools showed a high degree of accordance between formal and written curriculum on the one hand and perceived and operational curriculum on the other. Frequently ecology is taught with the schoolbook as a manual. Often, students worked autonomously. Only cycles and pyramids of biomass got extra attention from the teacher. Nearly no references to a dynamic view were made. In the interviews with the teachers I traced the strong trinity of syllabus, schoolbook and examination. This is the teacher's guide in lesson preparation. They do not use handbooks on ecology; they do not experience the theme as difficult, which is striking when we think of the findings in section 5.3, where ecology appeared to be a difficult subject in education.

Personal views of teachers and ecologists compared

In order to compare the ecological views of teachers with those of researchers, I used a multiple choice questionnaire (see Appendix 2), in which the questions reflected conceptualisations of ecosystems, corresponding with the four views on the concept 'ecosystem'. The questionnaire was administered to 63 teachers and to 63 researchers at the Netherlands Institute for Ecology (NIOO). At the time of the abovementioned publication (Westra et al., 2006) the results of 28 teachers and 28 ecologists were available. Here I will report on the full sample.

The responses were analyzed by means of the HOMALS-technique. This technique can be used to identify similarities in answering patterns across individuals. Based on the individual 'answer profiles', a similarity metric can be computed for each pair of respondents. Based on these similarities, all respondents can be represented in a diagram, such that respondents with the most similar answers are closest together, and respondents with the most different patterns are farthest apart. Depending on the structure in data, the optimal diagram may be one-dimensional (all respondents ordered on a line), two-dimensional (a plane), or higher dimensional (space, or hyperspace), although higher dimensional plots will be hard to visualise. In practice, a two dimensional diagram often proves a suitable format (Greenacre, 1993). In all cases, an average respondent, whose answers represent the average pattern across all respondents, would end up in the origin. Finally, it should be noted that the dimensions in a HOMALS plot do not have a predefined meaning: they are just an outcome of the optimal scaling process, which is to represent in the diagram as much as possible of the variance across respondents. The outcomes of the analysis are presented in figure 5.4. However, there will be a corresponding diagram with

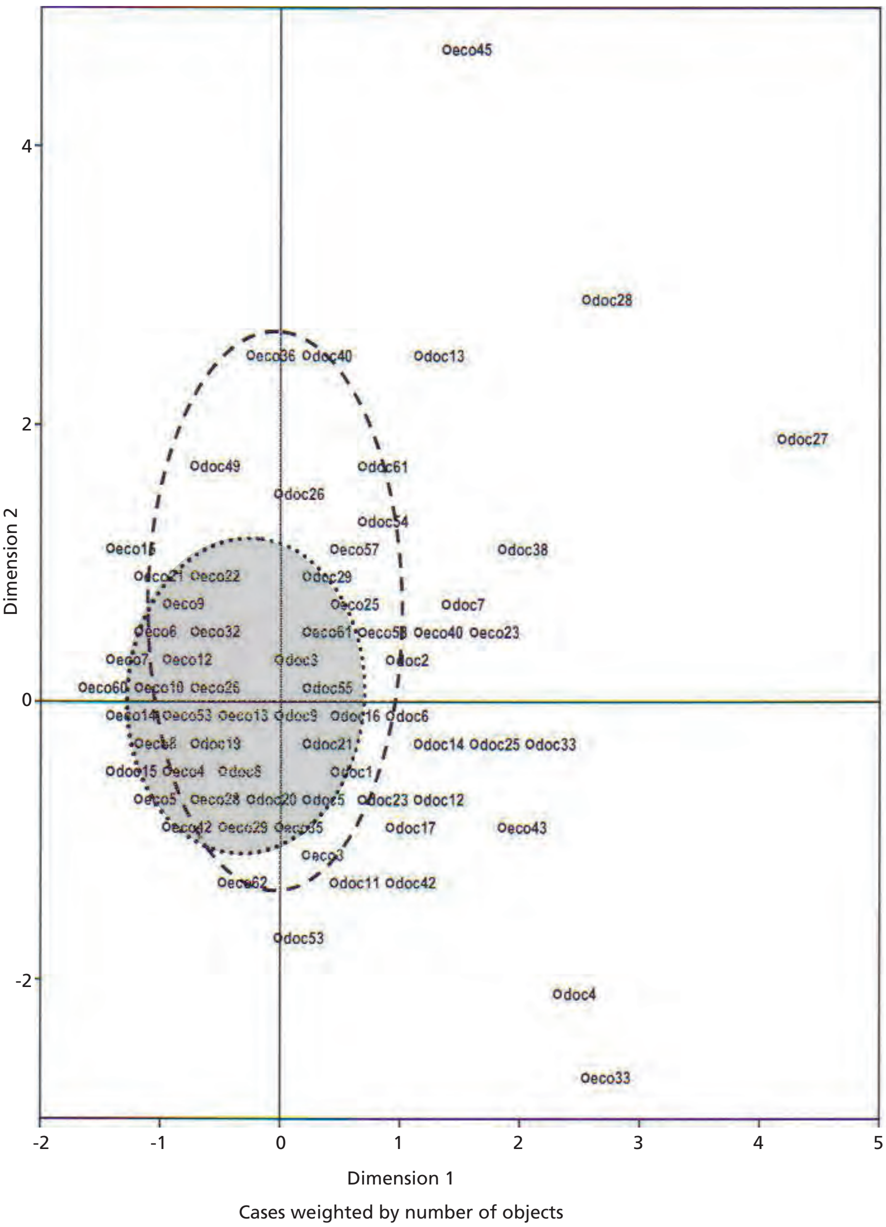


Figure 5.4. Homals-analysis of 63 teachers (doc) and 63 ecologists (eco). The areas in which we find 90% of the teachers (white) and of the ecologists (grey), are marked by a dotted line. Individual differences are indicated by plots. The greater the difference with the mean value is, the further the plot is from the 0-point. Plots which are near each other indicate a high level of agreement on questions.

items from the questionnaire, and this plot can be used to give meaning to the dimensions: if an item takes an extreme position along one dimension, the response to this item will have a strong influence on one's position along this dimension. This corresponding diagram is presented in figure 5.5.

In addition to the individual points, the areas which contain 90% of the teachers and 90% of the ecologists have been marked off with ellipses. Although there is considerable overlap between the two, on average, the teachers are somewhat more to the top right quadrant, whereas the ecologists tend to be more towards the bottom left quadrant. The variation among teachers is larger than that among ecologists. Therefore, I conclude that the ecologists form a more homogenous group than the teachers, concerning their view on ecosystem

From the figures 5.4 and 5.5 it can be concluded that most 'distant postions' are to be found in the group of teachers, in most cases because of anwers from the type 'I doubt, I do not know', such as 6_3, 7_3, 9_4 or 10_4.

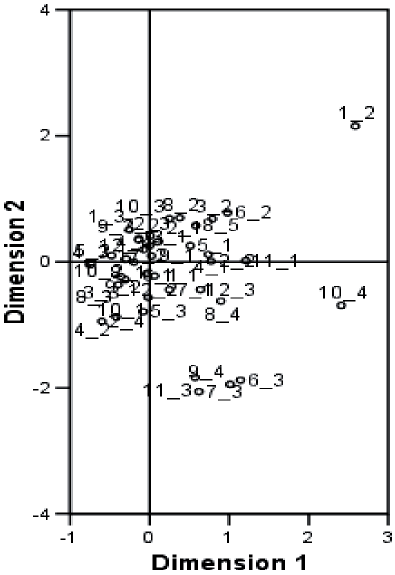


Figure 5.5. Homals-analysis of the answer patterns of 12 questions of 63 teachers and 63 ecologists. For example 10_4 means question nr. 10 with the chosen answer alternative 4.

For each question the percentage of accordance between the answers of the group of teachers and the group of ecologists was determined (see table 5.2). Because the biology education is not the same for every biologist who becomes a teacher, there will be differences in ecological background within the group of teachers. As only 14 out of 63 teachers had ecology as their main subject, their group was not subdivided into teachers with and without a substantial ecological background. The percentage of accordance in answers of both groups was also compared with the answers which would have been given by a person with a consistent dynamic view. In this way I investigated to what extents the view of the teachers and the view of the ecologists agree with parts of this modern view (see table 5.3). A χ^2-test was used to calculate whether the differences in frequency were statistically significant (p=.05).

Table 5.2. Frequencies of the answers of teachers (doc, N=63) and ecologists (eco, N=63).

Alternative	nr 1		nr 2		nr_3		nr_4		nr 5		χ^2 * = significant
question nr.	doc	eco	doc	eco	doc	eco	doc	eco	doc	eco	
1	45	47	1	1	16	14	--	--	--	--	0.37
2	7	15	11	4	29	28	14	15	--	--	16.63*
3	17	16	12	12	32	35	--	--	--	--	0.32
4	37	12	4	1	17	33	4	14			75.98 *
5	36	27	17	24	10	11	--	--	--	--	5.13
6	52	51	8	6	3	4	--	--	--	--	0.94
7	25	8	32	50	6	3	--	--	--	--	45.61*
8	41	32	4	6	9	2	13	9	5	3	30.81*
9	12	9	20	16	26	33	4	3	--	--	3.81
10	29	11	14	36	17	14	3	1	--	--	47.53 *
11	24	9	37	49	2	4	--	--	--	--	28.94 *
12	33	34	22	17	7	11	--	--	--	--	2.95

Table 5.3. Percentage of accordance between answers of teachers and ecologists with answers in line with a consistent dynamic view (N=63).

Question nr.	Percentage of accordance with teachers	Percentage of accordance with ecologists	χ^2 * = significant
1	73	76	0.08
2	23	24	0.07
3	53	56	0.26
4	27	55	7.31*
5	27	39	3.38
6	83	84	0.02
7	40	13	36.13*
8	21	15	1.78
9	32	26	1.00
10	22	58	13.44*
11	59	79	2.94
12	53	55	0.03

On some aspects, significant differences between both groups were found, e.g. about the nature of ecology as a science (question 10), the development of ecosystems (questions 7, 8 and 11) and the nature and maintenance of equilibrium and stability (questions 2 and 4). There is more agreement about the position of man (questions 1 and 9), the extinction of species (question 6) and scale effects (question 12).

I find a significantly lower percentage of accordance with a dynamic view in teachers' answers than in ecologists' answers, where question 4 (on stability) and 10 (on the nature of ecology as a science) are concerned. In question 7 (on predictability of developments in an ecosystem) I find that ecologists have a significant lower percentage of accordance than teachers. The ecologists assume in a vast majority of 82% that predictions are possible, but will not always be fulfilled (7_2): a standpoint that is also good to defend within a dynamic view.

It can be concluded that the views of teachers are not only clearly different from those of the ecologists, but also that the latter have a more consistent pattern in their answers showing a dynamic view, which was proven with another technique (Westra et al., 2006). There are also strong inter-individual differences between teachers, and it seems difficult to link their answer patterns with a specific view.

In a supplementary investigation I handed a questionnaire to 65 teachers and 65 ecologists. They were asked to indicate from a list of 26 concepts or topics in ecology (see table 5.4) the ten concepts or topics they would choose as ecology content of the curriculum, supposed they were asked to advise in a curriculum reform. The percentage scores of teachers and ecologists on the concepts and topics can also be found in table 5.4.

Table 5.4. A list of 26 concepts or topics, from which the teachers and ecologists selected curriculum content.

Number	Concept or topic	Percentage of teachers	Percentage of ecologists
1	*Natural equilibrium* in an ecosystem	63	38
2	*Stability* in an ecosystem	18	38
3	*Diversity* of species in an ecosystem	65	65
4	*Complexity* of the relations in an ecosystem	46	49
5	*Dynamics* of populations (fluctuations of density in time and or space)	62	51
6	*Heterogeneity* inside populations (genetic variation in survival chance inside populations)	34	46
7	*Carrying capacity* of a population	38	25
8	*Niches*	40	46
9	*Scale effects* (large versus small areas)	15	8
10	*Food web*	68	71
11	*Trophic levels*	34	40
12	*Cycle of matter long term* (with geological and biological components)	42	57
13	*Cycle of matter short term* (with only biological components)	32	28
14	*Energy flow*	65	72
15	*Relations:* competition, mutualism, commensalism and parasitism	58	65
16	The idea that an ecosystem is a *system* which is composed of *components* and with characteristics which cannot be directly derived from the characteristics of the components which form the ecosystem, like populations or abiotic factors like light or water.	38	76

Number	Concept or topic	Percentage of teachers	Percentage of ecologists
17	The idea that an ecosystem can be open or (nearly) *closed* with more or less clear *boundaries*	20	11
18	The *development* of ecosystems in relatively *short term* (succession)	58	54
19	The *development* of ecosystems in relatively long term (evolution)	42	68
20	Insights from the *dynamic* and the *chaotic* view and their implications on development in ecosystems	5	8
21	The relation between *population dynamics* and *population genetics*	22	25
22	The *position of man*: (non-)participant in the ecosystem	31	54
23	The possibility to *'make'* (create) an ecosystem	17	11
24	*The predictive value* of ecological knowledge in hunting, fishery, nature management and –conservation	31	36
25	The use of (*computer*) *models* of ecosystems	18	18
26	The development of a *competence* for students to use ecological knowledge to take a *standpoint* in urbanistic developments, nature conservation, decisions on fishery, preventive and curative measures in environmental problems	46	54

Clearly, some concepts are very popular in both groups, such as the concepts 10 (food web) and 3 (diversity). However, there are also remarkable differences in valuing the relevance of concepts in both groups. For instance the concepts 1 (natural equilibrium) and 14 (energy flow) are clearly more chosen by teachers, while the concepts 2 (stability) and 19 (*development* of ecosystems in relatively *long term* / evolution) are clearly more chosen by ecologists. From the top five of both groups, only two are present in both lists. For me as a propagator of dynamics and modelling in ecology, it is somewhat disappointing that the topics 20 (insights from the *dynamic* view and the *chaos* theory and their implications on development in ecosystems) and 25 (use of *computer models* of ecosystems) have a low ranking in both groups. Compared with earlier British investigations (Cherrett, 1989; Hale, 1991; Hughes, 1998) I observe a shift in the choice of concepts and topics, although comparison is difficult, because I did not use the same 50 which were used in these investigations. However, I may conclude that food webs (on the 11th place on Cherret's list of the 50 most important concepts according to ecologists) and biodiversity (on the 14th place) seem to become more important, while energy flow (on the 3rd place) and niche (on the 6th place) for ecologists are decreasing in importance.

5.6 The feasibility of systems thinking as an educational activity

In section 4.3 it has been suggested that systems thinking could play a supportive role to gain insight into modern conceptions of the ecosystem. There have been previous studies to implement systems thinking as a supportive activity in secondary education, and in this section I will review the findings on whether this could be a feasible approach to promote the desired insights.

To understand complexity in ecosystems, it seems important for students to develop a competence to relate different levels of organization. This systems thinking competence enables to deal with complex multi-causal ecosystem problems (Boersma, 1997; Boersma & Schouw, 1988). In systems thinking, an ecosystem is considered to be an open and complex adaptive whole, in which the parts (populations or functional groups of populations, and all kinds of abiotic factors) influence themselves and each other in nonlinear ways, over time giving rise to complex dynamic patterns. This kind of thinking may be helpful for students in directing their attention at particular features of the ecosystem like the distinction of open and closed systems, hierarchical levels, feedback and temporal delay which cause dynamic patterns (Booth Sweeney, 2000). Biological education may stimulate this kind of thinking and consequently help students in making substantiated decisions concerning ecology-related issues (Van Hasselt et al., 1993).

In two earlier studies on systems thinking in biology education, the sequence of levels of biological organization to be addressed, was an essential component in the didactical structure of genetics (Knippels, 2001) and of cell biology (Verhoeff, 2003) respectively. The latter explained the idea that biological entities can be considered as a sequence of nested open systems. Students were invited to interrelate between the different levels of organization. They learned to consider each level of organization both as a discrete whole and as an assembly of interacting parts, which contributed to greater coherence in their understanding. Knippels found that a well-considered sequence of levels of biological organization was helpful in reducing the 'complexity and abstraction' problem in genetics education. This sequence implied: starting from the organism level, descending to the cellular level, and ascending again to the organism level. Since this didactical structure could be compared with a yo-yo, it was called the yo-yo LT-strategy. She suggested that this yo-yoing between levels of biological organization could be extrapolated to higher levels such as the population and the ecosystem. The power of conceptual systems thinking is that it makes it possible to talk about biological objects and processes in general terms, giving rise to meta-models: models that could be of use in all kinds of biological systems. What should be developed is the possibility for students to go to and fro between such meta-models and concrete biological objects and processes (Boersma, 1997; Schaefer, 1989). However, systems thinking as well as (computer) modelling are demanding activities for most students, and it is not self-evident that these can be successfully taught in upper secondary education. Yet, regarding each level of organization both as a conceptual unit which can have properties of its own, as well as an assembly of units interacting at a lower level, could lead to more coherence in their understanding (Verhoeff, 2003).

In studying an ecosystem it is important to envision how genes, organisms, populations, and the abiotic environment interrelate. Such a system is comprised of multiple levels of organization that often depend on mutual interactions. The relations between the levels are not intuitively obvious. Order is contrary to intuition, not reached by centralized control imposed from inside or outside the system, but is a dynamic and emergent characteristic of the self-organizing system. Epistemologically this is far from the familiar Newtonian metaphor of a clockwork-like nature (Jacobson, 2000). The complex and dynamic behaviour proves hard to understand for secondary school students studying ecology (Barman et al., 1995; Grotzer & Bell-Basca, 2003; Magntorn & Helldén, 2003; Munson, 1994). Students and experts appear to have different epistemologies. Students tend to concentrate on structures, i.e. description of the elements of the system. Experts focus on the behaviour, i.e. interactions and mechanisms and functions (or the 'purposes') of the elements of the system (Hmelo-Silver & Green Pfeffer, 2004). Current teaching is not very helpful to students, because it does not pay attention to systems thinking (Boersma, 1997).

The use of systems thinking to grasp complexity is growing, although not everybody is convinced of its efficacy in solving learning problems with these complex systems (Booth Sweeney, 2000). Applying systems thinking to concrete biological instances appears to be a complicated task for students (Verhoeff, 2003). For the development of systems thinking in classroom a sequence of several types of cognitive representations has been recommended (Ossimitz, 2000):

1. a verbal description of the elements which are discovered;
2. graphic illustrations, like feedback loop diagrams (see figure 5.6);
3. stock-and-flow-diagrams;
4. a number of mathematical equations.

These representations correspond with the sequence of activities in modelling ecosystems (see section 4.3).

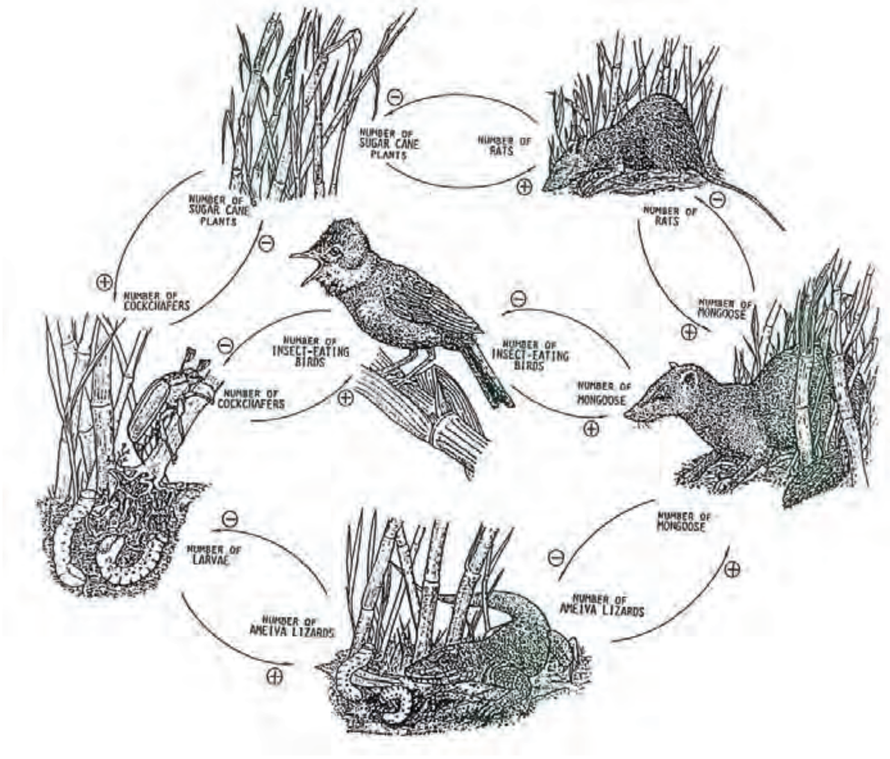


Figure 5.6. A graphic of an ecosystem with feedback loops; the depicted organisms symbolize populations (from Schaefer, 1989, p.52).

Several lists with categories of system thinking skills have been suggested. Ossimitz (2000) distinguishes four 'main dimensions':

1. thinking in (explicit) models: building models and distinguishing between reality and models;
2. thinking in feedback loops and interrelated structures: going beyond one way-cause-effect relations;
3. dynamic thinking: recognizing patterns over time (oscillations and delays), not just events;
4. practical steering of systems: making the right action at the right time in the right place.

Ben-Zvi Assaraf & Orion (2005) use a list of eight categories from Booth Sweeney (2000) and put these into a rank order. They rank the eight categories of systems thinking abilities into an increasing degree of complexity from 1 till 4, suggesting that students who are able to perform abilities of degree 3 can definitely perform skills of degree 1 and 2, but maybe not of degree 4 (see table 5.5). Their list seems helpful in implementing and observing systems thinking into classroom.

Table 5.5. An order of rank with categories of systems thinking abilities.
The abilities with a, b or c belong to the same category.

Ability to	
1	identify the components of a system and processes within the system
2[a]	identify relationships among the systems' components
2[b]	identify dynamic relationships within the system
3[a]	organize the systems' components and processes within a framework of relationships
3[b]	make generalizations
3[c]	understand the cyclic nature of systems
4[a]	understand the hidden dimensions of the system
4[b]	think temporally: retrospection and prediction

5.7 Students' experiences with computer modelling

In section 4.3 it has been suggested that computer modelling could play a supportive role to gain insight into modern conceptions of the ecosystem. In this section I will review the indications from educational research on whether this approach could be feasible.

Use of computer models in school

Modelling has been identified as a promising activity for teaching and learning science (Gilbert & Boulter 1998). For complex systems like the ecosystem we need to take the long road from concrete biological objects via models like two dimensional representations to mathematical formulas needed in computer tools. In an emergent modelling process (Gravemeijer, 1999; Gravemeijer & Stephan, 2002; Andresen, 2006) which is based on realistic mathematics education, students start with subject matter taken from reality. The models that students build are grounded in the way that contextual problems are solved by them. The modelling activities they perform are activities in which they organize their knowledge. Models emerge from these organizing activities. Subsequent acting with these models will help students to develop formal mathematics by way of mathematizing their own informal mathematical activities. In my investigation, mathematical modelling resonates with a dynamical systems view on the concept ecosystem. This view and the building of compartment models, prerequisites the use of computers.

Computer models in connection with ecosystems have been used in upper secondary school for a long time. They can be very helpful in grasping ecosystems' behaviour, where field experiments are complex, long term and difficult to sustain and interpret (Lutterschmidt & Schaefer, 1997). Not only static but also dynamic systems are within reach of students. Already in 1989 and 1991 computer models were used in the Netherlands, with for example a virtual pond (Hartsuiker et al., 1989) or predator-prey relations (Bennema, 1991; Morélis, 1991). A problem was that these models were text-based, i.e. they were written in formal computer language or in mathematical difference equations. To avoid problems for the students, the text was kept in the background, and the screen lay out was graphical. This reduced the role of the students to exploring activities: changing the values of some components and evaluating the effects. Insights into the relation between the components by constructing models themselves or by extending models could not be developed. The result was that the way the models worked was not transparent for the students. On the other hand, the popular LOGO[4]-object-based tools did enhance programming skills with even very young children, but these tools were not intended to clarify the relations between

4 Logo is a simple computer modelling tool that was developed in the 1960s by Seymour Papert. This tool is very adequate for children. In LOGO there are "turtles" that can work with interesting graphics on the computer.

components, which is very important in understanding ecosystems. Therefore the capacity to use mathematics by biology teachers and students had to improve, or another type of modelling had to be found. The latter possibility won.

Modern graphic modelling tools

With the availability of modern object-based[5] and variable-based[6] graphic and dynamic modelling tools, learning and teaching has changed. In many countries like the United States (Shaffer & Wallace, 2000; Hogan & Thomas, 2001, all working with Stella), Greece (Ergazaki et al., 2007, working with ModelsCreator), Cyprus (Angeli & Valanides, 2004, working with Model-It), and Austria (Ossimitz, 2000, working with Modus and Powersim) there have been experiments, even with very young children. Several researchers have asserted that the use of dynamic modelling tools belongs to the most intellectually demanding technologies that 'enhance the cognitive powers of human beings during thinking, problem solving, and learning' (Jonassen & Reeves, p.693). If students are really able to understand these models as abstracted representations of natural phenomena, they have an epistemological understanding of the nature of models and their purpose as an explanatory framework of the phenomena under inquiry (Gobert & Pallant, 2004). For ecology, it enables to analyze reciprocal in stead of unilateral relationships multiple in stead of single routes of causality (Pickett el al. 1994).

Graphic tools appear to be more adequate than text-based tools: students perform better in building new models as well as in exploring existing models with a graphic tool (Löhner, 2005). However students still have difficulties with computer modelling. Apart from difficulties in extending existing models, students do not fully distinguish the ideas and or purposes of the underlying models, the content of the models, and the experimental data which support or refute the validity or usefulness (Grosslight et al.; Westra et al., 2002). They also expect a model to represent the full richness of the real world (Hogan & Thomas, 2001). Besides they have severe difficulties in building models themselves, even after the use of tutorials and the demonstration of a complete model. These difficulties are not directly related with mathematical skills (Fisher, 1998). In the three major modelling activities 'analysis' (analysing the target phenomenon to its parts), 'synthesis' (synthesizing the structural elements

5 The model entities are objects from which the behaviour can be specified by rules.

6 The model entities are variables from which the behaviour is specified by their mutual relations.

into meaningful model units through semi-quantitative relationships) and 'testing-interpreting' (operations of requesting or performing tests of model behaviour), the synthesis activities appear to be the most difficult (Ergazaki et al., 2007). Besides it has not been proven that computer modelling supports the development of students' general capabilities to structure other complex systems (Schecker, 2005).

Experiences in classroom with the computer modelling tool Powersim

In 2001 the Centre for Science and Mathematics Education (now Freudenthal Institute for Science and Mathematics Education) in Utrecht started a project called 'Dynamic Modelling'. In this project several series of lessons were developed for upper secondary school students (5 VWO, pre university level, 16 -17 years old). These lessons were developed for biology, chemistry and physics, and tested in classroom situations (Westra et al., 2002). Powersim Constructor Lite was chosen as a variable-based modelling tool. In this tool, students do not start their modelling activities using a programming language with all kinds of formulas. Instead, they first sketch a model. This results in a screen showing an overview of the relevant factors and the relationships between those factors. The resulting model is suitable for exchange and discussion. After agreement about the construction of the structure of the model, the values and formulas are inserted. The required mathematics is less prominent than in text-based models, where a list of formulas has to be produced. In some cases it is also possible to draw a graph in stead of applying a difficult formula to specify the relation between two linked factors. If, for example, a process is promoted by enzymes, every student knows the kind of relation between the activity of such an enzyme and temperature. However, the mathematical formula describing this relation is quite complicated. It appears to be simple to draw the graph and implement this graph into the model. With this graphic tool, students are able to construct, evaluate, and adjust their model. Powersim was chosen, because handling and lay-out of the screen are simple and orderly: the model and accompanying result can be overviewed in one glance. It was also considered important that this tool could be used as freeware in classroom situations.

Classroom experience was encouraging. Students appeared to be challenged by the material about the water-, salt-, and temperature balance in the human body in extreme situations like running a marathon (42,195 km). They could sketch and build models rather quickly, immediately trying to find out if their expectations would be fulfilled by running the model. The modelling activities and the model arrived at, were used to stimulate thinking about biological phenomena like feedback loops and other types of relationships between factors and discussions about the nature of these relationships. However, in working with Powersim models, students had difficulties in finding exact formulas for described relationships. Feedback loops, so important in biological systems, also offered problems. They also had problems to find out what factors had to be linked. The teachers however had positive feelings about these lessons. *'I liked it. I was not yet familiar with such a modelling tool. However, the threshold was not as high as I thought it would be. I did use Powersim later on in my lessons with pleasure. In modelling you use an aimed, step-by-step way of thinking. My students picked up this way of thinking.'* (Westra et. al., 2002, p.335)

Compex: use of computers in the national examination in the Netherlands
In the same period the Dutch government stimulated the so-called Compex project. In 2002 in HAVO (general secondary education, highest level) and 2003 in VWO (pre-university education), an experiment with the national written biology examination started, in which about one third of the questions were offered in a format that required the use of computers by the students to find answers to the problems posed. This Compex project is still on voluntarily base, but probably it will be compulsory for all students in 2009. One of the skills students have to show is modelling. They are offered a cluster with 3 or 4 questions relating to a computer model about ecosystems, population genetics, or human physiology, also in Powersim, and have to explore the model (in HAVO and VWO) or to build extensions (only in VWO). As can be seen in table 5.6, students have more difficulties with building extensions than with the exploring activities. In Appendix 3 the cluster of questions from 2004 is shown as an example. In this case the students were offered a model about water economics in the human body. They had to explore this model and to build an extension.

Table 5.6. Results of modelling questions from the national biology examination VWO from 2003-2006. The p-value (varying from 0-1) gives an idea of the difficulty of a question. A value of p = 1 means that all students have given the right answer, where p = 0 means that no student has given the right answer. The questions marked with [a] touch upon exploring the models, the questions marked with [b] touch upon building of extensions in models.

2003 (N = 33)	ATP concentration in an athlete during exercise (sprint and marathon)	0.57	1[a]	2[a]	3[a]	4[b]
			.50	.61	.39	.38
2004 (N = 165)	Water economics of the human body during long distance walking	0.64	1[a]	2[a]	3[b]	
			.75	.61	.35	
2005 (N = 215)	Population dynamics of cod (*Gadus morhua L.*) and capelin (*Mallotus villosus Müller*)	0.53	1[a]	2[a]	3[b]	4[a]
			.53	.54	.35	.49
2006 (N = 707)	Population genetics concerning sickle cell anaemia and malaria	0.57	1[a]	2[a]	3[b]	
			.93	.95	.30	

6. From learning objectives towards the educational design

6.1 Introduction

The previous chapters provide the building blocks for the design of a learning and teaching (LT) strategy. Chapter 2 described my view on teaching and learning; chapter 4 described current scientific practice, to provide a global indication of the desirable learning outcomes; and finally, chapter 5 described the current status of teaching and learning about ecosystems in secondary education.

Based on these building blocks, which are the results of the explorative phase of my developmental research (see chapter 3), this chapter presents my first design of a LT-strategy. In section 6.2 I will elaborate on learning objectives and design criteria. In section 6.3 I will identify suitable social practices for students to learn about ecosystems. In section 6.4 I will describe the first draft of my LT-strategy. In section 6.5 I will present a detailed educational scenario to implement this strategy, i.e., a series of justified learning and teaching activities, including expectations about the resulting learning processes and outcomes, which guide the classroom research.

6.2 Learning objectives and design criteria

Learning objectives

A learning objective is defined as a desired learning outcome that has the character of an intentionally acquired mental program that has been added to or inserted into the repertoire which the student already has (De Groot, 1978). In this study, my main aim will be to achieve a basic level of ecological literacy. In order to attain this aim, the students must have a basic insight into modern conceptualizations of the ecosystem. Therefore, my objectives will be that students are able to:

1. identify relations between organisms, populations and between the community and the non-living (abiotic) environment and to represent them in a scheme (B1.1 and B1.4)[1]

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1 Codes between brackets refer to the current Dutch syllabus for the national written biology examination at pre-the university level, see Appendix 1.

2. exemplify the relation between complexity, dynamics, stability and diversity in an ecosystem.
3. apply their knowledge and understanding of the concept ecosystem and subordinate concepts to various concrete examples of an ecosystem.

As I have argued, students' ecological understanding may benefit if they can use systems thinking and modelling activities. My objectives with regard to systems thinking will be that students are able to:

4. recognize an ecosystem as a (special example of) an open system, which means that not only the parts but also the relations between the parts are relevant and that the systems boundaries are not always clear-cut.
5. recognize the different levels of organization in an ecosystem: ecosystem ➔ community ➔ population ➔ organism and to yo-yo between these levels (B1.7).

With respect to modelling, I aim that students can:

6. represent the relations in an ecosystem in a model and quantify the relations with the help of provided data.
7. use models in predicting the effects of possible changes like climate change, extinction of populations, or human intervention.

Finally, ecological literacy refers to societal debate and decision making.
Participation in such activities requires that students can:

8 take an argued position in a discussion about intervention in an ecosystem, based on weighing pro's and cons.
9. exemplify man's position in ecosystems: influencing and being influenced.
10. underpin the measures taken for the conservation of ecosystems, with ecological, economical and normative arguments.

In Table 6.1 the behavioural verbs and content terms of these learning objectives are presented. In comparison with the learning objectives about ecology in the recent Dutch syllabus for the national written examination, I cover only a small part of the learning objectives. There is no attention in this series for tolerance zones, niche and habitat from domain B, energy and matter from domain D, succession from E1 and diversity and gene change in E2. The reason for this restraint is that I focus on students' ability to grasp dynamics and complexity of the ecosystem.

Table 6.1. Learning objectives: behavioural and content terms

Number	Behavioural verb	Content term
1	Abstracting (schematising)	Concept Ecosystem
2	Explaining	Concept Ecosystem
3	Applying	Concept Ecosystem
4	Nominating	Systems Thinking
5	Nominating	Systems Thinking
6	Applying	Modelling
7	Predicting	Modelling
8	Informed decision making	Concept Ecosystem
9	Explaining	Concept Ecosystem
10	Informed decision making	Concept Ecosystem

Design criteria

When these learning objectives are combined with the findings in the explorative phase, this leads to a number of design criteria.

My educational view, presented in chapter 2, required that ecological concepts would be contextualised in authentic practices. An adequate practice should meet the following criteria:

1. The practice should not only be realistic, but also not too complicated for the students to grasp the concept of the ecosystem and the sub-ordinate concepts of complexity and dynamics. As students are no practitioners and do not have the knowledge of practitioners, the practices should be adapted in the sequence of performed activities as well as in their complexity, to make it useful in classroom.
2. The practice should be clear and relevant (personal and/or societal) for the students, in terms of familiarity with the activity of the participants in the practice.
3. The practice should rely on the use of 'ecosystem' as a recognizable and functional key concept, interpreted as an open system with interrelated factors. Besides, population, organism, dynamics and complexity have to be recognizable sub-ordinate concepts.
4. In the practice there should be an important role for systems thinking activities. It should be necessary to explore the relationships of, and to yo-yo between, the

various levels of organization, in order to grasp the hierarchical structure of the ecosystem.

5. In the practice modelling activities should have a necessary role to gain a quantitative insight into the dynamics of the system over time and space. The modelling process should start with sketches, going up via simple computer models into more sophisticated ones.

I had intended to use not just a single practice, but a series of three practices to promote re-contextualisation of the acquired concepts. This requires that:

6. There should be a sequence of three practices of increasing complexity. This sequence should be plausible for the students.

I had also intended to adopt elements of a problem posing approach. This requires that:

7. The basic problem to be solved in the practice should elicit student's ideas. It should evoke a 'global 'motive for students to become involved and it should continuously evoke 'local' motives to keep the learning process going, leading to solutions of the problems they are confronted with.
8. To support the autonomy of the learners, the learning and teaching strategy should be transparent for students: this implies that at any point it should be clear to the students what learning activities they have to do, when and why.

6.3 Selecting appropriate authentic practices

I have chosen to use concept-context combinations as they function in authentic practices (see chapter 2).

For the current purposes, an adequate practice would reveal the complexity and dynamics of an ecosystem. Design criterion 5 implies activities where quantitative developments in an ecosystem or parts of the ecosystem in the course of time are followed. In these activities I focus on the development of the 'state' of the system, in which selected components (e.g. populations, or organisms, or parts of those) are being influenced by various factors, which also mutually influence each other and which may also depend on factors from outside the system, in a nonlinear way (Holland, 2000).

Re-contextualization of the initial conception of the concept 'ecosystem' and sub-ordinate concepts presupposes the introduction of several practices. I will use three of them, with increasing complexity and dynamics (see design criterion 6). The purpose of the introduction of these three practices differs. While the first is used to acquire an initial conception, the second aims at extending the initial conception, and the third is used for testing the student's abilities to use this extended conception in an unfamiliar context.

In order to get the students involved, I stipulated as a condition that the practice should be relevant and familiar (see design criterion 2). In a densely populated country like the Netherlands, there are many examples of human activities interfering with ecosystems, which could be suitable for promoting ecological literacy. However, in many cases human control is so dominant that the dynamic behaviour of the system becomes rather predictable even without a model. To the students, such systems would not evoke the required need to build models (see design criteria 1, 5 and 6). Nevertheless, I found some suitable practices.

First practice. A group of ecologists working on optimization of mussel culture
As a first practice, I found (applied) ecological research by the Netherlands Institute of Ecology (NIOO) on mussel cultures *(Mytilus edulus* L.) in the estuarine ecosystem of the Easter Scheldt (see figure 6.1 and 6.2). This research is promising because of its economic aspects, the human impact and its manageable complexity from a student's perspective. In comparison to a 'natural' ecosystem, the complexity of this system is reduced by the mussels being 'sown' as young animals on selected locations, in controlled quantities, and by the mussels being harvested when they are fully grown, which brings ecological factors such as birth rate, density, and death rate under control. Mussel breeders try to achieve an optimal production and a sustainable mussel culture. They have asked scientists from NIOO how to optimize yield (dry-weight in grams) of mussels from this dynamic ecosystem. Mussels grow under the influence of biotic factors like food (plankton), competition and predation, and abiotic factors like water temperature, the tide and velocity of the water current. For mussel breeders it is not only important to know how an individual mussel grows, but also how it grows in a densely populated mussel bank. When there is not enough food, every mussel suffers and does not gain the minimum dry weight which is demanded at the auction. As a consequence, the entire production may remain unsold. So, what could be an optimal density of mussels, taking into account varying environmental factors?

In the EU-funded MABENE-project (Herman, 2004), NIOO-researchers conduct research to support the mussel breeders. Their work can be divided into three types of activities. They are collecting data in the Easter Scheldt and in their laboratories, such as measuring physiological parameters (e.g. the filter rate of the mussels) and abiotic parameters (e.g. the velocity of the water current). They design and produce special equipment that is needed for their measuring activities. They use computer modelling, because it is too time-consuming and too expensive to test the complete dynamics of the population in real practice. All these activities focus on finding out the optimum density of mussels to enable a good harvest in a continuously changing environment.

The NIOO research practice satisfies all the design criteria in section 6.2 to serve as the introductory authentic practice in our LT-strategy. I expect that the practice is familiar and transparent enough to evoke a 'global 'motive for students to become involved, because of its economical interest and human impact (see design criteria 2, 7 and 8). It also allows the development of an initial conception of the concept 'ecosystem', with reduced complexity, since it focuses on a specific population, a mussel population, and concentrates on the most important biotic and abiotic factors influencing the growth of the members of this population, the individual organisms (see design criteria 1, 3, 4 and 6). It will also make it possible to introduce modelling in the classroom gradually, starting with sketches, followed by relatively simple computer models (see design criterion 5).

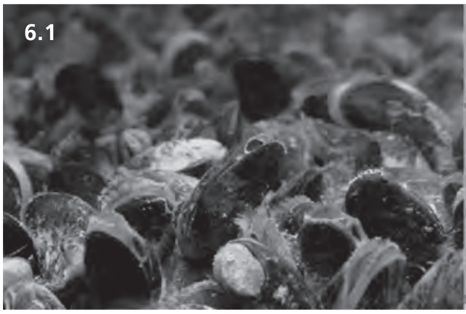


Figure 6.1. Mussel culture.
Figure 6.2. The Easter Scheldt area (in the south- western part of the Netherlands)

Second practice. Managing rabbits in the dunes
Nature management in the dunes of North-Holland provides a second, more complex, practice. The North-Holland Water Works Company (Provinciaal Waterleidingbedrijf

Noordholland, PWN) runs a water resource-area in the dunes. Some ecologists employed at PWN serve as nature managers to maintain this area. Among their concerns is a population of rabbits (*Oryctolagus cuniculus* L.) which did not recover after an epidemic of VHS (Viral Haemorrhagic Syndrome).

When the rabbit densities were low as a result of the epidemic, vegetation changed. From a profusion of juicy grasses and herbs there was a development towards more tough plants like dune reed, sand sedge and herbs. As a consequence, the recovering rabbit population was confronted with a different scene, which hindered its revival because this vegetation cannot be eaten by them (Bakker, 2003). The central problem for the nature managers is: how could we favour the increase of the density of the rabbit population in the reserve? One of the suggestions they would like to test is using a specific race of cattle to influence the vegetation in the rabbit area. Also in this practice, computer modelling is needed. After all, the ecosystem that is involved in this practice is more complex than the former one, since the population density of rabbits is far more variable than the mussel population density, caused by natural reproduction and death, which did not play a role in the mussel culture. In the suggested recovery measures, including the introduction of a population of Scottish Highlander cattle, there could be influences on more factors than just stimulating the desired restoration of a 'rabbit friendly' vegetation.

Also this practice meets the proposed criteria. The practice differs from the mussel practice in that the related ecosystem is more complex (see design criterion 6).

Third practice. A dilemma in nature conservation. What to do about the overcrowding of African elephants?

Finally, as a third practice to assess students' understanding of ecosystem behaviour, I sought a practice in which an unfamiliar, but complex ecosystem is involved. I found a suitable practice in the problem of expanding populations of elephants (*Loxodonta africana* Blumenbach) in Africa. To decide on a course of action, a conference was held (The 'Great Elephant Indaba'), with participants from different backgrounds (Marshall, 2004). It was held in the Kruger National Park in South Africa in October 2004. The central problem was: how to handle the overpopulation of elephants? Different solutions were suggested by participants who had a focus on different levels of organization. Again, to trace the consequences of the proposed solution, modelling could be helpful.

This practice has much in common with the second one in terms of complexity, but is much less familiar to the students. A central issue in this practice is that even knowledgeable participants in the discussion can have trouble understanding each other if their reasoning is at different levels of biological organization. These difficulties become even more pertinent if normative or economical arguments enter the discussion along with ecological arguments.

Also this practice meets the proposed criteria, while it differs from the first two in being the most unfamiliar.

6.4 A prima facie structure for the leaning and teaching strategy

A metaphor of the learning process

A learning process could be described in a metaphor: a route from the starting point which is 'here', towards the desired learning outcomes, being at the 'opposite side of the river'. In this metaphor, the LT strategy looks like a suspension bridge over this river. To the learner both sides of the river must remain in sight, and the function of the suspension ropes must be clear. A suspension bridge is built of two suspension ropes, together with cables used as transverse bonds. The width between, as well as the number and type of these bonds are important. The wider the bridge, the more room will be left for the traveller to choose a direction. The number of transverse bonds represents the number of steps and gives information about the size of the steps. A sophisticated LT strategy will provide appropriate step sizes at each step. The learner crossing this bridge will have to engage in all activities required for his learning process. In this metaphor one could say that the cultural historical theory (see chapter 2) tells us something about the size of the steps (being just into the zone of proximal development, not so big that the risk of 'falling into the river' exists). Whereas the problem posing approach (see chapter 2) requires a sense of direction (i.e., meaningfulness) at each step of the learner (see design criterion 8).

Thinking about steps during learning activities is also necessary when deciding on the sequence of the ecological organization levels, i.e. using systems thinking. Yo-yoing between levels of biological organization such as molecule, cell and organism can be extrapolated to higher levels such as the population and the ecosystem (Knippels, 2003). I elaborate this idea in this study (see design criterion 4). One could start with a top-down approach: starting with abstract factors (ecosystem or population) and then zoom in to a concrete factor (organism) or with a bottom-up approach, which is just the other way round. Because the concrete level is more familiar to the learners, which will offer them more help going through the learning activities, I have chosen for the second approach, as did Magntorn (2007) before us (see design criteria 2, 4 and 8). It is interesting here, that Knippels started top-down, from the organism into the direction of the cell. While this may seem an opposite approach, in fact Knippels followed the same logic, in all cases the start is at the familiar and visible level while the unfamiliar and invisible level comes later.

The use of social practices will not be sufficient to define the didactical structure of my learning and teaching strategy. A practice could clarify how ecosystem behaviour can be studied in a series of meaningful activities. However, students are not on equal footing with scientists, and in order to allow student involvement the practice will need to be adapted (see design criterion 1). A crucial difference between the 'real' practice and its educational use is that in real practice scientists use the knowledge they already have to solve a problem, while the students solve the problem to acquire the knowledge. The ecologists in the mussel breeding practice, for example, use their biological knowledge base, as the classification of the world in organization levels and knowledge about behaviour, anatomy and physiology of mussels. They yo-yo easily between the concrete and more abstract levels; they can choose their own starting point, depending on the problem they want to investigate. To turn this into an effective educational practice, in the initial phase students must get opportunities to develop the required concepts and insights. This provides a second reason to start, unlike real scientists do, at the level of the concrete mussel (the organism) and then move up to the level of the population and the level of the ecosystem. Characteristics of the specific levels will 'emerge' during the learning activities of the students. While the order in which the various levels are being covered is different from the ecologists' order, it is important that the learners are aware of this sequence from the beginning, by appealing to ideas which are already familiar to them about the hierarchical order of the levels of organization. In all three social practices, the students yo-yo between the three levels of biological organization. When conceptualizing the students' computer models in the reflection phases in the first and second practice, these levels of biological organization are made explicit. By reflecting on the differences in view between the debaters, the same is reached in the third practice.

Learning and teaching strategy

An overview of the complete LT-strategy is presented in figure 6.3; this shows how the problem posing cycles (together with systems thinking and modelling) are embedded in the concept-activity-context approach. In the two subsequent cycles, the reflection phase (indicated by 5 and 6) is used to develop ideas from the models resulting from the students' computer modelling activities, towards the various conceptions of the concept ecosystem.

Learning process	Concept-activity-context	Phases of the problem posing cycle	Systems thinking (Levels of organization)	Nature of modelling activities
Aquisition	Context 1: Ecological research (mussels) How to optimize harvest? Activity: Computer modelling Concept: Ecosystem (dynamic/ not complex)	Questioning phase		
		Activity phase (3 & 4)	organism	a. biological object
				b. open systems model
				c. Powersim model
			population	
			ecosystem	
		Reflection phase		
Extension	Context 2: Nature management (rabbits) How to stimulate recovery of a population? Activity: Computer modelling Concept: Ecosystem (dynamic / complex)	Questioning phase(1 & 2)		
		Activity phase (3 & 4)	population	c. Powersim model
			ecosystem	
		Reflection phase (5 & 6)		
Testing	Context 3: Nature management (elephants) How to substantiate conservation of ecosystems? Activity: Arguing about what to do with overpopulation Concept: Ecosystem (dynamic / complex)		organism population & ecosystem	

Figure 6.3. Phases of the compound LT-strategy. The numbers refer to the phases described on p. 32-33. Shading indicates that the aspect is not addressed here.

To meet the design criteria 3 and 8, in the LT-strategy a series of problem posing cycles are intertwined with the practices, corresponding with the first and the second practice respectively. We zoom in on the first problem cycle (see figure 6.4), to detail the problem posing phases. In the structure shown, which has been adapted from the structure used by Vollebregt (1998), the activities are linked by the posing of problems which are all connected to the central problem of the used practice. On the left, the students' prior knowledge of ecology is shown. In the centre, the domain-specific motives are shown so as to keep the learning activities going. On the right, the scientific skills of systems thinking and modelling are shown, which are introduced and built up during the lessons. In comparison with earlier problem posing LT-strategies, less effort will be spent to let the students induce the desired motives themselves. In my strategy, the motives can also be supplied by the teacher, provided that he has first explored the learners' zone of proximal development by posing questions which will (hopefully) evoke motives for the learners to investigate the problem in more detail.

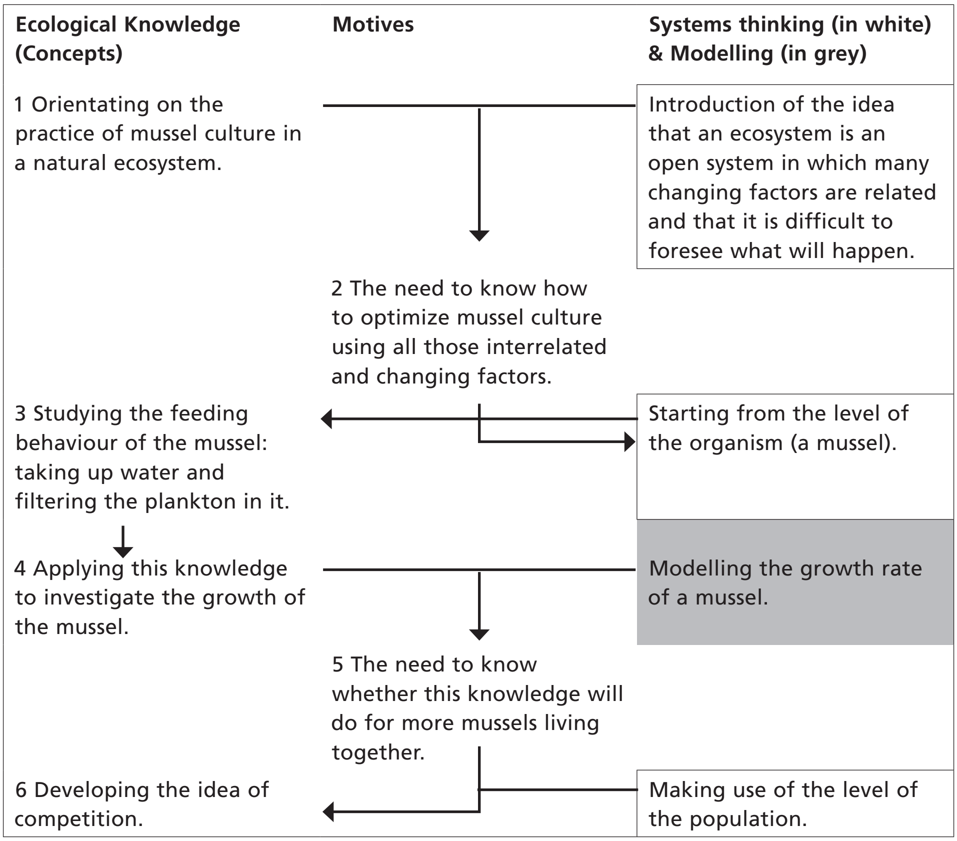


Figure 6.4. The first problem posing cycle of the learning activities in the first practice. The numbers refer to the phases described on p. 32-33.

6.5 A domain-specific scenario

Taking the LT strategy as described in the previous sections as a starting point, I outlined a series of lessons (table 6.2).

Table 6.2. Outline of the series of lessons.

Lesson	Subject
1	Introduction of ecosystems. Confrontation with the problems of mussel breeders, introduction of the social practice of the NIOO-scientists.
2	Anatomy, dissection and weighing. The mussel and its natural history: feeding behaviour, growth, flesh-weight and dry-weight.
3	Implementation of modelling to allow quantitative predictions, also in complex situations: a model of a mussel.
4	Bottom-up from the mussel as an organism to a population of mussels.
5	Bottom-up from the population of mussels to the ecosystem, by the introduction of birds which forage on mussels.
	Reflection on the use of systems thinking in an ecosystem and the value of modelling and making predictions
6	Top-down, by introduction of an exotic species (Japanese oyster) and its influence on the mussel(s).
7	Re-contextualization. Change to another social practice, with the rise and fall of the rabbit in the coastal dunes, disease and change of vegetation, human efforts to control these developments.
	Demonstration of the Lotka-Volterra model.
8	Introduction of a computer model with variable amounts of grass, area and density of rabbits. Exploration of this model.
9	Reflection on the value of this complex model.
	Exploration of the various types of arguments that people use in ecosystem related debates (ecological, economic and normative arguments).
After the lessons	Test. Re-contextualization. A newspaper article about how to handle a problematic population development, devastating an ecosystem: overcrowding of elephants in Africa. Questions about the concept of the ecosystem, making use of modelling and systems thinking and about the use of arguments.

For these lessons a scenario (as defined in chapter 3) has been developed in which, for each of the nine lessons (of 45-50 minutes), the intended learning and teaching activities were described in detail. This scenario also included what I expected the teacher and the students to do, and how to monitor the resulting learning and teaching processes and learning outcomes. As an example, a part of this scenario[2] is presented in figure 6.5.

Content in a lesson	Teacher's activities	Students' activities	Monitoring execution, processes and outcomes
Activity 8 Transfer from a qualitative approach towards a quantitative approach: a Powersim model Learning objective: 6 In lesson 3	Discusses the open systems model which was constructed in lesson 1, where complexity plays a role, but which is qualitative and static. Stimulates reflection on this model and on the information about food intake and dry-weight from lesson 2. Asks the students to think of factors which can be considered as constants and factors which could be considered as variables.	They articulate that certain factors are dependent of others (variables) and others behave independent (constants). They declare that in a model some factors will hardly have any influence, while others have a direct or indirect influence. They argue that quantitative and dynamic models give more and more exact information about what will happen with the dry-weight of a mussel.	**What?** Students' utterances indicating: 1. insight into the difference between constant and variable factors; 2. insight into the quantitative - dynamic possibilities of computer models, like 'more info', 'more exact', 'greater predictive power'. **How?** Analysing video-registration, reading student's notes. **Why?** Realizing the difference between qualitative and static versus quantitative and dynamic is a very important point, which says a lot about the way students perceive the processes.

Figure 6.5. Parts of the scenario (in the third lesson) of the series of lessons.

Based on this scenario, the series of lessons was produced. A workbook was written, a test-paper was prepared, a part of a video-movie was selected, as well as animations,

2 The complete scenario (in Dutch) can be found on http://www.cdbeta.uu.nl/vo/modelleren/default.php in the Biology part.

and all Powersim models I needed were prepared and tested.[3] Actual data I needed to use in the models were collected in collaboration with expert ecologists.

3 All these materials (in Dutch) can be found on http://www.cdbeta.uu.nl/vo/modelleren/default.php in the Biology part.

7. Research instruments in the classroom

7.1 Introduction

In order to evaluate the design presented in chapter 6, I conducted classroom evaluations, which led to revisions of the design. Three research cycles were developed, which means that subsequent versions of the design were field-tested. The current chapter describes the procedures and research instruments. Section 7.2 presents the classroom settings, section 7.3 describes the data collection procedures and section 7.4 addresses the data analysis. Chapter 8 will present the findings of these case-studies and implications for the design.

7.2 Classroom setting

In this section I describe the classroom settings in the case-studies of the three versions of the design. The selection of the schools was highly dependent on the willingness of the biology teachers to participate in my research. From a large network of biology teachers, I invited the most promising candidates. I sought for the best chances that the LT-strategy would be carried out as intended by conducting intake interviews with the teachers, to find out to what extent they were really interested in my research and its focus on optimising the learning processes of the students. Moreover, I used these interviews to find out whether the teachers had an open mind to deviate from their usual teaching approaches.

In the case-studies of the first version of the design, two teachers were involved. One had more than 25 years of teaching experience. The other had only been a teacher for three years, but in earlier classroom visits she appeared very skilled in her classroom performance. She also participated in the second version of the design, together with a colleague of hers, who had more than 25 years of teaching experience. In the third version of the design, two teachers at another school participated, one of them an experienced teacher with more than 30 years of experience, also active as a teacher trainer. His colleague had 7 years of experience. In addition, in the third version of the design, the learning and teaching strategy was also tested in the researcher's own classroom. This case-study was included because I was confronted with some serious problems in the introduction of Powersim modelling, which had a lasting negative effect on students' performance. I also wanted to investigate the effect of a teacher who was very experienced in Powersim modelling and who, as being the designer, had full knowledge of the LT-strategy. To avoid biases in the analysis of these data, a co-researcher was invited to make his own independent analysis of key moments in the lessons (see section 8.2).

Selection of the classes was based on current scheduling of ecology, i.e., in the middle part of the curriculum. Pre-university level was chosen to support the ongoing national curriculum innovation, based on the concept-activity-concept-approach (see chapter 2). This level (VWO) was supposed to provide a more ideal setting to explore the possibilities of our approach including systems thinking and modelling in an authentic scientific practice, than general secondary education (HAVO).

Students' prior knowledge about ecology did not differ much in the case-studies of the three versions of the design. All students had been taught some ecology in lower secondary education. Concepts such as producers, consumers, reducers, food chains, food webs, and the cycle of matter were known to them, although a little bit faded, since generally these terms are being taught when the students are 13 years old.

Table 7.1 summarizes the relevant characteristics of the schools involved. Demographic and performance data were based on national school statistics 2005 and 2006 and quality-indicators provided by the Inspectorate of Education[1]. All case-studies were carried out in upper secondary classes of pre-university education (abbreviations 5V, students of 16-17 years, and 6V, students of 17-18 years). In the Dutch school system this means that the students have completed three years of lower secondary education (the national core curriculum) and one year or two years of upper secondary level. They have all opted for biology. Complete upper secondary pre-university education takes three years.

Teacher preparation

To have the teacher well-prepared, I organized training sessions. In four sessions there were eight hours in total to discuss the scenario and the workbook, to get to know the anatomy of the mussel by dissection, and to master the graphical modelling tool Powersim. The latter poses serious difficulties to many biology teachers. In the training sessions all teachers had difficulties with the way the relation between factors

1 http://www.trouw.nl/deverdieping/article108012.ece;
http://www.trouwpodium.nl/ schoolprestaties2006/

Table7.1. Characteristics and details of the schools involved in the case-studies of the three successive versions of the design.

General school indicator	Case-studies of the first version	Case-studies of the second version	Case-studies of the third version
Name and place	Jac. P. Thijsse College Castricum (1a)	Jac.P. Thijsse College Castricum (2a)	Het Baken Park Almere (3a)
	Stedelijk Gymnasium Haarlem (1b)		Petrus Canisius College Alkmaar (3b)
Signature (Denomination)	State (public) (1a and 1b)	State (public) (2a)	Interdenominational (3a) and Roman Catholic (3b)
Number of students participating	45 (1a) 2 classes 34 (1b) 2 classes	37 (2a) 2 classes	45 (3a) 2 classes 17 (3b) 1 class
Total number of students	2025 (1a) 730 (1b)	2044 (2a)	3159 (3a) 2919 (3b)
% Ethnic minority students	0 (1a) 0 (1b)	0 (2a)	2 (3a) 1 (3b)
% secondary students graduating without delay	75 (1a) 73 (1b)	80 (2a)	77 (3a) 69 (3b)
Average grade national exam	6,6 (1a) 6,7 (1b)	6,5 (2a)	6,0 (3a) 6,2 (3b)
Case study details			
Time period	November-December 2004 (1a) March- April 2005 (1b)	November-December 2005 (2a)	May-June 2006 (3a) September-October 2006 (3b)
Grade and level	5V (1a)	5V (2a)	5V (3a)
	5V (1b)		6V (3b)
Age of students	16- 17 years (1a)	16-17 years (2a)	16-17 years (3a)
	16-17 years (1b)		17-18 years (3b)
Number and duration of biology lessons per week	3 (1a) (45 minutes) 3 (1b) (50 minutes)	3 (2a) (45 minutes)	3 (3a) (45 minutes) 5 (3b) (50 minutes)
Number of teachers involved	1 (1a) 1 (1b)	2 (2a)	2 (3a) 1 (3b)
Teaching experience of teachers involved	3 years (1a) > 25 years (1b)	3 years / > 25 years (2a)	> 25 years / 7 years (3a) > 25 years (3b)

General school indicator	Case-studies of the first version	Case-studies of the second version	Case-studies of the third version
Number of ecology lessons in the case-study	10 (1a) 10 (1b)	11 (2a)	10 (3a) 11 (3b)
Total number of ecology lessons	18 (1a) 18 (1b)	18 (2a)	16 (3a) 16 (3b)

was formalized in mathematical formulas. To provide the teachers with sufficient background, all models the students had to work with were covered in the teachers training. The expected student mistakes and specific Powersim problems we had experienced in previous case-studies or at other occasions were discussed and solved, to give them self-confidence in their teaching activities.

The role of the researcher in the classroom
Before the case-studies started, the researcher was introduced to the students in the classroom as a fellow teacher, also working as a Ph.D.-researcher in Utrecht University. I shortly explained a few aspects of my research project and its goals and mentioned some important implications for the students, i.e., the presence of video- and audio-recorders during the lessons, the handing in of worksheets, and the constant presence of the researcher in classroom. The students were asked to answer all questions honestly and to give their negative or positive feedback on the learning materials. It was also stated that the data and worksheets would be handled confidentially and would not be given to the teacher. The teacher stated that the series of lessons were a substitute for a part of the normal lessons in ecology and that it would be concluded by a written test. The teacher also pointed out to the students the study guide they had received, in which the content (and homework) per lesson was described. During this lesson the students also had the opportunity to ask the researcher questions. In all classes they came up with questions like: 'Why do you want to record us?', 'What are you going to do with the recordings?' or 'Why are you interested in the way we learn?'. The answers given by the researcher mostly satisfied students' curiosity and during the remainder of the lesson little attention was paid to the researcher sitting in the back of the classroom.

In the first and the second versions of the design, the researcher participated more or less in the teaching process. He walked around the classroom during group or dyad work and answered students' questions or asked questions himself. This setting offered the opportunity of having conversations with individual students and thereby probing how activities were interpreted or what the students meant by certain words expressed. This provided more insight into students' problems in relation to the learning activities and into the revisions that were needed for the second case study. Besides, the students were aware of the modelling skills of the researcher and tried to involve him in their modelling problems.

In the third version of the design I tried to reduce the participation of the researcher. It was expected that by now the learning and teaching process would run roughly as intended and that only minor problems with modelling would arise. Therefore, I made my observations mainly from the back of the classroom. Consequently, most conversations with students and teacher took place after the lessons. Sometimes a brief consultation with the teacher took place during the lessons, concerning the way the lessons had proceeded so far, what still had to be done or how specific outcomes could be used in the remaining part of the lesson. Of course, this does not apply to the last case-study, where the researcher did the teaching himself!

7.3 Data collection

In each case-study I collected data before, during, in between and after the series of lessons. Data was collected through classroom observations, audio- and videotaped classroom and group discussions, completed worksheets, written tests and interviews with students and teacher. Before the start of the lessons a pre-test was done to probe the ecological views of the students, using the same questionnaire that had been used with teachers and ecologists (see chapter 5). The same questionnaire was used as a post-test so as to determine any change in views.

In all case-studies the whole sequence of lessons was observed and audio- and videotaped. The teacher carried a tape recorder during the lessons. Before the start of group discussions and group dissection activities (where the groups consisted of three or four students) or computer activities (which were performed in dyads) tape recorders were placed on the tables of two groups or dyads to record the group discussions and the deliberations about computer activities. Teacher's notes and drawings were copied from the blackboard and students' worksheets were photocopied. During the observation, striking events and statements of both students and teacher were noted. By 'striking events' I mean events that validated or invalidated the expectations described in the scenario, like an activity that was performed with enthusiasm, a successful construction of a model, a sudden drop in students' motivation, or students getting stuck during a certain learning activity. Students' motivation and their questions were an important focus. The group work was observed to monitor what students were doing and whether they were on task.

In the second and third version of the design, evaluation forms were completed anonymously by the students, immediately at the end of the first three lessons. After the first version, I had the idea that it was not enough to have the classroom and group discussions. I also wanted to have an idea of the thoughts of not only the (few) students coming to the front in group discussions, but also of the others, the more 'quiet students'. Investigations also show that the latter can produce lots of information, using techniques like these evaluation lists, drawings and worksheets (Óskarsdottir, 2006). In these evaluation forms, questions about special issues were posed, mostly as propositions with a Likert-type scale. For example "I understand the aims of the series of lessons", "I would prefer learning from my biology schoolbook", "I clearly understand how a mussel takes up food" or "It would have been more logic to start with the mussel bank in stead of with an individual mussel". Also another type of question was used, where the students had to complete sentences like "What we are going to do in these lessons is….." or " I think the idea that a mussel can be described as a system, a whole which is set up from parts is a(n) . ………… idea".

All lessons were evaluated with the teachers, by interviewing them; their experiences were divided in 'successful parts' and 'obstacles'. The models the students constructed, explored or extended were collected and inspected. The test in the final lesson was analyzed to acquire specific information about students' awareness of the various levels of organization (organism, population, and ecosystem) and their skill in discriminating between ecological, economical and normative arguments, and their ability to sketch the presented information in a draft as a first step to build a Powersim model. Because of the fact that there is great hesitance to use computers in a test situation on many schools, I did not choose for actual computer modelling in the test. After the end of the series, three or four students per group were interviewed about their experiences with the lessons.

7.4 Data analysis

The aim of all data collection described above, was to answer my research sub-questions. Table 7.2 illustrates how the types of data sources were used to answer the research sub-questions. For example, observations during the lessons were used in finding the answer to all research sub-questions, while Camtasia registrations of computer modelling were only used in finding the answer to the research sub-questions 3 and 4, and the pre- and post-test answers in a questionnaire were only used in finding the answer to the research sub-question 5.

Research sub-questions:

1. *Which ecology-related authentic practices seem appropriate for enabling students to grasp and value the role of systems thinking and modelling?*
2. *What are the opportunities for systems theory to clarify complexity at various levels of biological organization such as organism, population and ecosystem?*
3. *What are the opportunities for computer modelling to clarify dynamics at various levels of biological organization such as organism, population and ecosystem?*
4. *Which pedagogical approach is helpful for students in using modelling and systems thinking?*
5. *Which pedagogical approach is helpful for students in developing scientific ecological concepts starting from concepts embedded in authentic practices?*

Table 7.2. Data sources used to answer my research sub-questions.

Data sources	Research questions				
	1: Authentic practices	2: Systems thinking	3: Modelling	4: Pedagogical approach for modelling and systems thinking	5: Pedagogical approach to acquire ecological concepts
Observations	•	•	•	•	•
Audio- and videotapes:					
o Teacher	• •	• •	• •		
o Group discussion	•				
o Dissection activities	• •	•	• •	• •	•
o Class discussion					
o Modelling activities					
Worksheets, drawings, models	•	•	•	•	•

Data sources	Research questions				
	1: Authentic practices	2: Systems thinking	3: Modelling	4: Pedagogical approach for modelling and systems thinking	5: Pedagogical approach to acquire ecological concepts
Written tests	•	•	•	•	•
Evaluation interviews with students and teachers	•	•	•	•	•
Evaluation lists (Likert type) *	•	•	•	•	•
Camtasia registrations of computer models			•	•	
Pre- and post tests of ecological view					•

* These lists were only used in the second and third case-study, driven by a need for extra information.

All video- and audio-tapes were transcribed verbatim. Students' worksheets, evaluation lists, and their written answers to the test questions were typed out and put in matrices in order to get a clear overview of all answers. Their drawings were also photocopied and their models inspected. The transcripts of the video- and audio-taped class and group discussions constituted the main data source in reconstructing the executed learning and teaching process, because they contained the most complete and objective information. The notes that had been made during the classroom observations guided interpretation of these transcripts. In addition, the interviews with the teacher and the students and the evaluation lists of the students were used to compare the researcher's observations with the teachers' and the students' interpretation and experiences during the lesson. In analysing the outcomes, the worksheets, drawings, evaluation lists, models and answers to test questions were used in addition to the transcribed video- and audio-material. In detail, analysing the transcripts included the following steps:

1. Close reading, using the first impressions (notes), obtained during the lessons.
2. Marking remarkable phrases, noting key words and ideas that came up.
3. Identifying students' reasoning patterns.
4. Identifying crucial support given or not given by the teacher.
5. Repeating the previous steps guided by the scenario.
6. Identifying moments that support or reject the assumptions made in the scenario.

Next, the data was formatted side by side with the scenario to compare the performed activities and actual outcomes with the intended activities and outcomes as outlined in the scenario (see table 7.3). Based on this comparison, I could not only identify successes and failures, but also attribute the causes of these failures, and infer implications for the design.

Table 7.3 Format used for analysis of learning activities.

Content:				
Function:				
Intended course		Executed course		Remarks
Teacher	Students	Teacher	Students	

Data fragments are identified with a code. The code 1a.3[3].C, for example, would represent case-study 1a, lesson 3, [fragment number 3 (referring to the scenario)], and data source Audio or video recording. Various data sources are referred to as: C: Audio or video recording; E: Evaluation form; I: Interviews for evaluation with students and teachers; M: Camtasia registration of modelling activities; O: Observations; Q: Questionnaires (pre- and post test); T: Written test answers; W: Worksheets, drawings and models.

8. Towards practice-based ecology education

8.1 Introduction

In this chapter, the empirical evaluation of my learning and teaching strategy is presented. I will describe what my 'laboratory findings' mean while working with 'students in the wild': the concrete classroom situation. Section 8.2 reports on the data selection and the interrater agreement. Section 8.3 provides a detailed comparison of the scenario and the actual proceedings in one case study of the final design. For each lesson I will describe the differences between the intended and the executed course, focussing on problematic points for the teacher as well as for the students. In section 8.3 I will answer the five sub-questions of my research question, also giving attention to the changes which have been made during the three case studies and the reasons for those changes, leading to the final design of my learning and teaching strategy.

8.2 Data selection and interrater agreement

Overall, I have conducted nine case studies with three different versions of the learning and teaching strategy (1a-3b, see also chapter 7). In the case studies with the first two versions the focus was on formative evaluation to improve the design. In the case studies with the final version the focus was on summative evaluation to answer my research question. In this chapter I will focus on the evaluation of the final design, and refer to experiences with earlier versions only insofar as needed to give insight into the design choices underlying this final version.

I had three case studies with the final design. In the first two case studies I was confronted with some serious problems in the introduction of Powersim modelling, which had a lasting negative effect on students' performance. In the third case study, I had the complication that the researcher was also the teacher. Nevertheless, I decided to take this third case study (3b), because it is likely to give the best idea of the course of events that I had in mind. To cope with issues arising from a confusion of the roles of the teacher and the investigator I invited a co-researcher to participate in the analysis of the material.

To give an idea of the comparison of the analysis of the researcher and the co-researcher I use parts from activity 3 in the first lesson and activity 4 in the second lesson (see 8.3 for an extensive description of these activities).

Both the researcher and the co-researcher wrote their comments to an overview of the intented and the excecuted activities. The researcher added only short comments (see table 8.1). The extensive comment of the researcher was kept secret until the co-researcher had had the opportunity to formulate his own extensive comment about the part.

Table 8.1. Format used for analysis of learning activities.

<table>
<tr><td colspan="5">Content:
The students have to make model drawings with various factors that influence the mussel or are being influenced by the mussel. They think of at least four factors that play a role in optimal mussel culture, such as moment and frequency of harvesting, the influence of the weather, the amount of dumped mussel seed, the rate of flow of the water, the amount of food, and the presence of predators. They are able to make clear for which factors the boundary around the mussel will be a real boundary.</td></tr>
<tr><td>Function:</td><td colspan="4">1. Students give utterances and perform modelling activities which make clear that they are able to describe components that influence a mussel in terms of direction and extent of crossing boundaries;
2. Students give utterances which make clear that they distinguish a hierarchy inside the group of components influencing the growth of a mussel;
3. Students give utterances which make clear that they understand that some components can be kept constant, while others are variable, and that these variables influence the dynamics of the system.</td></tr>
<tr><th colspan="2">Intended course</th><th colspan="2">Executed course</th><th>Remarks</th></tr>
<tr><th>Teacher</th><th>Students</th><th>Teacher</th><th>Students</th><th></th></tr>
<tr><td>Asks the students to build the model on p.12. of their workbook Instructs them to place various components around the mussel and to indicate with arrows the influence on the mussel (till the boundary</td><td>They build the model: a sketch with the mussel and various components such as wave, plankton, transparency, birds, flow. They are aware that some components have influence till across</td><td>“Suppose you have one mussel. The white is his internal environment; the blue is his boundary with his external environment: the water. And red indicates the boundary of the Easter Scheldt. You could say that this mussel is a system. It is built out of components and it has a boundary and outside there are all kinds of factors. Now you have asked yourself: what is important for an optimal mussel culture?</td><td></td><td>This part follows after an introduction in which the problem of Optimization of mussel culture has come to the fore and the practice of the NIOO-scientists has been clarified. The students</td></tr>
</table>

or across the boundary) or from the mussel to the component.	the mussel boundary and others have not. They are also aware that some components will have more influence than others and that a mussel has only a minimal influence on the components.	Suppose that you are a NIOO-scientist and you zoom in on one mussel and ask yourself: which factors influence this mussel and does the mussel influence these factors? So write down factors in the model and indicate with arrows if they influence the mussel or just draw the arrow the other way around. And I want you to draw the arrows until the boundary or though it, because you think the influence works also inside. What a boundary is for one factor, need not to be it for another.		(18, 6V level) did already brainstorm about factors that are important in mussel culture.
			“Do we need the boundary of the mussel or the boundary of the Easter Scheldt?”	
		Well, try this. About five factors with an arrow to or from the mussel. Later on we will come back to it.”		The task seems to be not quite clear. The students ask for explanation (procedural questions), after that they can perform their task. Look also in the copied sheets from their workbook, where their models can be found.
		“The boundary of the mussel. The mussel is our focus.”		
		“Exactly. Is this task clear? Five factors influencing or being influenced by the mussel.”	[inaudible]	
			“Sir, these factors, shall we put them in the blue compartment?“	
		“Yes, in the blue one. This means that the factors work from the Easter Scheldt on the mussel. Or the other way around.”		
			“The weather. Is that a factor?”	
		“Yes, for an example. The weather, it can be used.”		
		“Well, does the weather influence the mussel or is it the opposite?”	“But how should you place the arrow?”	
			“No, the weather on the mussel.”	

After both researcher and co-researcher had written their comments, a comparison between their comments was made in an open discussion. For each intended outcome the researcher had asked: has this been realised? If so, what is the evidence? (1). If not, where does the problem start and why? (2).

As an example of (1): "In their model the students indicate reproduction, food, disease, natural enemies, current, waves, other mussels, weather, temperature, excretion (on the average five components per student). This is what we expected."

As an example of (2): "Initially, students are not sure what to do. The teacher does not give enough information and the students do not use their workbook."

The co-researcher had used an enumeration of observations (1) and questions about these observations (2). He had also used a category of things that he expected to happen but that he did not observe (3).

As an example of (1): "Students mention the weather, other mussels and waves. They put these in order of importance on the base of 'its influence on growth'.
There is no specification how the components influence the mussel."

As an example of (2): "Is it clear why they should name all these and what will happen later with these? In other words, is it a meaningful activity for the students?"

As an example of (3):
"I cannot find the idea that the components do not only have a direction, but that they are also in some way related with the optimization question that is central in the chosen practice".

The co-researcher did also mention that the teacher is relatively often speaking, which was used by the researcher to look even more critical than he already had in mind to the role of the teacher. And in the end the co-researcher gave the advice to use another arrangement as used in the format such as in table 8.1 and to put the intended and executed course not next to each other, but below each other, which was accepted to do by the researcher.

After two sessions with four different parts of the series of lessons, the researcher and the co-researcher converged on the way the material had to be analysed.

8.3 The intended and executed course of the lessons

Table 8.2 presents an outline of the series of lessons. This is an extension of table 6.2 (p. 104). For each lesson, I will describe and compare the intended and the executed activities.

Table 8.2. Outline of the activities in the series of lessons.

Lesson		Activity
1	1.	Orientation: introduction of the central problem and learning aims.
	2.	Zooming in to concrete ecosystems.
	3.	Extension of the knowledge of mussel culture and of the problems which have to be solved by the scientific practice of the NIOO- scientists.
2	4.	Reflection on the acquired knowledge.
	5.	Zooming in on feeding and excretion of the mussel.
	6.	Working on the anatomy of mussels.
	7.	Weighing mussels.
3	8.	Reflection on models.
	9.	Modelling with a computer: a model of the growth of a mussel.
4	10.	Orientation on a bottom-up approach from the mussel as an organism to a population of mussels.
	11.	Confrontation with ecological and economical reality.
	12.	Weighing and validation.
5	13.	Modelling a population effect.
6	14.	Extension of the bottom up approach: from the population to the ecosystem.
	15.	Modelling the ecosystem.
7	16.	Reflection on systems thinking and development of concepts.
8	17.	Re-contextualization, going to another practice.
	18.	Modelling in another practice.
9	19.	Modelling and its value.
	20.	Discriminating arguments.
After the lessons		Test. Re-contextualization. Reading a newspaper article about how to handle a problematic population development, devastating an ecosystem: overcrowding of elephants in Africa. Answering questions about the concept of the ecosystem, making use of modelling and systems thinking and about the use of arguments

First lesson

1. Orientation on the series

Function: to clarify the central question and the learning objectives of the series of lessons, with the aim to satisfy a need for structure from the students

In this part the problem posing approach is not yet visible. It is the teacher who clarifies things at the beginning. Only from the second activity on, students' ideas are becoming part of the learning and teaching sequence.

Intended

The teacher introduces the aim of the series, using the list of learning objectives (p.5 of the workbook). He formulates the central question of the series: "Can we understand complexity and dynamics in an ecosystem?" He also clarifies how this series fits in school ecology program. He gives the example of a test from p. 5-8 in the workbook as a homework task.
The students listen and ask questions if things are not clear.

Executed (6.06 minutes)

The teacher starts with an introduction of the series, talking shortly about the central problem of the series. Then he talks about all learning objectives that are formulated in the workbook. After this lesson, 36% of the students (n = 17) report to understand these aims (3b.1.E). The students filled in an anonymous questionnaire at the end of the lesson or the beginning of the next lesson. Of course these answers give only an indication of what they think.

In the lessons they do not pose any questions. They are listening quietly, giving answers when they are invited to do so.

The teacher gives a short definition of the meaning of the terms dynamics and complexity. The students do not react to these terms. Although the teacher does not probe students' ideas on ecosystem, he inquires them about their acquaintance with the levels of organization such as organism and population.

T: "Do you have any idea of what a population could be?"

Lance: "One group of animals, one species."

T: "One species. So, all magpies of the world for example?"

Niles: "No, all magpies in a special area."

T: "Ah ha. In one area. Sounds good to me. Now, one level higher is the ecosystem. If we take the

example of the magpies, what would be the accompanying ecosystem? Who of you?
Joanne: "Uhm … the natural area where they live."
T: "Right. So there will not live only magpies, but also other species of plants and animals."

(3b.1[1].C)

To at least some of the students a population appears to be a familiar concept.

After that the teacher pays attention to (computer) modelling and its value for understanding dynamics, complexity and levels of organization. He stresses the point that by being able to use a modelling tool, it will be possible to answer questions related with human impact on ecosystems, which is most important.

And finally, he introduces the competence to give arguments to justify a specific way of acting in an ecosystem, and recognize the character of these arguments: ecological, economical or normative. He talks about a test that will be given after the series. Such a test will not necessarily use the animals from the series, like mussels or rabbits. In the test will be investigated if the learning aims are attained. As an example some questions are introduced in the workbook (p. 5-8), which can be solved as a home work task. The teacher works rather fast and he says a lot. This part is executed in about 6 minutes. For the students this could be rather overwhelming: also it could explain why they do not react with questions.

As a conclusion I could say that it has been pointed out clearly, but in a rather high speed, what the aims of the series are, but that it is not made completely clear at this moment what the concepts complexity and dynamics are about. This could lead to problems in the next part, where some understanding of complexity and dynamics is needed.

2. Zooming in to concrete examples of ecosystems
Function: to justify the sequence of presentation of the ecosystem related authentic practices that have been selected

Intended
The teacher gives the students three examples of (strong human influenced) ecosystems: farming on a field; culturing mussel in the area of the Easter Scheldt; managing rabbits in a nature reserve area. He asks the students which of these three will be most adequate to start with, when you want to get insight into the complexity and dynamics in an ecosystem.

The students are aware of the fact that in the nature reserve area there are many complex relations. The rabbits move around, they will reproduce, they will die by all sorts of causes. It will be rather complicated to start with the rabbits. In a field complexity and dynamics will hardly exist. So, it seems reasonable to start with mussel culture.

Executed (7.15 minutes)
Three ecosystems are introduced by the teacher.

T: "Suppose we take three areas where man has an important influence. A field with potatoes or maize, with some herbs on the borders, an estuarine area like the Easter Scheldt with lots of mussels, and a dune area with all kinds of animals and plants. Where would you start to get a good impression of the complexity and dynamics? And why would you choose this area?"
Leo: "I would start with the field, because there are not many animals. So you do not have many influences and it is easy to build a system."
T: "OK, bright thinking. Not too complex, because of the few animals. But not everybody agreed. Why not? Yes, Niles?"
Niles: "Sometimes there are more animals."
T: "What do you mean?"
Niles: "Well, the seasons, sometimes there are more birds and that makes it more complex."
T: "Why should that be a problem?"
Ger: "Well, every day can be different; it does not seem to be in a logical order."
T: "So you mean it will be unpredictable. Does somebody else have an idea? Can a maize field be considered as dynamic?"
Eve: "Uhm, not really."
T: "No, I agree with you. Sometimes there are maize plants, sometimes not, there may be birds like Ger said, but next year there will be the same amount of maize again if the farmer wants it. It is reasonably good predictable what happens. So, maybe we could choose between the other two, which of them seem more complex and dynamic?" [Most of the students call for the estuarine area].
T: "So the estuarine is more dynamical. Why?"
Niles: "Because of differences in water velocity, the tides."
T: "If you look at human influence, where can man have most influence?"
Daisy: "That is difficult to decide."
T: "Suppose, a mussel breeder works in the estuarine, he has introduced a bunch of mussels. After a while he will harvest them: so bringing in, getting out. Now compare that with a game reserve worker who is involved with rabbits. Who of them has the strongest control?"
Marlin: "The game reserve worker."
T: "Who agrees with Marlin? Oh, not many. Leo, why don't you agree with her?"

Leo: "Well, with the mussels it is more easily to control, there is no reproduction there."

T: "Do mussels not reproduce?"

Niles: "No, they grow, after that they will be harvested."

T: "Indeed. They are harvested and the reproduction does not come to the fore. So the mussel breeder controls a very important factor, the density." And therefore we take, as a compromise, the mussel breeding to start with. It is not as complex and dynamic as the dune reserve, but not as dull and predictable as the maize field. After we have got some experience with the mussels, we go on to the rabbits. However, the mussel culture is something special and relatively unknown, so I first will show you how it is like and how it could be investigated."

(3b.1[2.]C)

I conclude that the students are not really convinced that the sequence the teacher has explicated is the best one: only 25% of them report after this lesson that they think it sensible to start with mussels (3b.1.E). The problem here seems that the students have to discuss about concepts such as complexity and dynamics which they are not familiar with. They know the words, but are not known with their specific connotation in an ecosystem. So it is impossible for them to make an underpinned choice. But it does not create a tension; they accept the choice that has been made by the teacher.

3. Extension of the knowledge of mussel culture and of the problems which have to be solved by the scientific practice of the NIOO-scientists

Function: to get familiar with the first authentic practice of the NIOO-scientists working on mussel harvest optimization

Intended

The teacher shows a short fragment (4'00") from a video movie "De mossel natuurlijk" (The mussel in nature), which gives some idea of the mussel culture.

The students watch this fragment.

Thereafter, the teacher forms groups of 2-4 students. He invites these groups to think about the problems of the mussel culture, by asking them to describe sub-questions that should be investigated by the NIOO-scientists in order to answer the central question in this practice: "How could the mussel culture be optimized?" As a support for the students, he points to the three questions about mussel culture on p. 9-10 of the workbook:

1. How long will it take before the mussels reach the desired weight? 2. What is the maximum density of well growing mussels on a bank? 3. Which factors are most important?

Before they start, the teacher shows a Powerpoint presentation in which the activities of scientists from NIOO (Netherlands Institute for Ecology), who carry out investigations on mussel breeding, are shown.

The teacher points to think about differences and similarities between mussel culture in the sea and trout culture in a pond.

The students mention as a similarity that in both situations the environment has much influence on the yield. As a difference they mention that man has far less control in the Easter Scheldt: the circumstances in this open area are much more changing, among others because the boundaries are less sharp. The influence of the tide will be very important.

The teacher asks the students to think about what the specific contribution of the scientists could be for mussel culture. He asks them to complete the model drawing on p.11 of the workbook. He explains the drawing, with the mussel as a system with a boundary, embedded in his environment, where various factors are related with the mussel.

The students tell that the mussel breeders will not have access to exact information for all factors that play a role and will not be able to construct computer models to investigate the collective influence of all those factors.

They make model drawings with various factors that influence the mussel or are being influenced by the mussel. They think of at least four factors that play a role in optimal mussel culture, such as moment and frequency of harvesting, the influence of the weather, the amount of dumped mussel seed, the rate of flow of the water, the amount of food, the presence of predators. They are able to make clear for which factors the boundary around the mussel will be a real boundary.

Executed (31.22 minutes)

The teacher starts the fragment. In the end one of the mussel breeders says: "Nature is constantly changing and unpredictable." The teacher reacts to this statement by telling the students that the breeders have asked scientists from NIOO (Netherlands Institute for Ecology) to carry out investigations aiming at optimizing mussel harvest in this unpredictable situation. The students quietly watch the video, they do not ask questions. There are no signs of strong involvement at this moment.

The teacher asks the students to think in groups about what is important to know in order to answer the question of the breeders about the optimization of the mussel culture. The students express a number of questions like: What makes mussels grow, what are good temperatures? What is the effect of more food? What are the initial weight and the final weight of a mussel? How much room does a mussel need? What is the effect of water velocity and plankton? What is the growth rate of a mussel? (3b.1.W).

Actually, the questions address the level of the organism and the abiotic factors that influence (aspects of) this organism. Factors which play a role on the level of the population or the ecosystem, such as predation, competition with other mussels or with representatives of species, are not mentioned.

Next, the teacher shows a Powerpoint presentation in which the activities of scientists from NIOO who carry out investigations on mussel breeding, are shown. In 10 minutes a lot of information passes by very fast. However, after this lesson, 75% of the students report to understand what the NIOO-scientists actually do, after having seen the Powerpoint (3b.1.E).

He does not talk about comparing mussel and trout culture and also not on why the NIOO-scientists are needed (afterwards he declared this omission, because he wanted in any case to introduce the model drawing and there was not much time left).

The teacher says that these lessons will start at the level of the organism. He asks the students to complete a model drawing in their workbook (see figure 8.1) which shows the mussel. This start can be discussed. Another possibility would have been to start on the level of the population, because this is the focus for mussel breeding. The breeders start with a number of young mussels, which is deposited as a group on a suitable place in the Easter Scheldt, giving rise to a mussel bank. To verify if it would not be more logic in the eyes of the students to start on the level of the population (the complete mussel bank) they were asked if they could agree with the idea that it would have been better to start on the level of the population. After this lesson, only 10% of the students report to agree with this idea (3b.1.E).

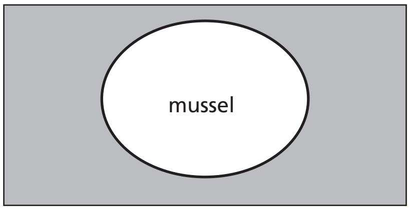


Figure 8.1. A scheme of the mussel as a system.

The students mention several factors. They also tell which of these factors can or cannot pass the boundaries of the mussel. Most arrows are drawn from the environment to the mussel and most of these arrows pass the boundary (see for an example the drawings in figure 8.2). Only 'current' does not pass. Both girls involved in figure 8.2 choose 'reproduction' as an example of the mussel's influence on the environment. This suggests that these girls have interpreted the arrow as a representation of the concrete transfer of the reproductive cells of the mussel into the water, and not a as an abstract representation of the mussel influencing the environment. Reproduction can be, by the way, a cause of confusion, because actually the mussels do not reproduce in the Easter Scheldt. They reproduce in the Wadden Sea, in the Easter Scheldt they are harvested before they reproduce, which is logical, because reproduction costs a lot of energy (biomass) in these external fertilizing animals. The teacher does not go into this.

In accordance with the majority of arrows drawn from outside to inside, most students do not think that a mussel has much influence on the environment (3b.1.W).

T: "Is this correct? Are there far more arrows from environment to mussel than the other way round?"
Leo: "Yes. A mussel is only a very small animal and the environment is much bigger."

(3b.1[3].C)

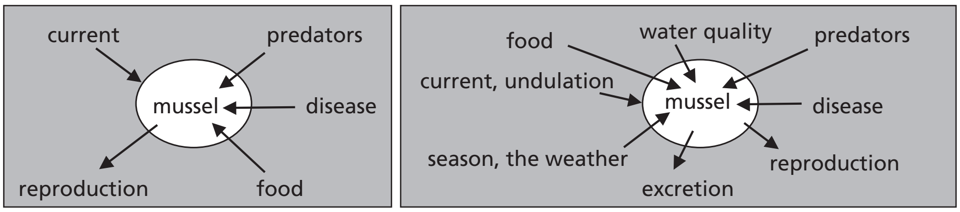


Figure 8.2 The drawings of a mussel and related factors of Joanne (left) and Charlie (right). (3b.1.W)

Over the course of this first lesson, many issues have been touched upon. As a consequence, some issues have been addressed only superficially. The teacher did not take time to go into the specific problem of the systems' boundary of the mussel and the comparison between the mussel culture in a open sea area and the trout culture in a pond, which should have given more insight into the authentic practice of the NIOO-scientists and its specific problems.

Second lesson

4. Reflection

Function: to discriminate between the 'nature' and the 'value' of the various factors, and to develop a motive to answer the central question

Intended

The teacher asks the students to reflect on what they have learned so far about the relation between the mussel and its environment. He asks them which factors they have discovered and how they influence or are influenced by the mussel. He uses the factors and model drawings as a transition to the central question of the optimal mussel culture.

The students name the factors they have discovered. They are aware that to be able to answer the central question they have to:

1. *restrict themselves to some aspects of the mussel;*
2. *concentrate on growth as most obvious phenomenon;*
3. *find out what is the input (feeding) and the output (excretion).*

If the students do not mention point 1, the teacher asks them to think about which factors are most important for an optimal mussel culture. If they do not mention point 2, he introduces growth. If they do not mention point 3, he introduces feeding and excretion.

Executed (5.28)

The teacher confronts the students with all the factors they have thought of in the first lesson and asks them what to do, taking into account the question on optimization. The students show they are aware of the rationale to solve this central question.

T: "And now we have a very important point. When you remember the task of the NIOO-scientists ...we want a good prediction about a good mussel harvest. When the scientists would see the long

list of factors which you together have made, what would they do next? Let us suppose that you are a scientist yourself. You are confronted with 25 factors. What has to be done next?"
Shirley: "I think he is going to investigate if there are more factors."
T: "OK. More factors there are. Let us suppose he has 50 factors. And which step will come next?"
Joanne: "He should make an arrangement based on their importance."

(3b.2[4].C)

Joanne seems to be aware of the point 1. The discussion goes on.

T: "OK. This seems sensible. He will choose the factors which are important. A model will always be a simplification of reality. Well, we want to know which factors are important. How do we decide now? Remember what our question was: he is interested in growth of the mussels. What will he choose?"

(3b.2[4].C)

The teacher is giving away point 2 here.

Eve: "Things that influence growth."
T: "Yes, that is a good remark. He will be interested in the factors that influence growth. Which factors will that be? Who of you has an idea?"
Caroline: "Water quality."
T: "Water quality. What else?"
Myra: "The amount of food."
T: "Exactly. This is very important. He has to know what is the food of the mussel and how much it eats. So, if I know how much it eats, do I know how fast it will grow?"
Caroline: "No."
T: "What else do I have to know?" […]

(3b.2[4].C)

Although interested and cooperative, the students do not seem to know the answer.

T: "If you think of your own bodies. If you know what you have eaten on a specific day, you will weigh all the food and drinking, do you know what your weight will be in the evening?"
Ger: "No."

T: "Why not?"
Ger: "There will be digestion."
T: "OK, digestion. Even more, what else could there be?"
Niles: "There will be dissimilation."
Charlie: "And excretion."
T: "Excretion. Very good, Charlie. Growth is the difference between food intake and excretion."

(3b.2[4].C)

With some help, at least some of the students seem to be aware of point 3.

In conclusion, the teacher succeeded to stimulate students' thinking about the factors that are important for growth, but in some cases he has been too dominant, which can inhibit active thinking of the students.

5. Zooming in on feeding and excretion of the mussel
Function**:** to acquire basic biological knowledge that is needed to answer to the central question about mussel optimization

Intended

The teacher shows an animation about the feeding mechanism of the mussel. He brings to the students' attention the 'strange' character of this mechanism. The students describe the filter feeding, going from the inhalent region, via the ctenidia (gills), to the mouth. They also describe the discharge of water via the exhalent region.

Executed (6.25 minutes)

The teacher tells the students that today they will work with real, but dead (cooked) mussels. Therefore, as an introduction to this activity, he will first show them an animation which demonstrates the way of feeding of mussels. Some quotes from the conversation on this theme.

T: "Here you can see how a current of water with food particles goes along the gills. What factor causes this current to keep flowing?"
Ger: "These cilia."
T: "Right. So, it is not the tide or so. He keeps the water flow by moving his cilia."

Niles: "But where do these food particles go to"
T: "OK, let's start the animation again. Where do the particles go?"
Charlie: "To the gills."
T: "OK, remember this. We will come back to it before we start with the real mussels."

(3b.2[5].C)

Afterwards he asks the students to recall what they have seen in the animation and to put it in their workbook. Most of them give a rather accurate description, where the transport of food with a water current from the back side is mentioned, together with the filtering in the gills and the further transport to the mouth in the front side.

Anne: "The water flows into the mussel; it takes the food out with the gills. There it discriminates between food and non -food, it eats the food and 'spits out' the rest. The water flow is maintained by the cilia."
Marlin: "The mussel absorbs water through the gills. In the water are food particles and other things. The food goes to the mouth; the rest is excreted with water."

(3b.2.W)

This is confirmed by the fact that, after the lesson, 57% of the students indicate that the animation explained to them quite clear how mussels feed (3b.2.E).

This activity seems successful: students describe in a short period the feeding behaviour of mussels.

6. Working with mussels
Function: relating animation and model drawings with natural phenomena

Intended
The teacher shows the students cooked mussels. He asks them to investigate the structures they have discovered in activity 2 and to link them with the mussel culture: which of the structures will be eaten after harvesting?

The students investigate the inner anatomy of the mussel and try to locate the structures. They *realize why the foot is so small and indicate the mantle and its content as the parts that are important in mussel culture.*

Executed (19.52 minutes)

The teacher starts reading aloud a text of NIOO-scientist Luca van Duren (p.13-14 of the workbook) about filter feeding and the velocity of this process. Then he introduces the real mussels. The students have to study the inner anatomy of the animals which are cooked before, because it is not ethically acceptable to dissect living animals (which will resist strongly to be opened, by the way).

The students investigate the anatomy, guided by the questions in the workbook that they have to answer. They understand why a mussel will use his constrictor muscle ("when predators come") and why it is no problem to have only a small foot ("because he only moves a little bit"). The flesh will be "all" according to some, or more precise: "the mantle, gills, palps, and digestion gland". (3b.2.W).

Everybody is working hard on this task. Some of them become really involved in the mussels and ask questions about their reproduction. After this lesson, 60% of the students report that this activity is fascinating, also 60% that they understand the feeding mechanism of the mussel (3b.2.A).

Also this activity seems to be successful: the students have worked hard and autonomously on the mussel's anatomy and are able to link the factors they have used in their model with natural phenomena related with the mussel.

7. Weighing
Function: to pick up basic knowledge about quantitative parameters

Intended
The teacher explains the three different types of mussel weight: total weight, flesh-weight and dry-weight. He asks the students to weigh the total weight and flesh weight of a mussel and to dry the flesh in an oven to find the dry weight later. He mentions the threshold of flesh weight / total weight × 100%, which has to be above 16%. This threshold is very important in the mussel auction. If a sample of mussels stays below this threshold, the whole batch will not be sold.

The students perform the weighing activities and calculate mean values for all three types of weight.

Executed (16.12 minutes)

The teacher tells the students that they have to perform three weighing activities, two immediately (total weight and flesh-weight) and one (dry-weight) after a week in an oven, where the water leaves the flesh by evaporation. He explains the differences between these three types of mussel weight and the threshold of 16% that the ratio of flesh-weight /total weight of a number of mussels has to pass for sale in the auction.

The students perform the weighing. After the lesson, 93% of them report that they understand the difference between flesh-weight and dry-weight (3b.2.E). After the weighing activities, the student Leo volunteers to calculate the mean values in the group of total weight and flesh-weight: 9.95 gram and 3.66 gram, respectively. This leads to a mean percentage of 36.78 %, which is far above the threshold of 16%.

The students seem to understand the technique, all of them not only write down their own results, but also take the average data from the blackboard.

Third lesson

8. Reflection on models
Function: to understand what can or cannot be reached with different types of models

Intended
The teacher comes up with the model drawing from the first lesson and with the information about feeding and weight from the second one. He asks if we can solve our question about optimization.

The students consider that this model is complex, but not quantitative and dynamic. They understand that time has to play a role in the model so as to predict growth. The teacher asks the students which factors will change in time (are variable).

The students think that some factors are dependent on other factors, they could change. Other factors are independent (they are constants, that can be fixed by the mussel breeders). In the calculation of growth, some factors do not play a role at all; others play a role, be it direct or indirect.

The teacher asks what could be an advantage of computer modelling in this calculation.

The students realize that calculating developments can get so difficult that their mind or a calculator do not lead to an adequate outcome.

Executed (17.16 minutes)

The teacher reminds the students of the model that they made with all factors related to the environment of a mussel. He puts a summary of all the factors mentioned on the whiteboard. Then he mentions a disadvantage of this model.

T: "This model is complex, but not dynamic. I do not see any figures; I cannot know how the situation will develop in future. It will be interesting to find relations between the factors and to find out what a mussel breeder could regulate; what could he keep constant and which are variables he cannot control? What do you think he can control?"

(3b.3[8].C)

Here the teacher gives away the first question, telling already that the model is complex, but not dynamic.

Lance: "The current."
T: "The current. How should the breeder do that?"
Lance: "If he does not want current, he could put the mussels in closed tanks."
T: "OK, that is possible. Why should he not opt for this solution?"
Eve: "The mussels need food."
T: "Right. So why not build enormous aquaria?"
Eve: "It would cost a lot of money to supply food."
T: "OK. So he takes the risk that he cannot control this factor. He will ask NIOO-people to investigate how this factor will vary. Is there another factor the breeder can keep constant? Pollution, predators, disease, other mussels, temperature?"
Daisy: "Other mussels."
T: "OK. And does he do so?"
Daisy: "Yes."
T: "Surely, you have seen this in the film fragment. How did he do so? Where did the mussels come from?"
Anne: "From the sea."

Shirley: "The Wadden Sea."
T: "Yes, from the Wadden Sea. He puts in a certain number of mussels. And he harvests all of them on a certain moment. There is no reproduction in the Easter Scheldt. The breeder controls the number of mussels. But there are factors which he cannot control and this is where the scientists come into the fore."

(3b.3[8].C)

I conclude that the students show understanding of the influence of various factors on the growth of the mussels, but that the end is not satisfying. After all, from the fact that scientists are needed, we cannot conclude something about the need for modelling. More should be said more about this.

9. Modelling with a computer: a model of the growth of a mussel
Function: to get acquainted with a quantitative approach

Intended
*The teacher creates a transition from the real mussel via model drawings to Powersim computer modelling, by showing them the subsequent stages on p. 17-20 of the workbook (see figure 8.3). In these figures the students are confronted with a series of models starting with a picture of the mussel. Hereafter, they see a schematic drawing, a mussel as a system and at last a Powersim model of the mussel filtering and dissimilating, with the quantitative change in dry-weight as the focus. Then he asks them to work in dyads and to build their first two models, making use of the instruction in their workbook. In the first model the intake of food is a constant (being filter_rate * plankton_concentration * efficiency factor), while in the second model the plankton_concentration is dependent on the variable sunlight intensity and the filter rate is dependent on the size of the mussel.*

The students read the text of chapter 3 about the construction of the basic Powersim models of a mussel and build these models.

Executed (39.22 minutes)

The teacher starts talking about modelling, using the four figures in the work book. Most of the students examine these figures attentively, there are no questions.
After reading the text, they first answer questions in the work book about systems boundaries. About the boundaries of the mussel and the Easter Scheldt can be said

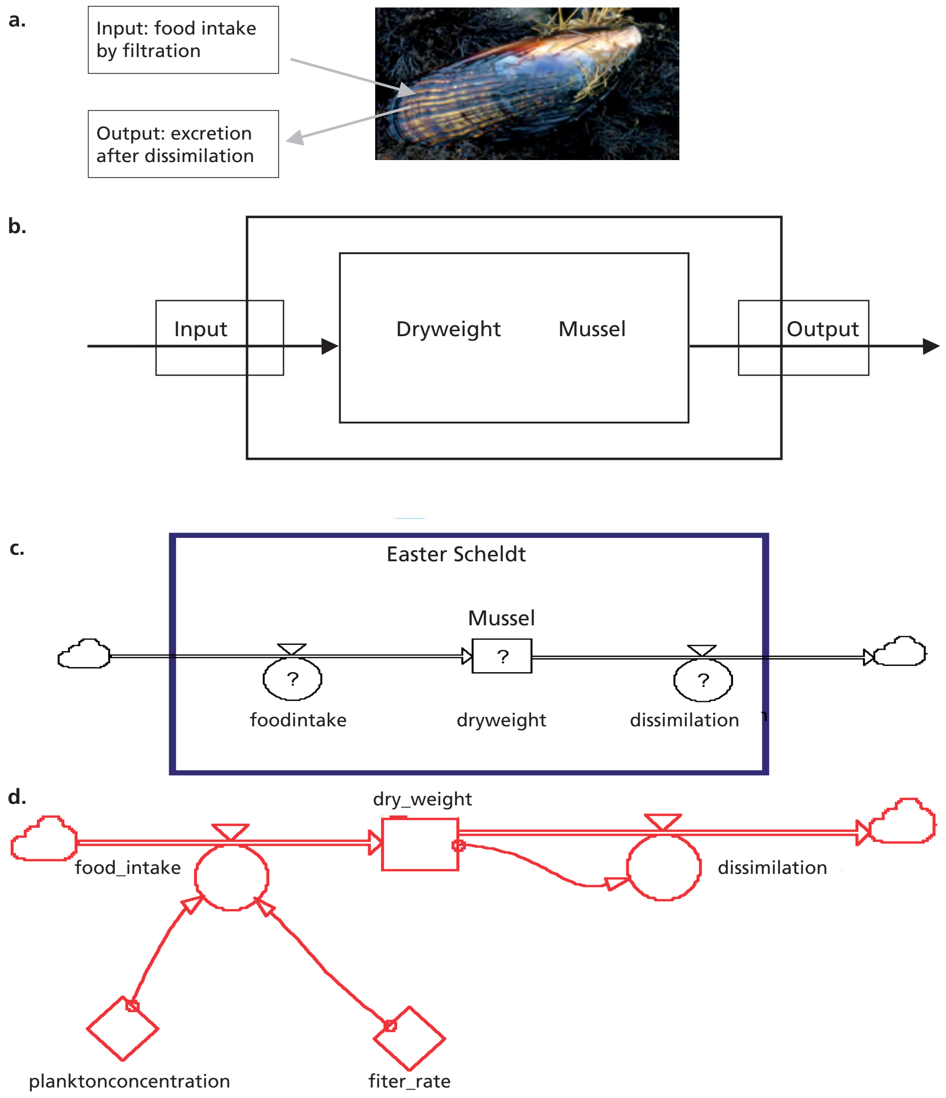


Figure 8.3. The steps from a mussel (a) via a drawn model (b) to the Powersim model, which in c is combined with systems boundaries of the mussel and of the ecosystem, and in d presented in the form the students are building it.

that for all of the students, the system boundary of the mussel is the shell and the boundary of the Easter Scheldt is the coast. When they are confronted with the question about the necessity of digestion of the food, it does not ring a bell. They do not realize that there should be a system boundary of membranes enclosing the internal environment of the mussel, which means that big food molecules have to be broken down to smaller ones which can pass these membranes (3b.3.W). Food, water, and waste products can, in their view, pass the system boundary of the mussel. Some of the students consider the system boundaries of the Easter Scheldt to be closed boundaries, while others write that water can pass, for example in a flood (3b.3.W).

Next, the students start to build their Powersim models in dyads. After 13 minutes the first couple has completed their first model. Some of the dyads have some syntactic difficulties, like with a comma or a dot for introducing a decimal point[1], or with typing formulas in the Definition function. Some students do not immediately see how interrelated factors should be linked with each other, and supplied with a constant number to specify their relation.

However, at the end of the lesson all dyads have built the first model, while some have already started with the second, more realistic one. Most students understand that both their models fall short: only 13% believes they are sufficient to predict growth. Also, a majority of them (87%) expects that the mussel breeders need the NIOO-scientists to optimize their harvest. And 80% of the students think that one mussel will have no influence on the plankton concentration in the Easter Scheldt. Their ideas about models are somewhat contradictory. On the one hand, 73% of them expect that a model will be better if you introduce more and more factors. On the other hand, 67% agree that only important factors should be introduced in a model (3b.2E).

These models do not create big problems for the students.

Fourth lesson

10. Orientation on a bottom up approach from the mussel to the population
Function: to get an insight into the level of the population and its specific character

1 In the Netherlands a comma is used generally for indicating a decimal point, where Powersim uses a dot.

Intended

The teacher recalls the building of the first two models of a mussel. He asks the students if these models can be used to inform the mussel breeders.

The students understand that mussels do not live on their own, but in a big group on a mussel bank.

The teacher asks if one can get the total weight of those mussels by multiplying the number with the calculated weight of one mussel.

The students mention the phenomenon of competition on food.

The teacher asks the students to make a model drawing of the population (being the group of mussels on the bank), including the boundaries of this population and new factors coming up, to find out any differences with the level of the organism.

The students indicate that the mussels together will have influence on factors such as food concentration, flow of the water or influence on each other by pushing one another aside. They realize that a population will have more spacious boundaries than one mussel, but that this population cannot be found at any depth of the Easter Scheldt.

Executed (16.08 minutes)

The teacher first reflects on the two models which (a part of) the students have built and indicates some problems. Some dyads have developed models that are actually running, but they have arrived at far too high weights, because they did not fill in a low value constant in the formula for filtering. In these dyads, there was only a minority that corrected their models, because they remembered the flesh-weight values. The teacher tells the students that they will have the dry-weight soon now, which gives them a good opportunity to validate their model more accurately.

Then the teacher continues by asking something about the second, more realistic, model which most of the students have already started with, or are beginning to start with.

T: "This second, more realistic model that you are working with. If you have finished it, could you go with it to the mussel breeder? We know the weight of the mussel after about 550 days. Can a scientist bring this result to the breeder?"

Eve: "No."

T: "Why not, Eve?"

Eve: "There is nothing about water flow or about enemies in it."

T: "Can everybody understand Eve's argument? And there is more. Does this breeder cultivate one mussel?"

Kelly: "No."

T: "No, a lot of them. So, now we have a problem. Suppose you have a good idea of the growth of one mussel. Can we now just multiply with for example 1000 to get the weight of 1000 mussels?"

Shirley: "You have to take the average weight."

T: "What will be the problem for the mussels?

Joanne: "Shortage of food."

T: "OK. The mussels lie on the bank. What are they doing?"

Kelly: "They filter water."

T: "Right. According to this formula they filter water and take an amount of plankton out of this water. Now suppose there are a thousand of them. Is filtering still as easy as for one?

Joanne: "No, there could be a shortage of food."

T: "Right. There will be competition for food in biological terms. Look at the figures (see figure 8.4) where you can see three scenarios. Could you fit number 1 with no mutual influence, or competition or just the opposite, cooperation, because maybe the mussels work together in filtering the water."

The students all agree on 1 being 'no influence', 2 'competition' and 3 'cooperation' in figure 8.4.

(3b.4[10].C)

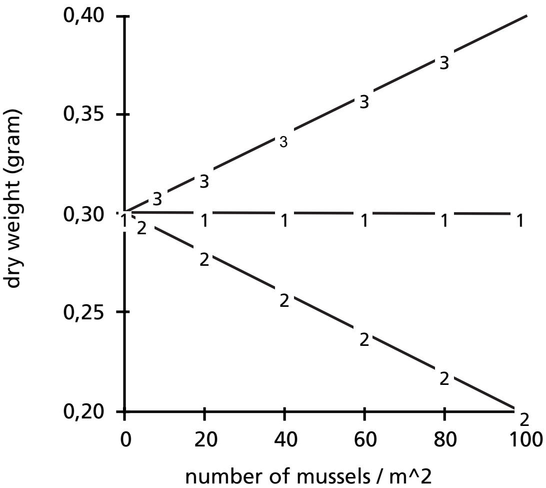


Figure 8.4. Population-effects in three scenarios.

The students first spend a lot of time (about 20 minutes) finishing their work on the second, more realistic model of the growth of a mussel. Hereafter, they start to draw a model of the mussel population. Most of them do not clearly indicate systems boundaries and do not formulate more specific characteristics than influence of the population on the food (plankton concentration). Many of them write 'competition' in their model, and use arrows from one mussel to another and back.

Although they know what a population is, the students have difficulties to think of specific characteristics besides competition.

11. Confrontation with ecological and economical reality
Function: to link the acquired knowledge to the central question

Intended
The teacher reminds the students on the 'strange' feeding behaviour that was named in lesson 2. He asks the students to think about what, as a consequence, might be the result of living together on the bank for all mussels. And about what could be the consequences for mussel breeding, especially on the mussel auction.

The students declare that all mussels will grow badly in this situation and that all of them will stay below the critical threshold at the auction.

Executed
This part has not been dealt with. The teacher pays attention to the consequences for the auction, but not before he introduces the activities 12 and 13.

12. Weighing and validation
Function: to link real data with the model, making possible validation of the models after running

Intended
The teacher remembers the students on the measurements they have to do on dry-weight, which will give them an idea of a realistic value of the dry-weight. This is important in the critical dry-weight on the auction[2]. The students weigh the mussels that have been in an oven for a number of days and have gradually lost all the water that was inside.

2 A critical ratio between flesh-weight and total weight of 16 % corresponds with a dry-weight of about 0.25 gram of one mussel.

The teacher asks the students what the contribution of the NIOO-scientists can be on determining the effect of mussel density on the dry weight of the mussels.

The students realize that the scientists can perform measurements and build models where all important factors like for example density and plankton concentration can be taken into account.

Executed (10.05 minutes)
The teacher asks the students to take some time to determine the dry-weight of the mussels, which have been dried in an oven for a week now.

They go to the oven, determine the dry-weights with a balance and express that these dry-weights are really very low. The average value is calculated on 0.7 gram (3b.4.W). Actually, this activity should come earlier to really help students to validate their models. The actual value of the dry-weight can only be used for the models to come and should have been available before the first model was run.

Fifth lesson

13. Modelling a population effect
Function: to quantify the effect of the density (a population characteristic) on dry-weight

Intended
The teacher tells the students that they have to build a population model. They can use an incomplete model, in which they have to match a number of factors with parts of the model. They have to test their model with varying densities of mussel and investigate the effect on dry-weight of the mussel.

The students, working in dyads, first try to find out the character of the factors they have to match with parts of the model. After matching and implementing the factors into the model, they relate all factors, try to think of formulas, test the model and validate it.

For students that proceed fast, there are some extra tasks about the special spring tide barrier in the Easter Scheldt and about mussels in the environment of Limfjorden (Denmark). The spring tide barrier is an open system (see figure 8.5) which can be closed temporarily in dangerous spring tide situations. The students can model what the consequences of closure for the mussels *are. NIOO-people do investigations on mussel banks in Limfjorden, where the influence of the tide is very small, while the wind has much influence on the water current (see figure 8.6).*

Figure 8.5. (left) The spring tide barrier. Figure 8.6. (right) Limfjorden Area (Denmark).

Executed (47.49 minutes)

The teacher tells the students they will have to continue on the level of the population. He says that it is a difficult step to pass from a model of one mussel to a model of a population, because factors that are specific for the population level will have to be introduced. He shows them the incomplete model (see figure 8.7) on the beamer and tells them that they have to fill in a number of factors on the places with the question marks to complete it (see figure 8.8 for the desired result). The cricital dry-weight (see p.116) is introduced into the model to enable the students to validate their model outcome with the outcome which is desired on the mussel auction.

The students try to match all the factors with the model and implement these factors on the places with the question marks. Most of them do realize that 'local plankton concentration' will be the stock and 'refreshment rate of water' will be constant, but filling in the other three factors ('supply', 'consumption' and 'difference in concentration') appears to be problematic; all of them need help to complete the 'jig saw' and also to fill in the relations that are needed to make the model run properly. Sometimes the model gets stranded and it has to be built all over again, which causes frustration for the students.

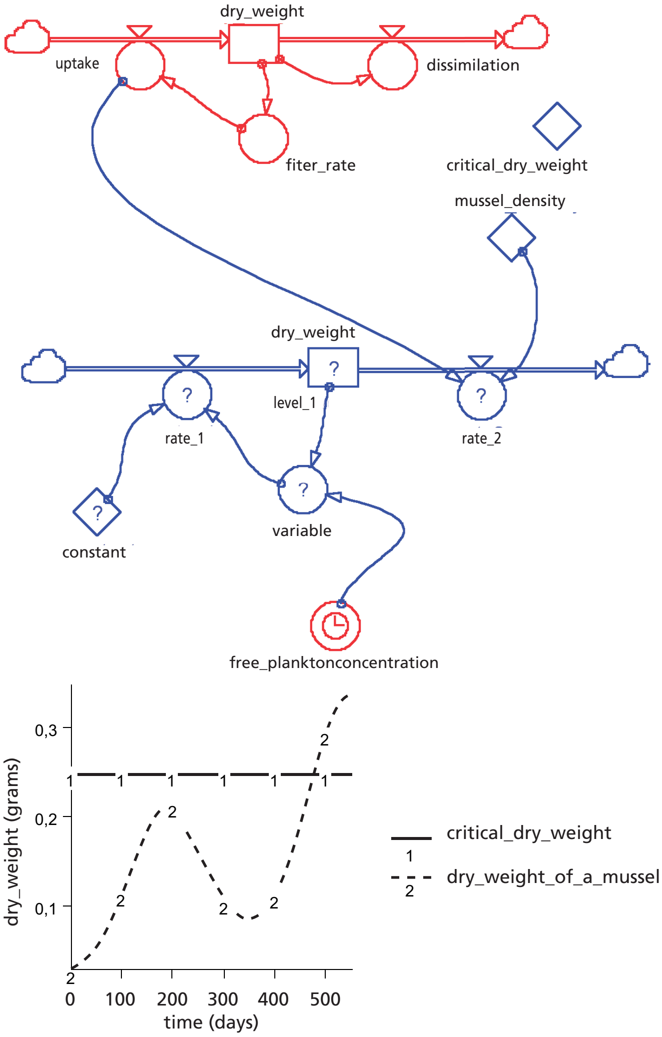


Figure 8.7. An incomplete model of a population of mussels, with an included model of a mussel and a graph with the dry-weight of a mussel and its critical dry-weight.

Eve: "It does not want to play the model. It freezes."

Lance: "I do not believe you. This computer is ………"

Eve: "Sir, we finally had the right model and now it freezes."

T: "Is that so? I am afraid you have to start all over again."

Eve: "Damn it."

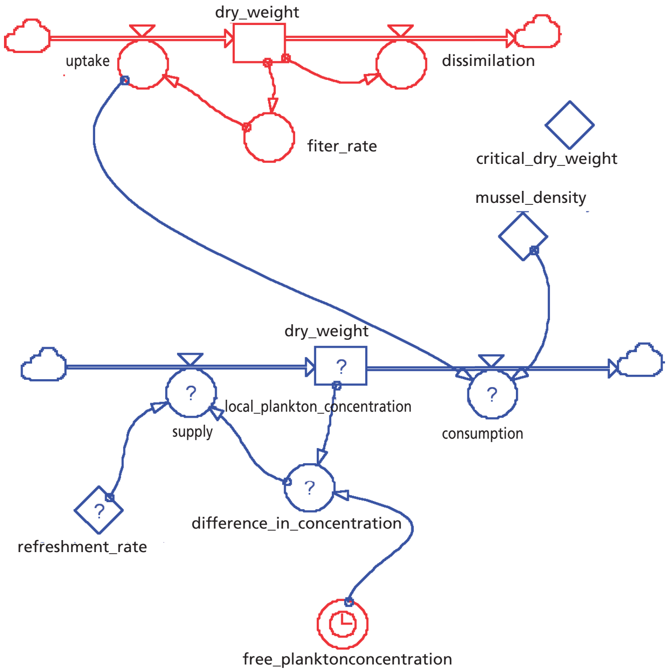


Figure 8.8. A complete model of a population of mussels, with an included model of a mussel. Only the nature and the quantification of the relations have to be filled in yet.

(3b.5[13].C)

The students use the rest of this lesson to complete their models of the mussel. Most of them have caught a backlog: they have not yet finished the population model at the end of this lesson. Only a few students have worked so fast that the 'extra stuff' about the special spring tide barrier in the Easter Scheldt and about mussels in the environment of Limfjorden (Denmark) can be tackled.

Sixth lesson

14. Extension of the bottom up approach: from the population to the ecosystem
Function: to be confronted with the ecosystem as the third level of organization

Intended
The teacher mentions the third level of organization: the ecosystem. Here the relation between the mussels and many other species comes to the fore. He asks the students to think which

animals play a role, besides conspecifics and food particles. The students are asked to make a new model drawing with the ecosystem in focus, with new factors and the system boundaries.

The students name competitive species like cockles, predators like oystercatchers or starfish and parasites like bacteria or maybe small crabs. They transform their drawing to a kind of food web.

Executed (21.56 minutes)

The teacher reminds the students of what they have done so far. To level off the differences in pace between the students, he first shows on a beamer the complete population model with competition, and lets it run with various densities of mussels.

T: "Now we start with a density of 1 mussel per square meter. This gives, as you see, the same result as our first model. And the graphs that you see of local plankton concentration near the mussel and free plankton concentration in the Easter Scheldt are the same. How can we explain that?"

(3b.6[14].C)

A total silence is the result. The students are looking at the model, but do not give signs of understanding.

T: "Why is there no difference in plankton concentration when we have one mussel?"
Niles: "He does not eat enough to make a difference."

(3b.6[14].C)

Hereafter, the teacher shows a Flash animation where is shown what happens with plankton near the mussel and at some distance.

T: "Now let us go back to the Powersim model, we will increase the density. What will happen?"
Eve: "Mm.., I think that dry-weight will go down."
T: "OK. What about the plankton concentrations?"
Eve: "Uhm…, I think they will be somewhat lower."
T: "Both of them?"
Britney: "Only the local concentration."
T: "I think you are right. Let us run the model … As you see, Eve's hypothesis is confirmed. The

mussels lose weight. And the local concentration stays behind. Now let's put the density on 4000. They lose weight terribly as you see. We can try 8000 also. Yes, it is even worse.."

(3b.6[14].C)

At this point, the teacher introduces the phenomenon of cooperation.

T:"But now there is something interesting. The NIOO-scientists with their special measurements have discovered an interesting phenomenon. That is, the mussel can indeed take advantage of each other also. Look, this small movie, called Paint Oyster, I got from them. There are two currents, with black and red ink. And they pass along the mussel bank. Look what happens."
Kate: "The black stays in the bank."
T: "Does the black current not pass the bank?"
Britney: "Yes, it does."
Eve: "No, it goes round."
T: "Indeed, the black current is swirling. What is the advantage for the mussels of this phenomenon?"
Sean: "They could reach their food better."

(3b.6[14].C)

After this discussion, the teacher summarizes two effects that can not be applied to the mussel, but can be applied to the population: competition and cooperation. In the three graphs in the workbook (see figure 8.9), with the question which of the three is best applicable for the cooperation of mussels leading to a better supply per mussel when the density increases, a vast majority of the students that already has reached this question, chooses for figure b. This figure suggests that the supply will be better with higher densities, but not in a linear way, as in figure a. The students show understanding of the qualitative and quantitative effects of competition and cooperation in a population.

Hereafter, the teacher makes a step to the third level of organization: the ecosystem. He seems to feel the pressure of time; this is demonstrated by the fact that he does not take time at all to investigate ideas of the students about this level and its specific characteristics. He starts immediately talking about the next Powersim model. In this model, birds are introduced as predators. This means that the next bottom-up step is put: from the population to the ecosystem.

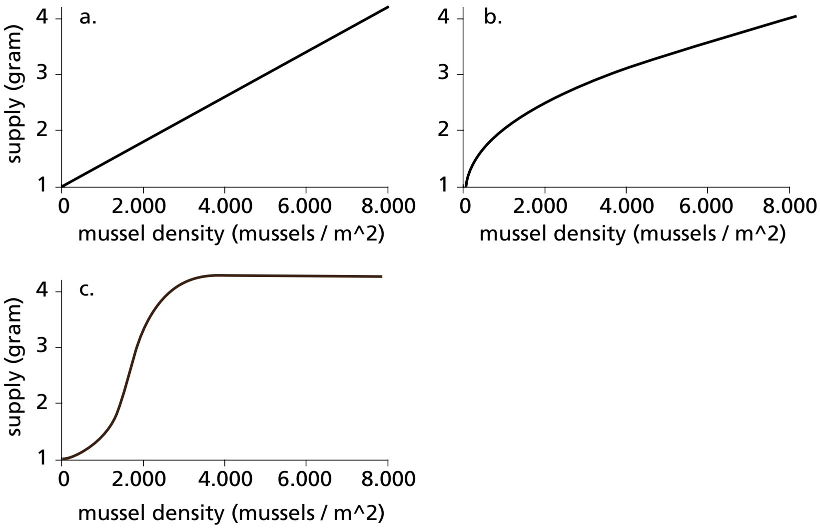


Figure 8.9. The relation between mussel density and food supply in three formulas:
a. supply = 1 + 0.004 * mussel density;
b. supply = 1 + 0.035 * mussel density^0.5;
c. supply = 1 + graph mussel density.

T: "You see a model with two populations at page 33. We choose for a predator population, which means animals that can attack mussels for food. Birds like the Common Goldeneye and the Eider Duck dive and they could eat the mussels. And you can take these birds as a constant factor, because they do not depend on the mussels. That is because they eat many other species. Remember, in Powersim you put a rhombus to introduce a constant factor. And the mussel density, which was a constant factor, only determined by the mussel breeders, is turned now into a stock, there is an outflow by bird predation now. If you have finished that model, we have finished working on this practice and we will go to the second one, about rabbits in the dunes."

(3b.6[14].C)

The teacher only asks the students to take some time to make the model drawing of the ecosystem. This remark is not enough to provoke the students, which is shown by their drawings where only a few show remarks about characteristic factors. As the boundary of the ecosystem most of them describe the seashore, while some write down that there is no boundary, because the birds enter and leave the water with their beaks to hunt for mussels. Some write other animals like starfish and other shellfish in their drawing. No one has designed a complete food web.

15. Modelling the ecosystem
Function: to quantify ecosystem related factors and their influence on the mussel population (density) and mussel (dry-weight)

Intended
The teacher asks the students to extend their population model with birds which are introduced as predators. The density of the birds is not dependent on the mussel density, because the birds have lots of other food sources. Therefore the density is introduced as a constant value. The consequence of the bottom-up approach is that more factors are needed, which makes the model more complicated.

The students build the model, while they first make a sketch of the extension, quantify and formalize the relations they have thought of with the help of offered real data and at the end run and validate their model and test it in various situations.

Executed (29.43 minutes)

The teacher has already instructed the students about building the model during the former learning activity.

The students extend their model to include the birds. They discover that there are no effects with the present day density of 500 birds on a total area of 10^7 m^2, because they forage over this very vast area of the Easter Scheldt. The students try to find out how many birds are needed to bring the mussels under a critical density. Some of them desperately want to calculate this number exactly. This could be an indication that the model is no longer related in their thoughts with the real world.

The students also observe that by the predation of a number of mussels by the birds, the density of mussels will decrease, but the surviving mussels will grow more, so they find effects on the levels of population and organism both.

Seventh lesson

16. Reflection on systems thinking and development of concepts
Function: to consolidate systems thinking ideas and developed concepts

Intended
The teacher explicitly talks about the system characteristics of the ecosystem and about the

bottom-up approach, from a mussel via a mussel population to the ecosystem of the Easter Scheldt and back. He asks the students to name a systems characteristic which can be found on each level and a characteristic which is specific for a level. He asks also what the value of this systems thinking is for the scientist, working on the mussel optimization problem.

The students are aware that at all three levels of organization there are interrelated factors. They determine that an organism lacks specific properties of a population such as density or competition. They also determine that a population lacks characteristics which are specific for the ecosystem, such as predation or parasitism. They find out that for the scientist all three levels are important, because all these levels influence mussel growth, for example through filter rate, competition and selective predation.

Executed (5.27 minutes)

In the former lesson, the last sentence of the teacher was: "If you have finished that model, we have finished working in this practice and we will go to the second one, about rabbits in the dunes." This can be considered as a prelude to a serious problem, because this suggests that he will go too fast to the second authentic practice, without taking the time to reflect explicitly on systems thinking and concept development. Indeed, the teacher starts immediately with the second practice about management activities in a dune area with rabbits.

He talks very short about the three levels the students have met in the first practice and then he continues:

T: "We are interested if you can use what you have learned about three levels of organization and how to model, in this new practice. You can find the model that we use for finding the solution of the dune manager's problem of how to get back a higher number of rabbits in the dunes, on your computer as duin1.sim."

(3b.7[16]C)

Hereafter, he asks the students to continue working on their models. Most of them are actively working on their models during the rest of the lesson. A big difference in pace between the dyads has come about: many of them are still working on the ecosystem problem with the birds, while others have already started with the rabbits. The teacher reacts to this by creating fewer central moments in the lessons. This leads to severe deviations from the scenario. There is (taken) too less time for really concentrating on re-contextualisation of the concepts that the students developed in the first practice and on focussing on the problem that is central in the second practice. Some of the students have already started working on the rabbit models. They are working hard, but they seem 'on autopilot': they are just doing the tasks from their workbook, without reading carefully the text about the practice and its problem.

Despite the difference in pace, most dyads work concentrated on their models, sometimes asking advice from each other or from the teacher. Most questions are about matters of calculation and about using the correct formulas for relations.

Eighth lesson

17. Re-contextualization, going to another practice
Function: to use the concepts they have developed in the first practice in another practice.

Intended

The teacher investigates whether the students are able to pass towards another practice in another ecosystem. He uses two steps for this transition.

First, the transition from the mussel optimization practice to the dune management practice is facilitated by making a comparison between mussel culture in Rìa de Vigo (Spain), where mussels reproduce and die from natural causes, with the culture in the Easter Scheldt. The students have to make a comparison in complexity and dynamics between both areas on the basis of information offered to them in the workbook. Hereafter, the practice of managing rabbits in a terrestrial (dune) ecosystem is introduced. The students have the task to find the differences in strategy between mussels and rabbits, when confronted with a lack of food. They have to think about what activities should be performed by the dune management people to raise the density of rabbits in the dunes. This density has decreased strongly during epidemics and has not gone up again after the decline of the epidemics.

The students are aware that in Rìa de Vigo the mussel population will show a more dynamic pattern than in the Easter Scheldt, because man has less control on reproduction and death there. This lack of control will result in a greater complexity.

They understand that rabbits, because of their mobility, can compete for food. Some rabbits will have much or at least enough food, while other rabbits will have nothing. This competition between individual rabbits will result in a cricital value for the density of rabbits: the carrying capacity. While mussels are all decreasing in weight in periods of lack of food, the density of rabbits will reach this carrying capacity, the rest will die. The students understand that the problem to be solved here is on the levels of population and ecosystem, not on the level of the organism. They think of factors like food and predators.

Executed (15.02 minutes)

In connection with what happened in the seventh lesson, the teacher also does not take time for re-contextualisation during this activity. He has observed that there are students who have already started working on questions about the mussels in Rìa de Vigo and the rabbit managing practice in their work book, while others are still working on the last model of the mussels. Now he just asks the last ones, also to read the accompanying pages in the work book and to answer the questions.

The students are able to solve these questions. They show understanding of the difference in dynamics and complexity between the Easter Scheldt area and Rìa de Vigo.

Joanne: "In Rìa de Vigo man has less influence, so there will be more complexity and dynamics."
Leo: "The system in Spain is more complex, because there are more factors. Also it is more dynamic."

(3b.8.W)

They are aware of the 'shift in level' in the second practice. Most of them write that in this practice the starting level will not be the organism. According to some of them it will be the population, many write down the ecosystem.

About the carrying capacity they think that food and predators are very important.

Marlin: "To get the rabbit population to increase, you have to keep the enemies low and take care of sufficient food."
Joanne: "The number of predators has to decrease, there has to be more food, plants."

(3b.8.W)

18. Modelling in another practice
Function: to understand the quantitative relations between the densities of rabbits and predators and between rabbits and food

Intended
The teacher asks the students to explore two ready-made models. The first model is the Lotka-Volterra model, showing density-dependent regulation between populations of rabbits and foxes. The second model is a model with a population of rabbits confronted with a variable value of the carrying capacity. This is caused by changes in the surface of the area they are exploiting and in the amount of food which is available. He asks the students about the level of organization and the time-scale of these models.

The students explore these ready-made models. They determine that these models are about the levels of the population and the ecosystem. It handles about the size of the population of rabbits, not about individual animals, being influenced by predators or food. They also realize that, as a consequence, the time-scale is in years.

Executed (33.37 minutes)

The teacher first takes some time to discuss the levels of organization and the time-scale.

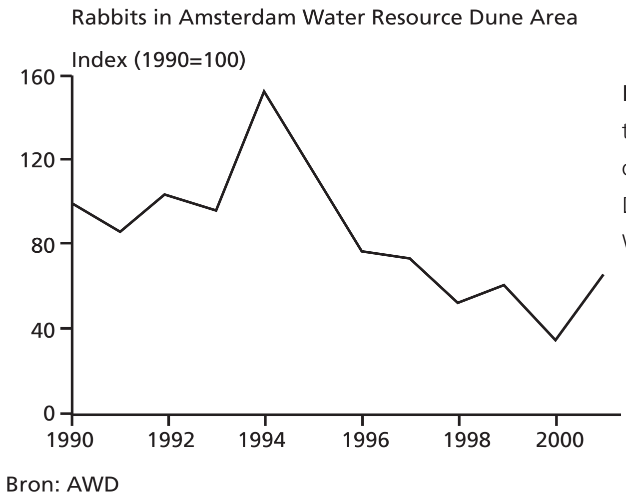


Figure 8.10. The development of the number of rabbits in the area of the Amsterdam Water Resource Dune Area. ('Amsterdamse Waterleiding Duinen').

T: "Before you continue with the rabbits, some remarks. If all of you could look at the graph on page 41 (see figure 8.10). What is the level of organization that is central in this graph? We have organism, population and ecosystem. I have read in your answers that it is not quite clear for some of you, what the right level of organization is here. Many of you write that the time scale here is in years and not in days like with mussels, because rabbits reproduce and take more time for it than mussels. I do not think that is true and it is also not the point. Look carefully in the graph. You see numbers on the Y-axis. So, what is the level of organization?"
Joanne: "The population."
T: "Right, Joanne. So we do not follow the development of one individual rabbit, but of the group.

(3b.8[18]C)

Unfortunately, the teacher does not mention the fact that many students have written the ecosystem as the level which is central here. So there is no real discussion about how to choose between population and ecosystem here.

After this, he asks the students to explore the two ready-made Powersim models. Most students have already started with this task; they continue their work on the dune models. They explore the Lotka-Volterra model and the model about rabbits with a carrying capacity in the dunes. They answer questions about a comparison between the formulas and the patterns in both models and about the dynamics of the second model in different situations.

Eve: "In both models the two stocks are dependent of each other."
Marlin: "In the second model we see the more grass, the more rabbits, just like the more rabbits, the more foxes in Lotka-Volterra."
Eve: "When the carrying capacity of the rabbits is halved, the period of the sinusoid pattern of the density of rabbits is 2 times longer and the amplitude 2 times as high. And when the area fit for grass to grow in the dune reserve is increased 10 times, the period is shorter and the amplitude is lower."

(3b.8.W)

The students do not seem to have serious problems with these exploring activities. They do not ask questions, they just explore the models and fill in the answers in their workbook. It is not completely clear if they really understand all that they are doing. But most of them report in an interview that they do understand the developments in the models.

I: "How did you see dynamics in the rabbit model?"

Leo: "Uhm .. we got all kinds of graphs.. with sinusoid patterns."

I: "And what happened with these patterns. Or were they always the same?'

Leo: "No, in due time the oscillations lowered."

I: "For example, yes. Did someone see something else?"

Ger: "When we decreased the area where grass could grow, the density of rabbits went totally down."

I: "Yes, that is right. And what did you see when you implemented a higher amount of grass? You did write about it in your workbook."

Ger: "The amplitude of the sinus went down."

I: "So dynamics can be seen in the sinusoid pattern. If the amplitude is high, is the dynamics strong or weak then?"

Marlin: "Uhm… strong."

(3b.I)

Ninth lesson

19. Modelling and its value

Function: to find out the advantages and the restrictions of models and their relation with the natural world

Intended

The teacher poses the question what the value of the used models is, in light of the problems to be solved.

The students think it an advantage that one can do 'experiments' without damage or high costs which can be the result of real field experiments; that one can understand complex processes; that one can predict what could happen. They name as a restriction that some processes are unpredictable and that it is difficult to take all factors into account. They say that the 'real world' is far more complex than the models.

Executed (23.26 minutes)

The teacher has looked through the workbooks of the students to find out what the students have done. He has observed that most of the students appear to have reached the last questions about the dune model in their workbook (p.45), where they have to answer, using the model outcomes, what causes the problem with the rabbit density in the dune area and what the influence of foxes will be. Some students have done extra things about the spring tide barrier in the Easter Scheldt, no one has done the optional assignment about the Japanese oyster, an invader into the Easter Scheldt. He first gives the students some time to finish their questions. Thereafter, he starts reflecting on the value of modelling.

T: "OK. Now let us talk about modelling. What is a model?"

Ellen: "A representation of reality, but simplified."

T: "Beautifully said. Now you have worked with computer models. What is the advantage of these models, compared to other models?"

Anne: "You can calculate with them."

T: "OK. What is the benefit for you of modelling?"

Ger: "You can learn more easily."

T: "OK. What about a nature manager? Why does he not just go measuring in the field?"

Burt: "It is easier to simulate nature."

T: "Easier, but if I have a real problem, what can I do?"

Niles: "He knows for example what will happen if he removes a species out of the ecosystem."

T: "OK. You can estimate the influence of a species. What else can you do? Think of our country where time is money."

Ger: "It will bring money."

T: "How do you mean?"

Ger: "It is better for the income. If a manager will be able to calculate what the optimal harvest will be for example."

T: "But why does the manager not perform experiments then?"

Ger: "It takes lots of time and it costs lots of money."

T: "And for a scientist?"

Lance: "With models you can exclude the influence of chance."

T: "That could be important. Real world is just chaotic. There will take place all sorts of strange things. And what sort of things does a scientist want?"

Joanne: "To create order."

T: "Exactly."

(3b.9[19].C)

I conclude that some students are aware of the simplifying character of a model and that they are able to name at least some advantages of the use of models in ecology.

20. Discriminating arguments

Function: to be aware of the various kinds of arguments people use to make a decision

Intended

The teacher poses the question what types of arguments (ecological, economic, normative) can play a role in the decision to act in the case of the decrease of rabbits, with the intention to restore their numbers. The students name for example the greater diversity of the ecosystem, the fact that there will be more visitors to the reserve, the fact that most people appreciate rabbits as 'cute animals'.

Executed (15.12minutes)

The teacher tells about the decrease of the rabbits which is caused by an epidemic, while the rabbit population did not recover afterwards. The dune managers did not understand why, so they did further investigations and discovered the changed balance between grass and shrubs. Then they thought of introducing cattle like Scottish Highlanders. Because of the feeding behaviour of these Highlanders, they supposed a shift of the balance into a 'rabbit-friendly' direction.

He asks the students about various types of arguments to restore the population of rabbits.

T: "Well, I hope you have any idea of ecological arguments that you will need in management discussions. But there are other arguments also. When rabbits are disappearing, people could say: "No problem, there are more shrubs now." If they will not say this, it is caused by normative arguments. They like the cute rabbits. And also economical arguments will play a role. Who of you could think of one?"

(3b.9[20]c)

Here he gives away not only the ecological, but also the normative type of arguments. He does not provoke thinking of the students.

Lance: "Collect toll. People like to see rabbits and they are prepared to buy a ticket to the dune area."

T:"Right. People will not like to go to an area with just shrubs. What would be problematic with normative arguments?"

(3b.9[20]c)

The teacher takes a position in the 'value' of the normative arguments here.

Shirley: "Well, if everybody likes rabbits and nobody shrubs, then you could have an area where shrubs are extinct."
Lance: "Not everybody will have the same normative arguments."
T: "That is right. And that will create a problem if you want to come to a decision. You can agree on ecological or economical arguments, but normative arguments are personal. For example, in a model you cannot build them in. Or am I mistaking?"
Ger: "No, of course you are not."

(3b.9[20]c)

I conclude from these quotes that he students seem able to discriminate between the three types of arguments. All of them agreed with the opinion of Bas Haring[3] whose opinion "A duck can have pain, 10 ducks can have 10 times as much pain, but a population of ducks does not suffer from pain." was quoted in their work book.

Elaine: "I agree with Bas. I think it is pitiful when an animal is in pain, but when a population disappears no one is in pain."
Britney: "I agree. If you talk about a group, this is unknown. You do not have feelings, because you do not have personal bond with the group. Therefore you do not care for."

(3b.9[20]C)

This means that they have the idea that normative arguments apply especially to the level of the organism.

The last part of the lesson (10 minutes) is used to tell the students about the test they have to make about these series of lessons. In an evaluation, 82% of the students

3 Bas Haring is a scientist- philosopher, writing weekly columns in a Dutch newspaper.

reported they have got a better understanding of the complexity and dynamics of ecosystems. And 77% of them thought they could discriminate well between the levels of organization of the organism, population and ecosystem. On modelling, 59% thought they could cope well with the Powersim modelling tool. Even 94% of them declared to be able to discriminate between ecological, economical and normative arguments, and 76% had the feeling that they could understand the effect of human influence in an ecosystem better. About the series of lessons, 71% thought that it was useful, 47% that is was clear, 53% that is was not dull and 63% that is was not too long. Of the students 82% thought it had been a good idea not to work with the schoolbook, but with authentic practices. The mean mark between 1 and 10 (10 being excellent) for the series they gave, was 7.2 (3b.9E).

In interviews after the series, modelling on the computer was their favourite activity. One of them declared that finding links between mussel and rabbit was the most interesting. 'The idea that the same modelling techniques can be used to understand totally different species in their environment was appealing to me.' (3b.I). Working on the anatomy of the mussel was controversial: some of the students thought this 'the most special part', while others said they 'hated cutting in the mussel.' Many of them also mentioned they did not like filling in the evaluation papers.

After the lesson

One week after the last lesson the students filled in the same questionnaire as before as a post-test to have an idea of a possible change in their ecological view. And they performed a 40 minute test in which they read an adapted newspaper article and answered questions about the practice in which elephant managing scientists in Africa tried to decide on measures to cope with overpopulation (see chapter 6).

These questions were about:

1. the change in carrying capacity of the elephant population;
2. to what level of organization the lifespan of elephants can be linked;
3. on what level of organization three specific participants in the discussion are focussing;
4 the influence of focussing on different levels for this discussion;
5. the advantage of using computer models in deciding about measures to inhibit overpopulation;
6. the different value of computer modelling for the various participants in the discussion;

7. sketching a Powersim model where the different factors from the article have to be implemented (number of elephants, sunlight, poaching & hunting, number of trees and anti-conception).

In 8.4 their answers will be discussed.

8.4 Answers to my questions and changes in the design

I will now formulate conditions that could lead to an answer to the five sub-questions of my research question and use my case-studies to answer these questions. I will also mention changes in the scenario that were introduced during the three versions of the design if the answers are (partially) negative or can be more positive.

8.4.1 Sub-question 1: Which ecology-related authentic practices seem appropriate for enabling students to grasp and value the role of systems thinking and modelling?

In chapter 6, I have chosen a set of three authentic practices, using eight design criteria. To answer the first question, I use three of these criteria.

The set of practices will be appropriate if it meets the following conditions:

1. The practices are clear and relevant (personal and/or societal) for the students, in terms of familiarity with the activity of the participants in the practice (design criterion 2);
2. There is a sequence of three practices of increasing complexity. This sequence is plausible for the students (design criterion 6);
3. The basic problem to be solved in the practices elicits student's ideas. It evokes a 'global 'motive for students to become involved and it continuously evokes 'local' motives to keep the learning process going, leading to solutions of the problems they are confronted with (design criterion 7)

Fulfilment of those three conditions will lead to the result that was desired, being to enable the students grasping and valuing the role of systems thinking and modelling. This would mean that the chosen practices are appropriate.

Condition 1: relevance

That the students appreciated working on authentic practices appeared from interviews and from the answers on the evaluation lists.

I: "What do you think about using such practices in stead of straight information in your biology book?"

Britney: "It was different."
Eve: "I think it was refreshing."
I: "Refreshing. And did you have the idea that you understood the relevance of this subject?"
Eve: "Better than with our book."
I: "Somebody else?"
Niles: "I think in a book it is more easily."
Joanne: "But this work gives more insight. I think I understand now how things are related in an ecosystem. "
I: "Yes, so it is more difficult, but it also gives more insight?"
Lance: "This makes it easier to apply your knowledge."

(3b.I)

The students are positive about the use of practices. From the answer of Lance, I conclude that he is aware of the relevance of this use.

In three case study groups, only 13%, 18% and 31% agreed with the statement "I think learning from an ordinary schoolbook is better than learning from such an authentic practice" (2a.1E-3a.1E-3b.1E).

That the students understood what kind of activities the scientists in the first practice perform, can be derived from the fact that respectively 48%, 42% and 75% agreed with the statement "After seeing the Powerpoint, I understand what NIOO-scientists do" (2a.1E-3a.1.E -3b.1.E) and also from the way the students talked about the various activities in the mussel optimization research. For example, in several case studies there were students who investigated the effect of extending the harvesting time in their model of the growth of a mussel. They were aware of the effect of the slowing down of the growth after 550 days.

Kevin: "This is not sensible, to keep them longer in the sea. Creating a new group on the mussel bank and harvesting the old group after 550 days is more profitable."

(1b.3[9]C)

The Powerpoint presentation about the activities of the NIOO-scientists on mussel optimization was introduced after the first case study, because I discovered that the students did not always have a clear idea about these activities. The students seemed aware of the activities of the NIOO-scientists and the dune management researchers and showed interest in and understanding of the models being used in both practices. As can be read in the representation of the discussions in the last case study (see 8.3), they understand what they are supposed to do and why and they are willing to participate, although they sometimes have problems with the activities, especially with constructing (parts of) models themselves. Also in the third practice, where the only activities of the students were reading an article and formulating answers to questions about the third practice, they showed understanding of the debating and modelling activities. Most of them did understand why arguing is difficult with participants being focussed on different levels of organization. Also they could match three of the debating persons with the level of organization they had in focus. They also could sketch the relations between the various factors playing a role, although the translation into a Powersim model sketch was rather poor. They understood that for debaters focussing on the organism and directed by normative arguments, modelling does not play an important role.

Condition 2: elicitation

Even if the students have become interested in the practices, there still appear to be many moments, where their involvement fades away, because they do not have a motive that keeps them going. There are critical steps in the LT-strategy, which require explicit attention in order to keep the students involved. To keep a relation between computer modelling and the natural world, students' activities were planned to be not just modelling activities, but also activities with real mussels, like studying their food tract. In the first version of the design, I just used a drawing activity. The students had to open and investigate a dead mussel and make a drawing of the food tract. This is not an activity that belongs to the authentic practice, but the students need this because, unlike the NIOO-scientists, they are not familiar with the anatomy of the mussel. Striking was that this activity triggered all type of authentic questions by the students, like 'How do they reproduce?', 'Where are their brains if they do not have a head?' (1a.2[6].C). The teacher picked up their involvement by getting an old wall picture as a support to discuss the anatomy of the mussel and answer their questions. This kind of questions was also posed in the second and third version of the design. In the second version of the design, I added two activities to the scenario, because I observed that the students did not get a good idea of the active filter feeding behaviour of the mussel and of the concept of dry-weight. They thought that the water entered the mussel because of the water current, the mussel himself being passive. I also found out that the concept of dry-weight, which is common for biologists, is not very common for students. Therefore they will not have any idea of the numerical value of the dry-weight of a mussel from which the flesh-weight is known. In modelling this caused problems because students could (or did) not validate their outcome with empirical dry-weight data. When they had an outcome after running their model, they were satisfied and not alarmed by a high number of grams, because they did not have any idea of what was the normal dry-weight. Therefore, I introduced an activity in which the students could measure the dry-weight themselves. I also added an activity in terms of watching two animations. In the first one, the feeding mechanism of the mussel can be followed precisely at different levels, which is enriching because students cannot see this mechanism in an anatomical lesson with a dead animal. In the second one, the effect of a mussel bank on the velocity of the water current passing the bank (and indirectly on the amount of algae they can consume) is made more transparent for the students. This animation also made clear, how accurate the measurements of the NIOO-scientists are and how sophisticated required apparatus.

In the reflection of the first practice the teacher repeatedly stressed the question': 'Can the NIOO-scientists go back to the mussel breeders with these results, and if not, what do they have to investigate more?' A negative answer can evoke a motive to proceed, with the aim to find the answer. Another question was: 'Can we use what we learned on he level of the organism, on the level of the population?'. The students realized that simple models concerning only one mussel, or even a complete population of mussels, are not sufficient to be used by the breeders. And they also realized that on the level of the population there are similarities, but also differences with the level of the organism. In 8.4.3, I will elaborate on this point.

In the first version of the design, the difference between the first and the second practice appeared to be quite strong in the perception of the students, which made it difficult for them to link both practices. To help them, I confronted them at the start of the second version of the design as a go-between (looking for their zone of proximal of development), with the mussel culture of Ría de Vigo in Spain[4], where the mussel population is not kept constant, before introducing the dune management practice. Different from the Easter Scheldt area, in Spain there are natural births and deaths in the mussel population. The students realized this would cause more dynamics, in terms of changes in the size of the population.

Isis: "Man can control the numbers of mussels in the Easter Scheldt much better. Complexity and dynamics will be smaller there."
Sacha: "In Ría de Vigo the numbers can be regulated less, there are more influences."
Lara: "There are more factors playing a role in Ría de Vigo, so complexity and dynamics will be greater. There will be more extremes because man does not keep the balance."
Jonna: "In the Easter Scheldt, people have much more control."
Yula: "The number of mussels can not be predicted, because many data are not known, and nature will regulate everything, opposite to the situation in the Easter Scheldt where everything is regulated by man."
Marlin: "Everything is a lot more difficult, by natural death, reproduction, and predation. These are factors which can hardly be determined, because they are dependent on other factors."
(2a.8.W)

The students seemed to understand the more complex applied practice of dune management, the difference with the scientific practice of mussel optimization, and the value of the modelling activities they had to perform. It must be stated however, that in my scenario, the dune management practice is not put forward as clearly as the practice of the NIOO-scientists. I did not use movies and Powerpoint presentations. That this did not cause serious problems can be explained by the fact that most students are rather familiar with the dune situation (the students that were engaged lived rather close to the dune area).

The activities in the rabbit management practice were all focused on modelling. In the reflection, however, students also showed to understand other kinds of aspects which play a role in dune management activities. They gave ecological, as well as economical, or normative arguments for managing measures, like the introduction of Scottish Highland cattle.

4 The culture in Ría de Vigo came into the picture while the NIOO-scientists were also performing investigations there, as well as in Limfjorden in Denmark (see p. 142-143).

T: "Well, there will be more arguments involved when this type of cattle is introduced. Who could give an ecological argument against it?"

Eddy: "They could destroy the plants and the soil."

Eileen: "The soil becomes more fertile through their dung. And some plant species will disappear."

T: "OK. And who can give an economical argument?"

Eddy: "It costs a lot of money to bring them here."

Jessy: "These animals are expensive."

Lara: "They have to be imported, because more tickets to the dunes will be sold when there are rabbits."

T: "And at last, a normative argument?"

Mitchell: "These animals do not belong in this environment."

Jessy: "They have to be imported, because it is a pity when the rabbits become extinct."

(2a.9[20].C)

See also 3b.9[20].C in 8.3, in which the students from the last case study showed to be able to discriminate between the three types of arguments.

The used practices seem to elicit students' ideas, leading to involvement in activities in the mussel optimization as well as the dune management practice.

Condition 3: plausibility of sequence

In the design, I developed a sequence in the presentation of the three practices. I started with an authentic practice in which a not too complex and dynamic ecosystem is involved. This handles about optimization of mussel culture. Mussel cultivation in a Dutch marine ecosystem is quite familiar to the students, although the practice of NIOO-scientists is not. Subsequently, I offered them a practice in which a more complex and dynamic ecosystem is involved, where rabbits living in a dune ecosystem are even more familiar to the students. Also here, the nature management activities in this practice are not familiar to the students. We finished with a practice in which an also complex, but rather unfamiliar African ecosystem is in focus. This practice involves activities in relation with how to handle overpopulation in African elephants. This sequence was sustained during the case studies. In the first version of the design however, after the fourth lesson, the initial enthusiasm of the students declined. Their interest in the activities of the mussel optimization practice was not enduring. In retrospect, they would have preferred to move on to the second (rabbit management) practice earlier. Besides, they were confused about the first practice, as it was presented as a combination of two related practices: that of mussel breeders and that of NIOO-scientists. In that combination the mussel breeders practice appeared to be dominant, which raised a question to the investigator such as: "Do you believe yourself that a mussel breeder will develop this kind of computer models?" (1a.3[8]. O).

Therefore I adapted the scenario before starting the second version of the design. First, I changed it in such a way, that the first practice was solely the practice of the NIOO-scientists who performed an investigation on mussel harvest optimization, instructed by the mussel breeders. Second, to find out if the students recognized and appreciated the logical character of the chosen sequence, I presented in the first lesson of the second version of the design a series of three familiar ecosystems: a maize field, the Easter Scheldt area where mussel culture can be found, and a dune reserve where rabbits are an important part of the ecosystem. I asked them which ecosystem would be the most suitable to start with in a series of lessons about complexity and dynamics in ecosystems. None of the students chose for the maize field, because they thought it to be not very complex and dynamic. But they found it difficult to decide between the practice of study of the mussel culture and the practice of managing rabbits in a dune reserve area; they were not sure which of both was the most complex and dynamic. After a discussion they had the idea that situations in a dune area are less adjustable by man than in the mussel area.

T: "Why do we prefer to start with the mussels and not with the rabbits?"
Tim: "They are more simple organisms than rabbits. And they cannot move."
T: "Why more simple?"
Tycho: "There are fewer factors involved. And man has more influence."

(2a.1[2]C)

The same happened in the third version of the design. See also 3b.1[2]C in 8.3.

But still the students had their doubts about the chosen sequence. With the statement "I think it is sensible to start with the mussel practice" only respectively 55%, 28% and 25% agreed (2a.1E-3a.1E-3b.1E).

After the discussions, however, they seemed to accept the order of introduction of the practices. Although they still were not convinced, apparently the idea that they had been given the opportunity to express their opinions about the sequence, made them feel known and understood. They did not have the opportunity to change the sequence, but they appeared to appreciate it, to be confronted with the justification of the choice. The third practice, used as a test, did not confuse the students. However, I did not investigate this deeply. The test was done after the period where the researcher was in contact with the students, so there was no opportunity to interview them about the test. I only had the answers to the question, which will be used further on.

Summarizing, I may conclude that the authentic practices I have chosen, are appropriate. They are clear and relevant for most students and offer them enough possibilities for active involvement, which is a prerequisite for getting seriously involved in systems thinking and modelling. The chosen sequence was not the sequence that the students preferred, but they accepted it after a discussion and worked without further objections.

8.4.2 Sub-question 2: What are the opportunities for systems theory to clarify complexity at various levels of organization such as the organism, population, and ecosystem?

Systems thinking was chosen as a tool to help clarify complexity for students, based on design criterion 4. This criterion demands that in the practice there is an important role for systems thinking activities. It is necessary to explore the relationships of, and to yo-yo between, the various levels of organization, in order to grasp the hierarchical structure of the ecosystem.

For this design criterion, I state that systems thinking is helpful under the following seven conditions:

The students:
1. Recognize the systems' open or closed character, with systems boundaries;
2. Recognize components and processes of the system;
3. Organize the systems' components and processes within a framework of relations;
4. Select central and side issues;
5. Recognize the level of organization;
6. Ascribe components to a specific level of organization;
7. Identify direct and indirect causes of complex phenomena.

Condition 1: system character & boundaries

Most students seem to be unfamiliar with the (rather abstractly formulated) idea that an organism can be seen as an example of an open system, with selective boundaries. In an evaluation paper completed immediately after the first lesson, I asked the students to complete the statement "The mussel is a system, a unit built out of components, being related with all types of factors from its environment. I think this is a ….. idea". The words that are filled in most frequently are 'strange' and 'logical, but I also found 'complicated', 'vague' and 'mussel dishonouring' (3b.1E).

In the second version of the design I introduced a change in the scenario, which was expected to provide more transparency about the systems character of a mussel, the population and the ecosystem and the closed or open character of this kind of systems, by using a number of overt questions. Most students proved able to tell for which factors the system of the mussel or the ecosystem is closed.

Eddy: "The boundary of the mussel can be passed by water, food (in) and waste products (out). The boundary of the Easter Scheldt can be passed by the sunlight (in), water (in and out from and to the North Sea)."

But not everybody agrees:

Joan "Water and food can pass the boundary of the mussel (in) and waste products also (out). But there are no arrows that can pass the boundary of the Easter Scheldt."
Tycho: "It is difficult to pass the Easter Scheldt border. The only way to do this, is taking mussels out of the sea and bring them to the city."

(2a.3W)

The idea of a systems boundary is difficult for the students. For the organism, students have the shell of the mussel in mind as the boundary of the organism, open for some components, but not for all. Nobody has the idea that the outer membranes could be perceived as the systems boundary. Open means to them that components can pass through the inhalent opening, not that they can pass the membranes. Where they have some idea of the boundaries of an organism and also of an ecosystem (for example the separation zone of sea and land area), they do not seem to have an idea of the boundaries of a population. They only give simple indications like 'a profitable life area', 'hard rock bottom' or 'depth' as the boundaries of a population.

Condition 2: components & processes

When confronted with the abstract systems idea of an organism (a mussel), most of the students were able to nominate a number of components from the environment, having influence on the mussel and also to tell what kind of influence such a component could have. This could give an idea of the processes in the system, for example when components are interrelated in a food chain.

Teacher: "What factors did you enter in your scheme with the mussel?"
Marion: "Sea currents."
T: "Do they influence the mussel?"
Marion: "Yes."
T: "What else?"
Jenny: "A sufficient amount of algae."
T: "Anything else?"
Eric: "Mm …the presence of other marine animals."
T: "Why?"
E**ric:** "Well, …, like crabs and starfish, they eat mussels."
Lisa: "Food, temperature of the water, they cannot live in cold water, I think. Also depth."
T: "Why depth, does a mussel need light?"
Jock: "No, but phytoplankton does."
Eric: "The soil, the currents."
Jock: "Currents do influence the soil, I think? And I think salt-content, especially near the coast."

(1a.1[3]C)

From the first remark of Jock it appears that he is aware of the need for light of the algae which are the food for the mussels, which means that he has an idea of a food chain: there is an indirect cause for a phenomenon (see also condition 7). See also the part about activity 3 in 8.3, where the students of the last case study nominated several components. Most of these students did not think that a mussel has much influence on the environment.

Condition 3: relations

When the students were asked to draw arrows relating the components they had mentioned with the mussel in a systems approach, most arrows were drawn pointing from the factor to the mussel. The arrows relate to processes that influence a component or the organism (being the mussel). Most of these arrows pass the boundary of the mussel (see for an example figure 8.1). The students did not think a mussel has much influence on the environment, so there are only a few arrows pointing from the mussel to some of the components. See also 3b.2[4]C in 8.3, where students in the last case study also have drawn most arrows from the environment to the mussel and most of these arrows passed the boundary of the mussel.

Most of the students were also able to draw correct arrows and give correct descriptions for the components influencing or being influenced in a systems approach of an ecosystem, but they had difficulties doing so for a population. This is in line with what was described in condition 1.

Their drawings on the population level do not show any sophisticated structure, they just put some words and arrows in their model drawing (see for an example figure 8.11). They know the 'abstract' definition about conspecifics which form a reproductive unit, but they cannot link this with the ecological reality. This should ask, in retrospect, for an explicit treatment. In chapter 9 I will elaborate on this point.

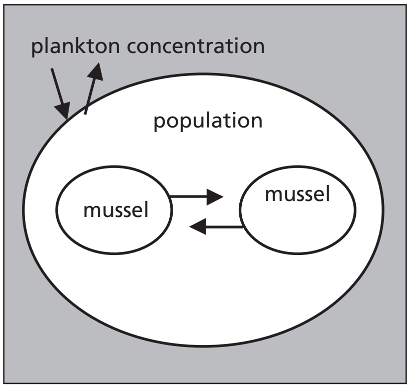


Figure 8.11. Drawing of a population of mussels with related factors from Nell (1b.4W)

Condition 4: central & side issues

That at least some students were able to select central and side issues in a systems approach is shown in the following citation where the students have to think about making a hierarchy in the various components, based on their importance to the development of dry-weight of a mussel.

T: "And now we have a very important point. When you remember the task for the NIOO-scientists ….we want a good prediction about a good mussel harvest. When the scientists see the long list of factors which you have made, what will they do now? Let us suppose that you are a scientist yourself. You are confronted with 25 factors. What has to be done next? You are going to build a model or something like that?"

Shirley: "I think he is going to investigate if there are more factors."

T: "OK. More factors there are. Let us suppose he has 50 factors. And which step will come next?"

Joanne: "He should make an arrangement based on their importance."

T: "OK. This seems sensible. He will choose the factors which are important. Well, we want to know which factors are important. How do we decide now? Remember what our question was: he is interested in predicting the growth of the mussels. What will he choose?"

Eve: "Things that influence growth."

(3b.2[1]c, already quoted in 8.3)

Condition 5: levels of organization

The students showed understanding of the three levels of organization that were used in these series of lessons. They demonstrated to understand that in the second practice the starting level is not the organism, but the population and that another time-scale is needed than in the first practice on mussel optimization.

Teacher: "How long was the period of investigation in the model about mussels?"

Jock: "Mm, …., 550 days."

Teacher: "And in this model with rabbits?"

Dean: "10 years."

T: "Why is that?"

Seth: "Rabbits live, on average, longer. And they will reproduce, the mussels are just dumped in the Easter Scheldt. So, mussels have to grow faster. Rabbits have to reproduce, which takes time. With the mussels you do not have to look so long, because they do not live long and after these 550 days they are just harvested."

T: "But a rabbit does not live for 10 years, does it?"

Seth: "No, but the population does."

T: "And the mussel population?"

Seth: "Well, the mussel population, the difference is, the rabbits are just part of nature, people do not take them out, but mussels, they are dumped and later harvested, but the population does not reproduce itself there."

(1a.8[17].C)

In the first practice I used a bottom-up approach, starting with a model at the level of the organism. Most students understood the transfer to the levels of population and ecosystem; they were well aware of the differences between the level of organization of the organism, the population, and the ecosystem. They understood the idea of a system such as, for example, a mussel being a part of another system (the population of mussels), although this idea did not have a special meaning for them.

I: "What did you think of the idea of the levels of organization, having this systems character in common?"
Marlin: "It didn't mean anything to me. I just thought there has been paid attention too long to these systems ideas. I can understand the idea of organism - population- ecosystem very easy, in a few minutes. I think, I do not need all those extra things."

(1a.I)

In accordance with the results above, in the final test, most students proved to be able to discriminate between the three levels (organism, population, and ecosystem) in the ecology-related and practice-oriented set of questions related with a newspaper article about how to deal with overpopulation of elephants. Three participants, who each have their focus at a different level of organization, take part in a discussion about how to manage the elephants in this specific case. The students were asked to make a match between the participants and their focus at a specific level. In table 8.3 the percentages of students' correct matches are shown.

Table 8.3. Percentages of students' correct matches with participants and their focus on a specific level (T)

	Focus		
Case study / Participant in discussion	Nr 1: Antonites (organism)	Nr 2: Mabunda (population)	Nr 3: Cumming (ecosystem)
1a (n = 21)	95	52	48
1b (n = 34)	95	63	74
2a (n = 37)	92	65	73
3a (n = 45)	96	56	58
3b (n = 17)	94	87	100

As can be seen, in the subsequent case studies the results of the students improve. In the first case study already, the distinction of the level of the organism appeared to be no problem, while the levels population and ecosystem seemed to be more difficult to distinguish.

Besides, the students were also aware how important it is to distinguish between the levels. Many of them answered to the question: "What influence it will have in a discussion, when the used arguments are not at the same level of organization?" for example "Because they have a different view, they will never agree", "They will not find a compromise, because not everybody has the same interests", or "They talk at cross-purposes."

Condition 6: level specificity

The students could ascribe components to a specific level of organization, and also understood the influence of components of the population or ecosystem level on lower levels.

T: "Which components are specific at population level?"

Ida: "Competition for algae, also reproduction."

T: "And what is the effect of introducing more mussels?"

Hilly: "The higher the density of mussels, the less every mussel can eat."

(2a.4[10]C)

They understood that it is not an individual mussel, but the population of mussels, that influences the concentration of plankton (food).

Josh: "So, when the density is raised, the mussel competes, and the individual does not grow so well, it is so meagre that it cannot be harvested." (1a.4.W).

They could tell that when birds forage on mussels, this has a negative effect on the density (level of the population), but a positive effect on dry-weight of the remaining mussels (level of the organism).

However, not everybody agrees on this last effect being positive!

Frank: "The more mussels are eaten by the birds, the better for the remaining individuals. Their dry-weight increases."

Jody: "Oh, but what is the benefit of that for the eaten ones?"

(1b.6[15]C)

Thus, these students do not focus at the same level of organization. Where Frank talks about phenomena on population level, Jody concentrates on the level of the organism. This means, it has to be very clear on what level advantage or disadvantage is considered. The same problem I already described in the discussion about taking measures in an overcrowded elephant population in the final test.

Condition 7: direct & indirect causes

As already stated in the case of Jock (condition 1) and of Josh (condition 6) it appears that at least some students can identify direct and indirect causes of phenomena. This is also apparent in students' answers to the question what went wrong with the rabbits after an epidemic. They realized, after exploring a model, that the vegetation has changed during the period that the rabbit numbers were low (the period when the epidemic was dominating the rabbit's numbers), which created a smaller area for the rabbits to forage.

Elaine: "The area that is suitable for rabbits has decreased during the epidemic."
Marlin: "The relation between the rabbits and the grasses has been disturbed."
Leo: "The grasses which could be eaten by rabbits have been pushed aside by other grasses, therefore the rabbits could not recover."

(3b.8.W)

As a summary, table 8.4 presents the results of the students in the subsequent case studies with seven abilities, related to systems thinking, I hypothesized they should develop. Because of the heterogeneous sources used to arrive at this result, I could not calculate an exact percentage. In three of the sources I used (I studied the notes in their workbook and the results of their test and observed their video-taped remarks) I scored their abilities on individual basis. In the other source (where I observed dyads working on the computer and listened to their conversations in performing their tasks), I scored on the base of these dyads. We see that there is only an improvement in the ability 1 (recognition of the systems' boundaries and of the open or closed character of the system) in the subsequent case studies. This could be the result of the specific questions about this subject that were added before the second version of the design.

Most difficult seems to be the ability 3 (organize the systems' components and processes within a framework of relation). This is the ability which is also very important in modelling. So, there is no unambiguous answer to the second sub-question. There certainly are opportunities for systems thinking. However, in some abilities the students perform well, but in other moderate or rather weak.

Table 8.4. The abilities and results of the students, divided into three categories: ++, + and ±, where ++ means an overall good performance; + a moderate performance ; ± a rather weak performance (W, O, C, T).

Ability		Results in the various case studies				
		1a	1b	2a	3a	3b
1	Recognize systems' open or closed character, with systems boundaries	+	+	++	++	++
2	Recognize components and processes of the system	++	++	++	++	++
3	Organize the systems' components and processes within a framework of relations	±	±	±	±	±
4	Select central and side issues	+	+	+	+	+
5	Recognize the level of organization	++	++	++	++	++
6	Ascribe components to a specific level of organization	++	++	++	++	++
7	Identify direct and indirect causes of phenomena.	+	+	+	+	+

8.4.3 Sub-question 3: What are the opportunities for computer modelling to clarify dynamics at various levels of organization such as the organism, population or ecosystem?

I had used computer modelling as a tool because I expected that it would help to clarify the dynamics of an ecosystem, based on design criterion 5. This criterion demands that in the practice modelling activities have a necessary role to gain a quantitative insight into the dynamics of the system over time and space. The modelling process starts with sketches, going up via simple computer models into more sophisticated ones.

For this design criterion, I state that modelling is helpful if the following four conditions are fulfilled.

Students must be able to:
1. Build, explore and run simple self constructed models or explore and run more complex ready- made models;
2. Work goal orientated in their modelling behaviour when provoked to build (sketch, construct, run and validate) or expand more complex models themselves;
3. Show that they are able to relate known natural phenomena to models;
4. Validate their models with empirical data.

Fulfilment of those four conditions will lead to the possibility for students to interpret a model's behaviour, for example by identifying dynamic relationships within the model of the ecosystem or demonstrating the ability to make generalizations and thinking temporally (retrospection and prediction) about developments in ecosystems and also to reflect on the models, using information from natural phenomena or vice versa.

Condition 1: building simple models and exploring complex ones
Nearly all students were able to build and run a simple computer model of the growth of a mussel, based on the daily increase of dry-weight of the organism with the help of a worksheet with the model already sketched. Most students were also able to explore ready-made computer models and to derive new biological implications from these models. My observations show that after one lesson nearly all students in all case studies had built the first model about the dry-weight of the mussel. Also the exploration of the Lotka-Volterra predator-prey model and the model with rabbits and grasses was successfully performed by nearly all students in all case studies. They were also able to express ideas about quantitative effects of changes on the level of organization of the organism, population, or ecosystem. They seemed to be aware of effects of, for example, population level at the level of the organism, as already described in 8.4.2 (condition 6).

Condition 2: building complex models
However, when it came to building or expanding more complex models on their own, most students had severe difficulties in formalizing the relations between various components in the model. In conversations with the students they were not aware of the mathematical background which lies behind this formalizing. They do not

know how to describe the sort of relation between two factors (like multiplication, addition or division) or how to quantify a relation (by using some constant). Many of them react with a mixture of surprise and annoyance ("It is not mathematics here, but biology!") when confronted with the mathematic aspects of the problem.
Table 8.5 shows students' modelling activities and their successes. I observed the dyads and made notes about the way they performed seven different modelling activities I distinguished. On the basis of these notes, I calculated the percentages of dyads being successful on the various modelling activities.

Table 8.5. The activities used in computer modelling, related with the percentages of dyads of students being successful in performing an activity (O).

	% of dyads, successful of performing modelling activities				
Type of activity	Case study 1a	Case study 1b	Case study 2a	Case study 3a	Case study 3b
Building a model with the help of a work sheet	81	91	88	85	92
Sketching of a model	30	35	38	33	40
Introducing the correct relations in a sketched model	30	35	30	40	45
Quantifying relations in a model	30	35	30	30	30
Empirical validating a model	40	45	60	60	70
Exploring an existing model	95	96	90	85	95
Extending an existing model	40	45	45	45	50

From several dyads I also had Camtasia recordings (15 frames per second) of their modelling activities. In an analysis of these recordings I observed the students and the strategy that they use to build their model. It could be seen that a majority of them did not use a preliminary sketch or another type of 'plan' before building the complete model. They did not seem to have insight in how the model should be built. Most of them worked more in a trial and error style: they put components on the screen, connect them with each other, and look for corrections when they are confronted with a problem. There seems to be some improvement (see table 8.5) in introducing the correct relations in a sketched model (a) and in validating a model, by comparing with natural phenomena (b). This can be attributed to changes I made between the versions of the design by offering incomplete models (a) and introducing the weighing activity (b).

In the first version of the design, many students were engaged, but got disconnected from the biological reality of the mussels (see also condition 3) and also lost much of their motivation during the autonomous building of a population model, starting from a model of one individual mussel. The students had serious problems in constructing this model completely by themselves, seeming not to know where to start at all. So, in the second version of the design I offered them the various factors that were needed in the model as a sort of jig-saw puzzle. This helped the students in successfully constructing a qualitative model, although still help from the teacher was needed for many of them. When after this stage in which they needed much help, they were asked to explore a complete model of a rabbit population in the second practice, they showed understanding of what was happening and linked their biological knowledge to the model (see also 8.4.2 condition 7). The students discovered that such a complete model could expand their biological understanding. However, in interviews they showed not to have much confidence in building a model independently. Their teachers confirmed these feelings. Some quotes about this.

Hama: "I understand a model when it is explained, but I am not able to build it myself."
Joline: "I work so hard modelling that I tend to lose contact with real world. But after all, I think modelling can help me understanding complex situations in nature, provided that I have more experience and that I don't have to build all models by myself. "
Teacher: "This is very difficult, not only for the students but also for me. I had to spend lots of time to understand the various models that were used."

(1a.9.I)

In another interview the students talk about their specific problems with modelling

I: "What was the most difficult in modelling?"
Marlin: "Uhm, well for example, from the first model to the second. All of a sudden we had these question marks in the model (see figure 8.5). We had to match the factors ourselves. In the first model there were small steps. Here you had to do many things at the same moment."
Elaine: "Well, a little bit with these … if you do not make progress in modelling, then it goes .., then you think it is boring because you can not go further."
I: "Yes, yes."
Elaine: "But, if it goes well or if you get the right clues, then you start to like it again."
Joanne: "Yes, less frustrations."

I: "Is that important?"

Elaine: "Yes, you keep thinking when it does not work, what is the reason, is it me, am I simply not able to do it?"

I: "Did you have the feeling that you needed much mathematics?"

Joanne: "Uhm, well just basic things. And everybody will know that already."

(3b.I)

In the first version of the design the students were also supposed to construct a model themselves of the complex ecosystem of the rabbits. The students tried hard to build this model, but no one arrived at a working model. So, in the second version of the design I constructed some complex ecosystem models myself, emphasising exploring and understanding what is happening to the rabbit population in the dune reservation. In that case, most students were able to explore these models, but also here, many of them did not attach their findings to natural phenomena. In interviews, the students said that they acted automatically.

Yula: "I do what is described, and the models work, but I still do not know exactly what happens in the dunes."

(2.9.I)

Condition 3: relating with natural phenomena

Working with the simple model of one mussel, a number of students asked themselves what would be the dry-weight if the mussels stayed longer in the Easter Scheldt. They ran their model for a longer period and discovered that the dry-weight did not increase much, so it would not be sensible to postpone the harvest longer than 550 days. An example:

Bernard: "The mussel breeder would have more benefit to drop new seed after those 550 days, because they grow faster than the old ones."

(1b.3.O)

This shows that Bernard is able to relate natural phenomena as described in the mussel optimization practice with his model (see also criterion 1 in 8.4.4).

When confronted with the statement that it is important to introduce real data into their models, most of the students agree (respectively 60% and 80%, 3a.3.E and 3b.3.E). Many students think that the more factors have been introduced, the better a model will be (respectively 71% and 73%, 3a.3.E and 3b.3.E). When interviewed about this they explain this idea by stating that this will be more like 'real world.' However, on the other hand many of them (44% and 67%, 3a.3.E and 3b.3.E) agree on the statement that it is sensible only to use important factors in a model. In reflection, the students described the value of modelling as making it more clear how nature works on time-scale, and they thought that it would be an advantage to use a model first, before doing experiments or taking measures. Some quotes:

Eddy: "You can find out with a model under what circumstances organisms do flourish."
Ellen: "You can find out what the relations between various factors are."
Marc: "You can make predictions on a short time-scale."
Marion: "When it goes wrong in a model, it is far cheaper than in actual nature."
Jenna: "You can investigate the affect of a change in all kinds of factors."
Yula & Karin: "You can predict the numbers of rabbits in special circumstances."

(2a.9C)

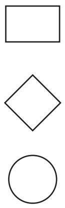
In an interview, the students declared to be conscious of the relation between their models and 'real world'.

I: "Were you busy checking your model's results, I mean … when you had these results, were you checking, is this possible?"
Bert: "I did check my model with dry-weight."
Joanne: "Yes, I experienced this several times, because I was wondering, will a mussel grow so slowly in a year? I thought this was very slow."
I: "You thought this growth was very slow?"
Bert: "Yes, you have some idea, but not exactly. But this growth is really not much. I remember that Leo came back from weighing our dry-weight and he had a high weight and I thought that it would be impossible."
I: It would be impossible. And, what was it, a miscalculation?"
Bert: "Yes."

(3b.I)

However, many students think that the models they have used are not adequate to describe or forecast natural phenomena, because they are not complex enough.

In the final test after the lessons the students had to relate information about natural phenomena from a newspaper article with their knowledge about computer modelling, especially directed to their ability to sketch a Powersim model. Many students were able to sketch such a model, using the information from the article they were confronted with. But inspection of their sketches revealed that most of them did not discriminate well enough between the Powersim characters (stock, constant or variable, see figure 8.12) in the model which should look like figure 8.13. This result can indicate either students' problems with the specific character of a component or problems with the transfer of these characters in Powersim language. There could be cognitive overload (Nerdel et al., 2003), due to lack of prior knowledge, in combination with the use of complex additional aids like the modelling tool. Lack of prior knowledge means a lack of sustainable schemata that could guide the acquisition of knowledge, which means that the learning material has a high cognitive load.



A stock is used for a quantity that could change because there is something added or taken out.

A constant is used for a quantity that does not change in time as an effect of a change in another factor.

A variable (auxiliary) is used for a quantity that can change in time as an effect of a change in one or more other factors.

Figure 8.12. The characters of factors that are used in Powersim models.

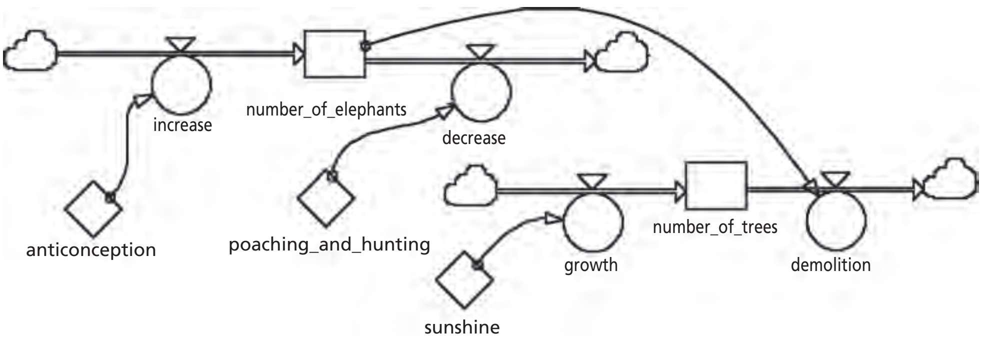


Figure 8.13 An example of a correctly sketched model in the final test. The arrows are used to indicate relations between components in the model.[5]

[5] Poaching and hunting is one of the measures suggested in the article to solve the overcrowding of the elephant population; anti-conception is another one. Sunshine is used as a factor that stimulates growth of the trees, which are the food source of the elephants.

In table 8.6 the results of the use of the Powersim characters by the students in the final test are shown.

Table 8.6. Percentages of students' correct matches with the types of factor in Powersim. S = stock; V = variable; C= constant, where the ones with * are the correct ones (T).

Case study	Elephants			Trees			Poaching & Hunting			Anti-conception			Sunshine		
	S*	V	C	S*	V	C	S	V	C*	S	V	C*	S	V	C*
1a	61,9	38,1	0	21,1	57,9	21,1	4,8	95,2	0	14,3	42,9	42,9	4,8	9,5	85,7
1b	80,6	19,4	0	26,7	70	3,3	0	51,6	48,4	0	46,7	53,3	6,7	30	63,3
2a	91,2	8,8	0	44,1	50	5,9	0	52,9	47,1	2,9	50	47,1	0	50	50
3a	87,5	12,5	0	20	67,5	12,5	2,5	50	47,5	5	45	50	5	45	55
3b	97,3	6,7	0	20	66,7	13,3	0	26,7	72,3	0	20	80	0	60	40

As can be seen, there is an improvement in the recognition of elephants as a stock during the subsequent case studies. However, this kind of improvement can not be found for the trees as a stock, and the poaching and hunting, the anti-conception and the sunshine as constants in the model. This lack of improvement could be the result of students' problems with the meaning of the word 'constant'. In Powersim syntax a constant is a factor which is not dependent on one of the other factors in the model, while a variable is a factor which is dependent on one of the other factors. Most of the students do understand the difference between both. And they realize that it is a complex matter. In a discussion about constants they hesitate about whether a predator is a constant or a variable and what decides this.

Marcel: "Predators are variables. They are dependent on the number of mussels, water velocity is not."
Eddy: "But predators like birds for example, are not only related with mussels."
T: "As long as the mussels are under water, the birds can not reach them."
Joe: "But other predators, like star fish or crabs, can."

(1a.2[4]C)

In Powersim models, constants can be changed from outside, by the modeller, who gives these constant another value. However, in the perception of the students a constant is something that does not change at all! Although some of them realize that change has to do with time-scale.

Dean: "I think there are two things. When do you call something variable? If it does not change in one week, or in one year, or in one decennium?"

(1a.2[4]C)

This could explain why for example the sunlight is perceived by the students as a variable (because it changes during the seasons) while in their sketches there are no components that influence the sunlight.

Most of the students understand the value of modelling in the test practice. When they are confronted with the question to nominate an advantage of building and running a computer model about elephant management with the factors 'hunting' and 'anti-conception' they express opinions like "Now you can see what will happen in the long run", "It will be possible to calculate effects of anti-conception or hunting" or "You can make an estimate of what will happen, which makes it better possible to decide whether you should hunt or not."

Condition 4: validating

Many students had problems in validating the outcomes of their computer models. A number of them made a mistake in some formula, resulting nevertheless in a 'running' model. I found that these students did not link their modelling activities to the 'real world'. When their mistake lead to a dry-weight of a mussel of for example more than 1 kilogram, some students were not upset. They were focussed on creating a running model and seemed not aware of the fact that a model is just a means to reach the goal of knowing more about natural phenomena. Also, it was not explicitly asked to compare the end result of their model with the dry-weight of a mussel. However, a deeper obstacle may be that many students do not perceive the biological world in terms of numbers. For instance, in the first case studies, they did not have any expectation of a plausible range for the dry-weight (that is the biomass) of a mussel. So in the second version of the design, I introduced a weighing activity, in which the students could determine the actual dry-weight of mussels. This is comparable with the actual procedure in auctions with mussels, where the dry-weight of the mussels is determined in order to have an idea of the value of the yield of the harvested mussels. These weighing activities did result in questioning the models, when the outcome was far too high. In fact, students most of the time asked their teacher what to do, when they realized that their model did not fit with reality, they did not try to lose the problem themselves. This suggests that they are primarily interested in solutions of the problem, not in acquiring scientific insight.

Summarizing, modelling has opportunities to clarify dynamics. However, there appear to be some complicated abilities for students. Especially the sketching, which requires goal orientated modelling behaviour, and the actual building, which requires an overview of the components of the system and the relations between them, expressed in formal (mathematical) language, cause problems for many students. They are aware of the links between their model and empirical data, but some of them seem to be too involved with modelling to think about these links constantly and validate their models with real world knowledge.

8.4.4 Sub-question 4: Which pedagogical approach is helpful for students in using modelling and systems thinking?

I sought to link a concept-context approach, where a context is interpreted from a cultural historical view, with a problem posing approach. To find out if this approach is helpful, I use design criterion 8. This criterion demands that to support the autonomy of the learners, the learning and teaching strategy is transparent for students: this implies that at any point it is clear to the students what learning activities they have to do, when and why.

For this design criterion, I state that the approach is helpful if the following three conditions are fulfilled:

1. The students understand the problem(s) they are confronted with;
2. The students achieve the learning activities needed to continue, being aware of how to perform these activities;
3. The teacher's interventions are leading to desired steps which are also understandable for the students (in other words, these interventions are creating a zone of proximal development).

The first two conditions are essential in the problem posing approach, the last one in the (cultural historical based) context-concept approach.

Condition 1: meaningful problems

As can be read in 8.4.2 and 8.4.3, systems thinking and modelling are demanding for students, especially modelling. I have tried to improve learning by using activities that are meaningful for the students. By observing and interviewing them and studying their evaluation lists, I found out that most activities were considered to be meaningful. As can be read in 8.3, despite the demanding character of the activities, most students worked concentrated on their tasks. They were fully involved in group discussions. There were only a few questions about why they should solve a specific problem. The time that they were off-task when they were modelling was on average not above 5%. As already described in 8.4.1, the students thought they learnt more about real biology and about things that were 'important, and not just interesting or funny' (1a.I). Many students did not agree with the statement that mussel breeders do not need NIOO-investigators to optimize their harvest (respectively 42%, 60%, and 73%, 2a.3E, 3a.3E, 3b.3E). Many of them declared to understand the aims of the series of lessons and the problems they are confronted with (respectively 64%, 67% and 44%, 2a.1E, 3a.1E, 3b.1E). It has to be stated here that many of them, in all case studies, were unsure about the link with the exam program.

Condition 2: knowing how to proceed

To help the students in their learning activities to proceed in the subsequent activities, I tried to determine their zone of proximal development, looking very carefully at their performance in activities in each case study and changing the scenario for the next case study. In every sequence of learning activities I analysed their reasoning pattern. For example when confronted with the factors playing a role on growth of a mussel, I refer to the discussion 3b.1[2]C, described in 8.3, where the students show to be aware of the rationale to be used when they are beginning to solve the central question in the first practice.

Inspired by the emergent modelling structure for the development of mathematical reasoning (Gravemeijer, 1999), I decided after the first version of the design where especially modelling appeared to be a difficult skill for the students, to distinguish a number of models from the start with increasing abstraction. The sequence I used corresponds with the first part of the structure for emergent modelling, consisting of a number of *models of* an object in a task setting, while the second part consists of a sequence of *models for* mathematical reasoning. It was decided to distinguish the following sequence of modelling steps in building the model of the increase in dry-weight of a mussel in time (see also figure 8.3 in 8.3):

1. Practical assignment with a biological object, the mussel.
2. Representation of the mussel as an open systems model with a systems boundary, input, throughput, and output.

3. Reconstruction of the open systems model of the mussel in a qualitative Powersim model.
4. Elaboration of the qualitative Powersim model into a quantitative Powersim model.

It should be stated that in the practice of the NIOO-scientists the modelling problems have another character. The modellers are skilled, mathematically trained people, who build their models in close contact with others that collect data about natural phenomena. In this contact there is a permanent exchange of ideas between both groups. For students the problem is that they are neither skilled modellers, nor do they have much knowledge about related natural phenomena. So, we need a huge adaptation in the kind and complexity of models, from the authentic practice to classroom practice.

In using small steps, I tried to address the zone of proximal development of the students. Every step has to be clear and inviting to continue, leading to the next step. Making the steps smaller resulted in a better understanding by the students of the relation between the real mussel and the Powersim model. This was demonstrated for example by students working on empirical validation of their model. They tried to investigate independently the effect of a longer runtime in their model on the development of dry-weight. Also some students made independently a new variable *dry-weight* × *density*, to find the optimal harvest possibilities for the breeders. They showed understanding of the relation between the model and natural phenomena.

In conclusion, I may state that, especially in the modelling activities, which form a substantial part of the activities in our series of lessons, it is still quite demanding for the students to be conscious of the way to proceed in their work.

Condition 3: tailored intervention

I have described in chapter 2 that I had in mind a combination of the problem posing approach with tailored intervention from the teacher who has to address the zone of proximal development of the students, in order to keep the learning process ongoing. A very skilled teacher is needed to find out especially where the students have problems in building their models and what kind of problems can happen. In chapter 9 I will elaborate on this subject. In many cases it helped a lot when the teacher offered the students a choice between different possibilities when they did not know how to proceed. For example, in the incomplete model of a population of mussels (see figure 8.7 in 8.3), two students found out what factors had to be placed on the spots where question marks are placed. But to remove the question marks, they also had to describe the relations between two or three factors in a formula (see figure 8.8 in 8.3). They did not know what to do.

Stefan: "Sir, could you help? We do not understand how to formulate the relation for consumption of local plankton."

T:"Well, which factors play a role in consumption?"

Anne: "Mm,… , uptake, and … mm, mussel density."

T: "Right. So, what should you do with these two factors?"

Stefan: "We don't know."

T: "Well, there are four possibilities. You could add them up, subtract them, divide them or multiply them."

Stefan: "I would say we should divide the uptake through the mussel density."

T: "That would mean the more mussels, the less consumption, isn't it?"

Anne: "Oh, I see, it has to be the more mussels, the more consumption, of course, we have to multiply them!"

(2a.5[4].C)

In interviews the teachers declared that they did feel uncertain about their modelling performance and their capacity to help the students.

"Not only the students had problems with Powersim, I myself had too. This made it difficult for me to help them."

(1a.I)

"When I had to do the jig-saw, I did not find it easy. I know the relations, but still it is difficult to think in this model symbols."

(1b.I)

"I was confronted with a model which looked very similar to the one I had exercised with. But it created very strange results when the students ran it. I could not find the error, which took a lot of time. And there were students waiting."

(3a.I)

In the training programme, I confronted the teachers in advance with problems students met in modelling in one of the former case studies and invited them to solve these problems. For example, in building the population model of the mussels, starting with the model of the mussel as an organism, the integration method[5] appeared to be an obstacle for the students. They started with basic Euler integration, which is the standard integration method in Powersim. When they build the already complex population model, this model may derail because of the rather imprecise way of calculation in Euler's method. The students do not know what to do when their model derails. I therefore introduced the teachers to the possibilities of the more sophisticated Runge-Kutta integration method, which prevents derailing. Another problem is that sometimes with wrongly formulated relations (for example when a division is used with 0 in the denominator) the computer freezes. The students have to start all over again if they did not save their model, which is very disappointing for them and sometimes caused frustrations. The teacher should be aware of this and instruct the students to save all their models to prevent this kind of problems. In modelling, there is also the danger that students lose contact with reality and are not aware anymore of the problem they are solving. The teacher should always be cautious to prevent this problem by introducing, together with modelling, data of and materials out of natural phenomena.

As was already described in 8.3, the teacher was inclined to concentrate completely on the content of the series of lessons. This was also found in the other case studies. The modelling activities did cost a lot of time. When students were having a backlog, the teacher used some time to get all students on the same level again, but neglected the reflection on the concepts that were already learned and the re-contextualization of the developed concepts in the first practice, which enable the students to use them in the second one. So, the tailored intervention lacked on the individual level, helping the students with a backlog personally, as well as on the level of the group.

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5 In Powersim the method of calculation is to start with the initial values and to calculate how these values have changed after a short time-interval. This is continued up to the set up end-time of the model. The problem can be that with the chosen time-interval the results can be not very exact and even that values can become negative, which can cause derailment of the model. To make the calculation more exact, the time-interval can be made shorter and shorter. The profit is a more exact calculation, but the disadvantage is more calculation time. Leonard Euler invented this technique in the 18th century. Later other methods were invented, which lead to better results with longer time-intervals and consequently less calculation time, for example the Runge-Kutta integration method.

In conclusion, some understanding of the problems posed has been reached. However, the students still have difficulties realizing the various learning activities to continue, especially in the modelling activities. The teacher's ability to detect modelling problems, to suggest solutions and to divide time between personal attention and group reflection seems necessary to keep the students involved and continuing their activities.

8.3.5 Sub-question 5: Which pedagogical approach is helpful for students in developing scientific ecological concepts starting from concepts embedded in authentic practices?

To answer the last sub-question, I use the design criteria 1 and 3. These criteria demand that the used practices are not only realistic, but also not too complicated for the students to grasp the concept of the ecosystem and the sub-ordinate concepts of complexity and dynamics. Besides, that the practices rely on the use of 'ecosystem' as a recognizable and functional key concept, interpreted as an open system with interrelated factors.

I state that my approach is helpful in developing ecological scientific concepts if it meets the following four conditions:

1. The students use the concepts ecosystem, dynamics and complexity in the first practice in an adequate way;
2. The students recognize that these concepts can have (slightly) different meanings in other practices;
3. The students use the concepts in an adequate way in another practice with some help;
4. The students use the concepts in an adequate way in still another practice without help.

Condition 1: adequate notions

I introduced the concepts ecosystem and dynamics by using an authentic practice in which the ecosystem related quantities in study (dry-weight of a mussel, density of mussels) vary over time. Most students appeared to be able to understand the influence of changing environmental factors, like the varying amount of food, the varying density or the varying numbers of predators (see also 8.3). They could explain the graphs showing the development of dry-weight over time, although they had difficulties with matching the pattern with the seasons in a year. Many of them did not see a relation between the sinusoid pattern of plankton over the year and the seasons. But they were aware of the relation between plankton and the dry-weight.

Eve: "When the plankton is decreasing, the mussel loses weight!"
(3b.3[9].W)

In a discussion about the plausible sequence of three ecosystems they had difficulties with the idea that the first practice was not too simple to be useful and also not too complex to be understandable. In a comparison with another mussel- related ecosystem (Rìa de Vigo) the students showed understanding of the difference in complexity between both ecosystems.

The students were able to give examples of influences from the level of the ecosystem on the levels of population and organism (see criterion 6 in 8.4.2).

Condition 2: practice dependent meaning
Although in all case studies there was paid too little attention to re-contextualization (see condition 3 in 8.4.4), the students seemed to have some understanding of the idea that the concepts of ecosystem, dynamics and complexity will be not the same in another practice. They are aware of the differences in complexity between the mussel culture in Rìa de Vigo and Easter Scheldt.

Some quotes:
Angie: "In Vigo it is more complex, because there are more variables over there. In the graphs of the dry-weight the amplitude would be greater."
Laura: "There are more components, complexity and dynamics will be increasing. There will be more extreme values."
Alan: "It will be far more difficult to build a model for the Vigo situation."
Manon: "Because of natural deaths, reproduction and predation it will be more difficult. There are components that we can hardly determine, because they are dependent of other factors."

(2a.8[17]W)

However, due to the fact that the teachers in our case studies did not pay much attention to the development of the concepts (see also hereunder), I cannot say much more on this point. Understanding the difference in complexity is certainly not equivalent with awareness of a difference in concept.

Condition 3: assisted application

In the second practice the students could use the concepts of ecosystem, dynamics and complexity. In the questions they showed understanding of the level of organization that was central in this practice, being the population of rabbits.

Irene: "Man has more influence on the numbers in the Easter Scheldt. Complexity and dynamics are at a lower level there."
Sacha: "In the dunes it is less constant, there are more influences."
Ann: "Here, it is more difficult to put in a model."
Mary: "It becomes more difficult, you have to take into account predators, and natural deaths, and reproduction."
Hilly: "It will be less regular here."

(2a.8.W)

They were able to answer questions about dynamics in the development of the rabbit population under study in this practice (see the description of the eighth lesson in 8.3). However, when they had to use these concepts in modelling, they just worked rather automatically with these concepts. They said, as was already mentioned earlier (see criterion 2 in 8.4.3), that 'they worked on auto-pilot'. The danger of blocking students' real understanding by concentrating on ready-made models because of severe problems with the construction of models by the students themselves, already manifest in earlier experiments as mentioned in chapter 5, is clearly present in our investigations.

Condition 4: spontaneous application

In the third practice, where they had to work in a test all by themselves without any help, most students were able to differentiate between the three levels of organization (organism, population and ecosystem), as can be read in 8.4.2. As the cause of the changed carrying capacity most students named the direct influence of predators / natural enemies (38%) or an indirect effect of a change in abiotic factors such as changed climate (38%). However, many students (75%) did not succeed in assigning the right level of organization to the organism specific character of lifespan in elephants. Also many students had difficulties to construct a correct Powersim sketch to demonstrate the complex relations in the ecosystem, as can be read in 8.4.3.

In an interview after the series, most students answer to the question about what they did learn, something about modelling ecosystems. The concepts 'dynamic' or 'complexity' are not used in their answers. They appear to perceive modelling as a goal, not as a means to understand ecological concepts. Hereunder two quotes:

Bert: "Now I know how to investigate, to model, to simulate the world in micro format actually."
Elaine: "It looks, yes. . I think … you learn how to use a computer, I knew working with computers, but this modelling, we never did such things before."

And then there is an understanding of complexity when she continues:

Elaine: "That is what I think. You see much better how everything depends of each other."

(3b.I)

In conclusion, my approach did not succeed in developing real understanding of complexity and dynamics of an ecosystem. Especially the fulfilment of the conditions 2 (the students recognize that these concepts can have (slightly) different meanings in other practices) and 4 (the students use the concepts in an adequate way in still another practice without help) appeared to be problematic.

8.5 Student's view on ecosystem

In my LT-strategy I went bottom-up towards the level of the ecosystem. From there an overview can be given from all three levels of organization, which makes it possible to perform the necessary yo-yoing activities between these levels. This gives the possibility to find out effects from one level on the other. However, the construction of models has been so time consuming that there has not been enough time to reach 'the top of the mountain'. In all case studies there have been problems with completing the content that was offered. Although the content has been reduced (the part with accidental immigration of *Phaeocystis* algae has been deleted after the first version of the design, and the part about the introduction of Japanese oyster, a competitive mussel has been made optional after the second version of the design), there were still many students who had lack of time. All teachers responded to this lack of time by concentrating on the models, trying to get the students on the same level again. They did this at the cost of the time reserved for reflection on what the students had learned and for re-contextualisation. Therefore there was not much progress in concept development. Relatively much time has been spent on the first practice, not enough time was left for the second. And it was this second practice where the complexity and dynamics of the ecosystem were in focus, because in this practice the related ecosystem was more complex and dynamic.

From the foregoing, it is not surprising that the comparison of a pre-test and post-test, which could give an idea of the view on ecosystems (see also chapter 5), does not show a substantial change in the view of the students in the case studies. To investigate this possible change in the view of the students, I compared their answers with the answers which would have been given by a person with a consistent dynamic view. I calculated the total score of 'correct' answers from all students in the various case studies, in their pre-test as well as in their post-test. A $\chi 2$-test was used to calculate whether the differences in their scores were statistically significant (p=0.5). For a comparison I also calculated the scores of research ecologists and teachers. In table 8.7 the results are shown.

Table 8.7. Total scores of the 'correct' answers of students to 12 different questions concerning their view on ecosystems. Due to technical problems we did not perform test in case study 1b.

	Ecologists	Teachers	case study 1a		case study 2a		case study 3a		case study 3b	
			pre-test	post-test	pre-test	post-test	pre-test	post-test	pre-test	post-test
Total score	350	304	101	128	89	104	126	131	56	55
N	61	61	37	37	35	35	43	43	17	17
Average score ± Standard Deviation (maximum score = 12)	5.74 ± 1.81	4.98 ± 1.82	2.73 ± 1.44	3.46 ± 1.45	2.54 ± 1.04	2.97 ± 1.22	2.93 ± 1.24	3.05 ± 1.40	3.29 ± 1.11	3.24 ± 1.35

The differences in the scores between ecologists and teachers appear to be significant (χ^2 = 6.05), as well as the differences in the scores in the pre- and post-test for the students in the case study 1a (χ^2 = 7.22). However, the differences in the case studies 2a, 3a and 3b are not significant. These results are difficult to explain. I would expect that the results would improve during the successive case studies, because I introduced improvement on the basis of my experiences.

9. Conclusions and implications

9.1 Introduction

In this last chapter I will answer the research question and reflect on some aspects of the work which has been done in the past four years.

In section 9.2 I will answer the research question, concerning the validity, feasibility and effectiveness of the used learning and teaching strategy. I will also reflect on the design criteria for this strategy and on the intended learning outcomes. In section 9.3 I will reflect on the use of authentic practices in the case studies, in particular the process of educational adaptation of the practices and the re-contextualisation which is needed to pass from one practice to another in the sequence of three practices will be discussed. I will also try to answer the question whether findings from my investigations can be of help for a more extensive use of authentic practices in upper secondary biology education. In section 9.4 I will reflect on problems I encountered in systems thinking and in section 9.5 I will pay attention to problems I observed while working with modelling. In section 9.6 I will describe some ideas for further research, especially for more specific investigations about the development of ecological concepts and the use of various modelling tools and systems thinking in ecology. In section 9.7, at the end of this thesis, the researcher, being in a special position as he is also an experienced teacher, phrases some personal considerations.

9.2 The answer to the research question

For a long period of time the ecosystem has been dealt with in a rather old-fashioned and non-dynamic way in secondary education. I have argued that the modern dynamic and chaotic views should also be dealt with, including dynamics and complexity as important sub-concepts which will help students in developing ecological literacy. Therefore, I was interested in developing a learning and teaching strategy, focussing on dynamics and complexity of ecosystems. In my research I sought to answer the following research question:

What are the characteristics of a valid, feasible and effective learning and teaching strategy about ecosystem behaviour using modelling and systems thinking in authentic practices?

With respect to the content covered, our explorations of current scientific practice suggest that a valid learning and teaching strategy should go beyond the cybernetic view, to cover also dynamic and chaotic aspects of ecosystem behaviour. This is clearly at odds with the current status in secondary education, where I found the cybernetic view to dominate the examination program as well as the schoolbooks, the teachers' views and the actual classroom practice.

However, understanding the complexity and dynamics of ecosystems requires some quite complicated reasoning that may be rather hard to implement in the classroom. I considered systems thinking as a promising way of reasoning for students to grasp the *complexity* of an ecosystem. This appeared to be true, although not all characteristics of systems thinking appeared to be equally feasible for students, due to differences in degree of complexity (Ben-Zvi Assaraf & Orion, 2005). I will elaborate on some specific systems thinking problems in section 9.4.

Furthermore, modelling seemed to me an activity which enables the students to gain insight in the *dynamics* of an ecosystem. Indeed, modelling appeared to be helpful. However, also here I was confronted with some difficult aspects for students, on which I will elaborate in section 9.5.

Only *informing* the students about modern views and about systems thinking and modelling would, in my opinion, not be enough. They need to get involved in ecological reasoning themselves. Therefore, I presented the students three authentic ecosystem related practices, which could make learning about ecosystems meaningful for the students. These practices should enable them to acquire the modern concept of the ecosystem. To be *valid,* these practices not only need to be meaningful. They also need to be on the one hand complex enough to grasp the idea of complexity and dynamics and on the other hand they should not be that sophisticated that they can not be transformed for use in classroom. Therefore, I used this as a criterion in the choices for adequate practices.

I conclude that my learning and teaching strategy is valid, in terms of *introducing adequate ecosystem related practices* where *dynamics and complexity* are important sub-concepts, enabling students to understand ecosystem behaviour.

To verify if this strategy was not only valid, but also *feasible* (2), I gathered empirical data working with the chosen practices in classroom in three subsequent case studies.

The students preferred the use of authentic practices in comparison with learning ecology from 'de-contextualized information' in their schoolbook. They understood the ecological background of the practices and expressed that these practices did realize them that ecology really matters in society. Previously, many of them had the idea that ecology was just something for biologists walking on waders through the fields or studying birds from a shelter, but not of real importance. In general they were highly involved in the various learning and teaching activities. They understood most of the activities of the practitioners and did not have problems with the ecological content that was offered.

I found out that it was important for the learning process to discuss the sequence of the chosen authentic practices with the students. Although they did not fully agree with the sequence, they appreciated the idea of being consulted and informed.

In working with authentic practices the problem posing approach (Lijnse & Klaasen, 2004) was helpful and students appreciated it. However, I found that such an approach is highly demanding in terms of the teacher's competence, especially when rather complex activities such as systems thinking and (especially) modelling are involved. In addition, the teachers have to assess the students' zone of proximal development which is also a difficult and demanding task.

The development of the concepts of ecosystem, dynamics and complexity during the lessons was problematic. The re-contextualization of these concepts, necessary at the end of every series of activities in an authentic practice, was largely neglected by the teachers, trying to get everybody to the end of the series of lessons in time and confronted with lack of time, caused by the very time consuming activities in autonomous building or extending computer models. Furthermore, the teachers were confronted with a 'planning problem'. For some of the students it was too early for re-contextualization, while for others it was too late to be of use, since they were already far involved in the next practice. Therefore, reflection and re-contextualization were disregarded. In all case studies, the teachers acted in a similar way: they tried to go on with the content by using small talks to undo backlogs. It was fascinating to observe that all teachers seemed to be focused on content and, when there was lack of time, chose to cut down on reflection and re-contextualization, activities which they are not very acquainted with, as they admit when confronted with their behaviour.

When I reflect on the design criteria I used for the construction of my learning and teaching strategy (see table 9.1), I can say that all criteria have been used in the learning and teaching strategy, with a problematic filling-in of the criteria 3, 5 and 6.

Table 9.1 The design criteria. An F indicates that the criterion is characteristic for feasibility; a V indicates that it is characteristic for validity.

1	The practice should not only be realistic, but also not too complicated for the students to grasp the concept of the ecosystem and the sub-ordinate concepts of complexity and dynamics. As students are no practitioners and do not have the knowledge of practitioners, the practices should be adapted in the sequence of performed activities as well as in their complexity, to make it useful in classroom (F/V).
2	The practice should be clear and relevant (personal and/or societal) for the students, in terms of familiarity with the activity of the participants in the practice (F).
3	The practice should rely on the use of ‘ecosystem’ as a recognizable and functional key concept, interpreted as an open system with interrelated factors. Besides, population, organism, dynamics and complexity have to be recognizable sub-ordinate concepts (V/F).
4	In the practice there should be an important role for systems thinking activities. It should be necessary to explore the relationships of, and to yo-yo between, the various levels of organization, in order to grasp the hierarchical structure of the ecosystem (V/ F).
5	In the practice modelling activities should have a necessary role to gain a quantitative insight into the dynamics of the system over time and space. The modelling process should start with sketches, going up via simple computer models into more sophisticated ones. (V/F).
6	There should be a sequence of three practices of increasing complexity. This sequence should be plausible for the students (F).
7	The basic problem to be solved in the practice should elicit student’s ideas. It should evoke a ‘global ‘motive for students to become involved and it should continuously evoke ‘local’ motives to keep the learning process going, leading to solutions to the problems they are confronted with (F).
8	To support the autonomy of the learners, the learning and teaching strategy should be transparent for students: this implies that at any point it should be clear to the students what learning activities they have to do, when and why (F).

Concerning criterion 3, most of the time has been spent on the levels of the organism and the population, which has left too less time for the level of the ecosystem. Therefore the sub-concepts of dynamics and complexity, which are especially important on this level, did not get enough profundity.

Concerning criterion 5, the students did start with sketches and went up via simple models to complex ones. However, somewhere along this road there were some severe complications for the students, on which I will elaborate in section 9.5.

Concerning criterion 6, as already described, the students valued the fact that there was a discussion about the sequence of the offered practices, but they were not convinced that this sequence was plausible. A problem was that the concepts of dynamics and complexity, which were central in the discussion, did not have a profound meaning for them at that moment.

I conclude that my LT-strategy is feasible, in terms of the characteristics of a realistic, clear and relevant use of practices, with a transparent role for systems thinking; where there is a problem that elicits students' ideas; and where the LT-strategy is clear to the students.

In some aspects our learning and teaching strategy appeared to be *effective* (3). Most students performed rather well on discriminating levels of organization, exploring models and getting an idea of complexity and dynamics, although on the last subject their understanding appeared to be rather superficial.

However, it is premature to conclude that the use of authentic practices as contexts with embedded concepts, is not only feasible but also effective (see also Goedhart, 2004; Lijnse, 2007). Many of the students had severe difficulties to structure the systems' components and processes in a framework of relations, with the level of organization of the population and its systems boundaries and especially with the autonomous construction of computer models. When the intended learning outcomes (see table 9.2) are compared with the learning results, the study reveals that quite a number of the intended learning outcomes were realized, such as the outcomes 1, 3, 5, 7, 8, 9 and 10. However, the outcomes 2, 4 and 6 were certainly not (completely) attained, where 2 is an outcome which is central in my opinion. These findings are confirmed by the fact that I found no significant shift towards a more dynamic view in comparing the students' views in a pre- and post-test.

Table 9.2. The intended learning outcomes.

1	identify relations between organisms, populations and between the community and the non-living (abiotic) environment and to represent them in a scheme (B1.1 and B1.4)
2	exemplify the relation between complexity, dynamics, stability and diversity in an ecosystem.
3	apply their knowledge and understanding of the concept ecosystem and subordinate concepts to various concrete examples of an ecosystem.
4	recognize an ecosystem as a (special example of) an open system, which means that not only the parts but also the relations between the parts are relevant and that the systems boundaries are not always clear-cut.
5	recognize the different levels of organization in an ecosystem: ecosystem → community → population → organism and to yo-yo between these levels (B1.7).
6	represent the relations in an ecosystem in a model and quantify the relations with the help of provided data.
7	use models in predicting the effects of possible changes like climate change, extinction of populations, or human intervention.
8	take an argued position in a discussion about interventions in an ecosystem, based on weighing pro's and cons.
9	exemplify man's position in ecosystems: influencing and being influenced.
10	underpin the measures taken for the conservation of ecosystems, with ecological, economical and normative arguments.

Although reflection and re-contextualization of the concepts got too little attention, the students did show some understanding of the correspondences and differences between the concepts used in the practices. For example, they were able to describe differences in dynamics between the ecosystems in use in the first and second practice and to tell which level of organization was central in the second practice. In the third practice, they understood that it is important to know on which level participants focus in ecology related discussions, to make real discussion possible. This suggests that the students at least partly re-contextualize autonomously, which could be enhanced by the fact that the three practices do not extremely differ from each other.

So, I conclude that my LT-strategy is only partial valid, insofar not all learning outcomes have been reached.

I can state that progress has been made in learning and teaching about ecosystems.

I succeeded in making students' education valid, on many points feasible and on some points effective. But there are some important problems to be solved. I did not succeed completely in developing a modern concept of dynamics and complexity. This is partly due to the fact that there was not enough time (reserved) for reflection and re-contextualization. Especially the modelling activity appeared to demand much time.

9.3 Implications for authentic practices

When I started this investigation, examples of the use of authentic practices in upper secondary biology education were not yet available. So I had to pioneer, looking for practices that seemed promising and that could be rather easily adapted for use in the classroom. It will be clear that the designer of a series of lessons has to know rather exactly what to expect of the (pre) conceptions that are already available in the consciousness of the students. Armed with this knowledge it will be possible to adapt an authentic practice to a 'classroom practice'. To keep the authentic character of the chosen practices, I used Powerpoint presentations and animations, especially in the case of, the practice in which scientists investigate how to optimize mussel harvest. The presentations and animations were developed with the help of the practitioners themselves. An often heard criticism about working with authentic practices is that it takes a lot of time to get the students acquainted with 'practice (context)-based knowledge', which will be at the cost of time spent on 'content-based knowledge'. In my case, this problem was not felt. I used about 22 minutes for practice-based knowledge in the first practice (a movie about mussel culture, a Powerpoint presentation about NIOO- activities and animations about measuring techniques). And no time for the second practice (because I expected that the activities of dune managing people were clear to the students). It will depend on the 'distance' between the specific activities of the practice and the pre-concepts of the students. In any case I think it will be sensible to use practices that can be grasped by the students or relatively easy to adapt, leaving out difficult activities without losing the essence of the practice.

From the beginning I tried to select promising practices in terms of being meaningful to students. In spite of some preliminary investigations about what students would like and the teaching experience of the researcher of more than 30 years, it remains difficult to predict what will be experienced as meaningful by students, which can be the result of a personal or societal relevance. Most of the schools I worked with in my case studies are situated near the dune area and not in the south-western part of the country, so it was not surprising that the students were more interested in the rabbit managing practice than in the mussel harvest optimization research, besides their stronger emotional links with rabbits than with mussels. Most students said they liked the approach I used, because it is more about the real world, and the problems posed are real problems, while their schoolbooks are not experienced in the same way. What they stated to be difficult in practice based lessons is what they had to learn. They appeared to be very uncertain about what to learn and how the final test would look like, which was caused by discrepancy between their 'school culture' and the series of lessons that I offered them. So I introduced a series of questions at the start of the lessons to make clear that the questions in the final test would not be about mussels or rabbits, but about the concepts that they acquired in the two practices. In retrospect, it would have been sensible also to introduce a complete exercise test before the third test practice was offered. Re-contextualization in passing from the second practice to the test practice is even more important for the students than in passing from the first practice to the second. In that case they have to show their ability to re-contextualize completely spontaneously, or maybe in a small group (depending on the way the test is organized), but anyway without the help of the teacher. In Vygotskyan language, it is necessary that the teacher has brought the students into their zone of proximal development, to give them the possibility to internalize the concepts I wanted them to learn. In the third practice I had the problem that the way of testing in many schools (students with pen and paper in a classroom, writing down answers) is not quite adequate for testing an authentic practice. In our case computer modelling would be an adequate test activity, but this could not be realized in the actual school setting.

After my experiences with a set of three authentic practices it is tempting to think about possible implications for the wider application of the use of them, all the more because in Dutch upper secondary biology education an experiment with the use of authentic practices (known as the concept-activity-concept approach) is ongoing (Boersma et al., 2005a). Where the students react positively to the idea of introducing concepts in a meaningful authentic practice (context), these experiences can be used as an example. Our successes and obstacles could be of value in the further development of the experiment. For example, our list of eight design criteria (see table 9.1) could be used as a kind of mold, with the exception of the criteria 4 and 5 (which are specific for systems thinking and modelling) and with an adaptation of the concept-based criterion 3 (dependent of the concepts in focus). Special attention is needed for criterion 6 about the sequence of the presented practices.

As the concept-activity-context approach also works with a set of three practices, it is essential to pay attention to a sequence of these three which is plausible or in any case acceptable for the students. Further, like in my investigation, it seems sensible to look for practices which are not too difficult to adapt for use in classroom and do not need a lot of explanation of practice based knowledge.

It seems fair to say that in interviews, many students stated that they appreciated working with authentic practices, but that they did not want the whole curriculum to be built around such practices. For example, when they have to learn a number of facts by heart, they prefer 'de-contextualized information'.

9.4 Implications for systems thinking

Students understood the systems character of the organism, population, and ecosystem and most of them were able to determine the correct level or levels that were involved in the presented practices and to yo-yo between these three levels. The students were aware that mussels as a population have influence on the dry-weight of each mussel as an organism, caused by the intraspecific competition for food. At the same time they understood that this competition is the result of the individual need for plankton algae as a food source. However, they had difficulties with the idea of systems boundaries, especially at the rather abstract level of the population. The students had rather concrete ideas about the boundaries of the organism ('its exterior') and the ecosystem ('where the sea stops', 'where the beach begins'). For the population they know the 'abstract' definition about conspecifics which form a reproductive unit, but they cannot link it to the concrete ecological reality. For them the population seems to be in a diffuse room somewhere in the ecosystem. They cannot point out the exact boundaries. Therefore, they should be helped by questions such as: 'Which mussels or rabbits do not belong to the population and why?' or: 'Is every place in the ecosystem suitable for the members of the mussel population, if not, why not?' A transfer is needed from the abstract definition to a concrete local description, for example as a student answered to my second question: 'Mussels will not live everywhere in the Easterscheldt. In some places it is too shallow, they will be eaten there. In other places it is too deep; so they will not find algae there.' There can be discussion about the most suitable way to introduce the population. The most practical solution certainly is to start with the formal description of the population as the assembly of conspecifics in a certain area, adding some characteristics which are specific for this level of organization, such as competition or cooperation. I used another solution, where I did not add these specific characteristics; these popped up when the students modelled a population as a group of mussels and saw things happen which could not be the result of the organism separately. A problem is that in Dutch biology schoolbooks the concept 'population' is embedded in different themes. The concept is used in lessons about taxonomy, where the abovementioned formal description is introduced, in lessons about ecology, where the abovementioned specific characteristics are introduced, and in evolution where the idea of the population as a gene pool is introduced. No links are created between these different conceptions of the concept 'population'. For example, a link between an entity living in a certain area and an assembly exchanging gene information is not made transparent for the students. Therefore, the difference between 'physical boundaries' (for example the shoreline) and 'genetic boundaries' (whether or not exchanging genes with each other) is totally unfamiliar to the students.

In biology education, systems thinking has a strong potential which is exploited for example by the producers of the national written examinations in the Netherlands. In the clustered questions about biological phenomena which they develop, they often invite the students to yo-yo between the various levels of organization. This is not only the case in ecosystem related questions, but also for example in questions about genetics, where students have to yo-yo between gene, cell and organism, or about evolution, where they yo-yo even more broad, between gene, organism and population. Teachers will have to use this yo-yoing to prepare their students for these questions. This legitimizes explicit attention for what systems thinking is about and for what its power can be. Systems thinking can be an effective strategy to help students in on the one hand getting a better idea of natural phenomena and on the other hand in helping them to perform better on their exams.

However, my investigations have made clear that, in particular at the level of the population, the systems character and its boundaries are not always transparent for students. The boundaries of the population were not directly relevant for the problems the students had to solve, so there was no motive to really think about this. In other practices more expertise in this field will be needed, which could be gained by introducing a practice where the systems boundaries of the population are meaningful, for example in an evolution related practice.

9.5 Implications for modelling

When the students were modelling, most of them did not have difficulties in exploring and running computer models. However, being asked to construct models all by themselves, they found it very difficult to feed in data from natural phenomena and also to relate the components (most of which they understood) to each other in their model.

In the first place they had problems in model development while keeping in touch with natural phenomena. This could be the result of problems with the *interpretation* of various components in their models. For example, the students did not have any idea of the real value of the dry-weight of a mussel. This could explain that they were not alarmed by values such as 1 kg. It is difficult to link natural phenomena with model output if you do not have any idea of the nature of these phenomena. I tried to solve this problem by introducing weighing activities to find the value of dry-weight.

More alarming was the observation that many students lost contact with natural phenomena during modelling. This could be caused by *not really understanding the abstract structure* of the model, where the students do not see the link between the components in this structure and natural phenomena. I have tried to use emergent modelling (Gravemeijer, 1999; Gravemeijer & Stephan, 2002; Andresen, 2006) by working with a sequence of representations *from* reality, followed by more and more abstract models, with the aim to use these models as representations *towards* reality. This could give the students the possibility to predict natural phenomena. However, during modelling many students still were driven away from reality, they seemed locked-up in their models and even did not always think about validating their models. This could also be the result of two other problems, which are more *linguistic* and *mathematically* based. Many students had difficulties with the symbolic language of the modelling tool, for example they could not discriminate between constants or variables. Many of them also had difficulties with formalizing relations between components, for example multiplying or adding up two components in an equation. Some had problems in interpreting the dynamics of their model. A graphic modelling tool shows a two-dimensional pattern, which could give a dynamic pattern when the model is run. The graph or table shows the actual development over time. Many students appear not fully to understand how these graphs develop, the mathematical equations behind these graphs are seldom viewed or understood. One of the difficulties is that differential calculus and integration have not yet been taught in mathematics at this level of biology education.

These difficulties are not easy to be solved, also because many of their teachers experienced the same problems. In biology, finding equations could be indeed more difficult than in physics. '*A physicist who is studying a system starts by looking for the adequate equations. Preferably, he searches for these equations in a handbook. If he cannot find them, he derives them from basic principles. A biologist, on the other hand, will not be able to derive equations simply by thinking about a certain animal population. He has to gather data and try to find equations that lead to comparable results.*' (Gleick, 1987, p.60) For modelling to become a success, it is necessary that the teachers get familiar with the used modelling tool. An intense teacher training programme in this subject will be needed. This programme should enable the teachers to use their biological knowledge in a 'language' which is not yet very familiar, a language with very specific difficulties. One of the basic difficulties is that most biology teachers are not used to formulate relations in mathematical equations. The reactions of many biology teachers to the use of the Powersim modelling tool in the Compex examinations in biology (see chapter 5) show that they, just like their students, have severe difficulties in extending models. In a certain way they transmit to the students the idea that upper secondary biology exists without mathematics. In scientific biological investigations it is quite clear that this is not the case; mathematics and modelling found their place in almost every biological investigation.

Therefore, if upper secondary biology education must be up to date, we need teachers to be trained in getting familiar with the syntax of the programming language as well as with basics of mathematical thinking in biology.

The modelling difficulties have taken so much time, that the students did not reach the point where they have an extended view of the complexity and dynamics of an ecosystem. In the post-test I did not observe significant changes in their (rather static) view on ecosystems. This is a rather disappointing result, which can be linked to the conclusion that the students did not attain our learning aim 2. In retrospective, this could be the result of a combination of too much ecological content and too difficult modelling in the series of lessons.

9.6 Ideas for further research

The results show that it did not get completely clear to students what complexity and dynamics really mean in the ecosystem after my investigations. Understanding complexity and dynamics clearly appears to need more time to develop a modern concept of 'ecosystem' for the students. It will be necessary to investigate what is needed to develop this modern concept. Should there be more attention for the biological content? Should there be less attention for modelling and more for using models? If not, what do students need to know already (about the language of the modelling tool, the mathematics of difference equations and the rationale of formalizing relations) to be able to construct models? How to use reflection and re-contextualization in a more effective way?

For example ready-made models could be used to explore dynamics in a complex ecosystem: the short term and long term effects of the removal and/or return of a species or the introduction of a new species. These effects can be studied as linear effects, which means on adjacent chains in the food web, but also as nonlinear effects, one of the things students appear to have severe difficulties with (Webb & Boltt, 1990; Hogan, 2000; Grotzer & Bell-Basca, 2003). Because of the difficulties with modelling, it would be interesting to see if exploring models and creating small extensions on existing models would create better understanding for students. Other subjects of investigation can be investigated as well. Complexity and dynamics are concepts that could also be used in the study of for example the hormonal household of the human body, cell biology, evolution or population genetics. A combination of systems thinking and (reduced) modelling could be used in authentic practices where these themes have a central position. A lot could be done to reduce the distance between some unfamiliar authentic practices and classroom situation. Further development of how to introduce data from natural phenomena (for example via contact between a research institute and schools) or showing expert activities of the practitioners could be the subject of investigation.

At last, the third test practice needs further investigation. How to find a way that offers students the opportunity not only to demonstrate their abilities to re-contextualize by answering questions on paper, but also by for example performing modelling activities on a computer?

1.8 Epilogue: the teacher as a researcher

From the beginning of my work as a researcher I had the feeling that I was working like a juggling artist, trying 'to keep three balls in the air'. Not only the ecological ball with the concepts of ecosystem, complexity and dynamics, but also the balls of systems thinking and modelling were in focus in this investigation. The last two balls were thought to be means and not goals in this investigation, but by many students they were perceived as goals. This could be caused by the fact that a lot of time was spent on modelling and systems thinking, at the cost of stimulating the development of concepts by reflection and re-contextualization. In my opinion several times one of the balls was 'coming down'. There were serious problems with keeping students' motivation during the series. I experienced difficult moments at the introduction of the first and the second practice, which the students were not familiar with. They had some knowledge of the related ecosystems in these practices, but most of the activities of the practitioners were unfamiliar to them. For the first practice I developed special materials to cope with this problem. However, for the second practice it was decided not to spend much time to get involved in what the practitioners' activities were and what their specific problem was, because the students seemed familiar with the ecological background. In retrospect, this was a rash decision.

Especially the modelling activities were problematic in all case studies, despite the fact that I worked hard to find improvements between the case studies. These improvements had some effect on students' motivation; after the first case study I did not experience any more problems with students who did not like to go on, because of frustrations, caused by models that did not work. But it appeared a journey between Scylla (using ready-made models with the danger of students working on auto-pilot) and Charybdis (asking students to build the models themselves, leading to failure, disappointment and frustration). As described in 9.5, the students had severe problems with the quantification and mathematical formulation of relations between various components in a model and also with the linking of their models with natural phenomena. Maybe I overestimated their possibilities and should have been somewhat more modest in our demands.

In all case studies the time seemed too short to do all what had been planned, despite of the fact that some parts were removed from the series between the subsequent versions of the design. The fascinating thing is that the reaction to this time problem was the same for all teachers, including myself: to keep the programme going by speeding up, at the cost of reflection and re-contextualisation, which are not very familiar activities for teachers, due to not being experienced in this field. To solve this problem I should invest in specific teacher training activities.

At the end of this investigation, I could say that there were some successes and some disappointments. I proved that there was indeed a lack of dynamics and complexity in upper secondary ecology education and did find some interesting points of departure which could help to fill this gap. Systems thinking and modelling appear to be helpful to get a more clear idea, respectively of the structures and processes which are important in complex ecology behaviour.

In my opinion, systems thinking can be an enriching activity for students, by the way not only in biology education, but in many fields where students are confronted with. To me it seems a good idea to be aware that for example a school community, a classroom, a factory or an ecosystem can be considered as a system: a complex of interrelated components with a boundary (Senge, 1992). It should be clear to the students that it is possible to look at various phenomena on different levels. This could enrich their ideas about for example the ecosystem, and make it possible to understand developments in this system which are nonlinear or have a time-delay. Just one sentence *'Man is not only an organism, but also an ecosystem'* (Kattmann, personal communication) gave rise to a complete lesson with systems thinking in one of my upper secondary classes last September, where we talked about dynamical developments in relations such as mutualism, commensalism and parasitism between man and all kinds of micro-organisms living on the skin and in the intestines of man.

I would like to stick to modelling, however problematic it appears to be. The autonomous building of computer models, especially, needs more attention to become understandable for students in such a way that they link their model results with real phenomena. It is good to realize that modelling is used here as a means and is not the goal of the activities. It should be clear to the students how they could use the models. The idea of emergent modelling, that I used explicitly in this investigation, should be investigated further. In biology, models play a very important role, not only as computer models but in many different forms, but in most cases without any explanation. In the science of biology, complex and dynamic computer models have captured a central position in all kinds of investigations. We should find a way to use models in such a way that on the one hand the teachers can really help the students to find their ways and on the other hand the students understand the syntactical and mathematical basics of modelling, while keeping in contact with natural phenomena. These phenomena should, in retrospect, have a more prominent place in the lessons. Only a little bit of mussel anatomy, a weighing activity and some Powerpoint presentations are not enough for students to experience the natural phenomena which I would like them to understand. We have to be aware of the risk that is so colourful described in the following citation: *'With the advent of mathematical modelling, computer analysis and seemingly ethereal concepts (all part of the science coming of age), ecology is increasingly perceived as complex, dull and incomprehensible to ordinary people, with little relevance to what is observed when looking at the natural, semi-natural and cultivated landscape. The original sparkle of 'scientific natural history' or 'interpreting the landscape with common sense', which was so much a part of the initial appeal of ecology, is being lost. As a seasoned course participant recently commented to the author, 'In my day an ecologist looked at a woodland with wise eyes and could explain to me what I was looking at, now he seems to stare at a computer screen with wide eyes and can tell me nothing that is meaningful.'* (Thomas, 1993, p.37)

What aspects of being a teacher were of help for me during this investigation? On the other hand, what aspects of this investigation during the last four years were of help for my further career as a teacher?

I think the long experience as a teacher did have the advantage that I have expertise about what will be possibly a successful strategy and what will be most probably dead ends. An experienced teacher has ideas about the pre-concepts which students hold and about bottlenecks in a series of activities. Being experienced however is no guarantee for the successful development of a learning and teaching strategy. I have discovered that the series had too much content for a majority of the students. Also, that despite all my knowledge about modelling, it still was problematic to keep all students 'on the road'. There are things that I can use during the rest of my career as a teacher. For that is what I want to do after finishing this thesis. Like my Swedish collegue Carl-Johan Rundgren said on the Eridob conference in Malmö last summer: *'Once a biology teacher, always a biology teacher!'* I use the ideas ofVygotsky in my lessons, continuously trying now to assess the zone of proximal development of my students, working more and more with them on a one to one base. For example, in talks about a complex concept, such as osmosis, I am continuously busy finding out whether the steps that I make with the student are not too big. Students are invited to make it immediately clear where they cannot follow anymore. And I wrap osmosis in a practice such as a factory where isotonic drinks are produced, offering the students the possibility to perform activities such as observing blood cells in an isotonic drink under the microscope.

I have become more aware of their pre-concepts of the levels of organization and their problems with syntax and mathematics in computer models, which we use as a school that is involved in the Compex experiment. In this experiment Powersim models are used in the national examination. In the series of lessons which I myself carried out with one of my classes, during analysis I discovered many things about my teaching style and the way I give feedback to students. For example, during the analysis of class conversation, I couldn't help thinking of the famous experiment with Kluger Hans (Pfungst, 1907). Like the calculating horse Kluger Hans could see from his trainer Freiherr von Osten, my students could see from my nonverbal reaction if I was satisfied with their answers or if they had to add some more. There are two sides to this story. On the one hand it is nice, because there is no sign of negative (inhibiting) feedback. On the other hand it is sad, because this does not elicit spontaneous thinking, but a kind of operant conditioning. It will be interesting to look for a way out of this dilemma. The period of four years that I worked as a researcher, were enriching. I am sure that it was an important stimulus for my development as a teacher. Being a sort of forerunner for the DUDOC-project[1], I hope my teacher-researcher colleagues, from whom the first have started their Ph.D.-studies in 2007, will have the same experience as I had.

1 In the DUDOC-project, upper secondary teachers are working as Ph.D.s, investigating reform ideas in science and mathematics education.

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Summary

This thesis describes developmental research which was carried out from July 2003 until July 2007 at the Centre for Science and Mathematics Education (now Freudenthal Institute for Science and Mathematics Education) at Utrecht University. This research aimed at a useful approach for modern ecology education in upper secondary school. The challenge was to develop a theory-based and empirically validated design of a learning and teaching strategy to reach this modern education. The central research question was:

What are the characteristics of a valid, feasible and effective learning and teaching strategy about ecosystem behaviour using modelling and systems thinking in authentic practices?

Chapter 1 describes the motive for this research. An ecosystem is complex and dynamic. Knowledge from and insight in this complexity and dynamics has societal relevance. However, because of lack of such knowledge and insight in upper secondary education, the students do not have the opportunity to develop ecological literacy. This literacy is, in my opinion, more important than acquiring a vast amount of ecological knowledge.

By making use of activities such as systems thinking and modelling, complex and dynamic processes can become transparent for students. However, students should perform these activities themselves, being aware of the relevance of these activities. Therefore, a learning and teaching strategy is developed making use of contexts, embedded as ecosystem-related authentic practices. In these contexts concepts such as ecosystem, dynamics and complexity are approached in a functional way.

The developed learning and teaching strategy, after having been tested in classroom, does provide an answer to the abovementioned research question. We will get an answer to five sub-questions related to the validity, feasibility and effectiveness of the strategy.

1. *Which ecology-related authentic practices seem appropriate for enabling students to grasp and value the role of systems thinking and modelling?*
2. *What are the opportunities for systems theory to clarify complexity at various levels of*

biological organization such as organism, population and ecosystem?

3. *What are the opportunities for computer modelling to clarify dynamics at various levels of biological organization such as organism, population and ecosystem?*
4. *Which pedagogical approach is helpful for students in using modelling and systems thinking?*
5. *Which pedagogical approach is helpful for students in developing scientific ecological concepts starting from concepts embedded in authentic practices?*

Chapter 2 focuses on the sub-questions 4 and 5. First, a description is given about how learning in upper secondary school takes place in general. In the Netherlands there has been a transition from a connectionist-behaviourist towards a constructivist approach. There is a shift of focus from transmission of knowledge towards construction of knowledge, where the teacher gets the role of a coach, more than as the transmitter of knowledge. The cultural historical approach is interested in the teacher's role as a coach as well as a 'mediator' between the student and culture. Construction of knowledge by the student can be described as a developmental process, which is cultural historically determined. Learning is not an individual process, but takes place in the interaction between the learner, his peers and the teacher. Also the use of tools is essential. Especially the focus on the learning activities of the students and the prominent role of the teacher as a 'representative of human culture' challenging the learners, are important. In this approach, learning requires a practice that invites students to participate in all kinds of activities of a social nature. Students work together, talk, discuss, and reflect on their activities. The authenticity of the practice could provide the learners, being interested in real world phenomena, with motives for learning. Used concepts have a specific practice related meaning. Therefore, a concept may have different meanings in different practices (here also called contexts). Students have to adapt this concept when it is required to use it in another non-familiar social practice. This process of adaptation is called re-contextualisation.

For education to be effective, it is desirable that students are willing and enabled to take an active role in the complete series of learning activities. The use of an authentic practice will not be sufficient to meet this criterion. The problem posing approach is a didactical strategy that aims to actively involve students in the learning process. The students participating in such an approach always know what they are doing, why they are doing it, and how they are going to proceed.

In the development of my learning and teaching strategy the concept-context-approach, where a context is described in cultural historical way as a practice, is linked with the problem posing approach. The learning activities of the students are linked by a sequence of questions which can be solved by performing these activities. In the end all answers contribute to the solving of the central problem in the series of lessons.

Chapter 3 also focuses on the sub-questions 4 and 5. It describes the research plan. I use developmental research. In developmental research, theory-driven, creative and practicable solutions to learning and teaching problems are designed in iterative consultation with experienced teachers and tested in classroom situation. This results in a domain specific learning and teaching theory which is helpful in classroom. There are two phases: the explorative phase and the cyclic research phase.

In the explorative phase, criteria for a supposed effective strategy are established. First, the most important characteristics of the modern concept ecosystem and sub-ordinate concepts such as complexity and dynamics are determined (see chapter 4). Then, possible learning problems that could evolve at the introduction of these concepts are analysed (see chapter 5). At last, a desired structure of the strategy, also determined by the view on learning and teaching (see chapter 2) is established (see chapter 6).

After the explorative phase, the cyclic research phase follows. The learning and teaching strategy is elaborated into a context-specific scenario (see further chapter 6). This scenario is tested in classroom in two or three research cycles (see further chapter 7). After each cycle the scenario is analysed using extensive multiple datasets. Evaluation of and reflection on the executed scenario provides indications for improvement (see further chapter 8). In developmental and classroom research there is a continuous going backward-and-forward which will eventually lead to a theory-based and empirically validated learning and teaching strategy (see further chapter 9).

Chapter 4 concentrates on the sub-questions 2 and 3. The scientific ideas of the concept 'ecosystem' are raised. There have developed various views on the concept, dependent on the perspective of people. Four views with their specific characteristics are described: the holistic, cybernetic, dynamic and chaotic view. Nowadays, dynamic and chaotic views are dominant in the science of ecology. In these views continuous dynamic development is central, equilibrium is just a snapshot in time. Predictions have only limited value.

Inside the scientific world there is no consensus about certain sub-ordinate concepts such as (temporary) equilibrium, complexity and stability and their interrelations.

To grasp complex phenomena, systems thinking is adequate. In this way of thinking there is specific attention for the levels of organization and for the way the components (populations, all kinds of abiotic factors) influence each other in a ecosystem in a non-linear, multicausal way, causing dynamic patterns. In this investigation I restrict myself (with arguments) to three levels of organization: organism, population and ecosystem. Various kinds of models being in use in systems thinking, like black box and glass box models, mathematical models and computer models, are described. Modelling did evolve from mathematically formulated descriptions of ecological relations towards an important computer based activity in studying ecosystems. This makes it possible to simulate and calculate complex phenomena, which enable predictions about (possible) developments.

Also in **chapter 5** the sub-questions 2 and 3 are in focus. The present situation in upper secondary education is central here. Ecology education uses static models (such as food chains or food webs) which do not provide students with the opportunity to grasp the dynamics of an ecosystem. I tested the assumption that holistic and cybernetic views were dominant in Dutch upper secondary education. Therefore the examination syllabus, three different schoolbooks and a number of lessons on ecology were analysed. The views of teachers and scientific ecologists were compared. In the examination syllabus, the schoolbooks and the lessons there are hardly any traces of modern ecological views. Between ecologists and teachers there are substantial differences in their views on the concept 'ecosystem'. Teachers are more inclined to old-fashioned views and they are less consistent in their views than ecologists. The choices of teachers and ecologists for important concepts that should be taught only partly agree with each other.

Chapter 6 concentrates on the sub-questions 1, 4 and 5. The learning and teaching strategy is developed after the explorative phase, which has been finished in chapter 5. The learning aims are determined, derived from the analysis of the modern concept 'ecosystem.' Eight design criteria are formulated, derived from the explorative phase. Next, a selection is made of adequate authentic practices. The three selected practices are described: ecologists investigating the optimization of mussel culture in the Easter Scheldt, dune managing people working on the management of the rabbit population in a water resource-area in the dunes, and scientists deciding together how to act in an area in Southern Africa which is overcrowded with elephants.

From the preliminary structure of the learning and teaching strategy, a scenario is derived, which is transformed in lesson materials (workbook and computer models). These will be tested in the first research cycle.

Chapter 7 shows the design for the research cycles. After presenting the data of the schools participating in the three versions of the design, the way of collecting data is described. Next, how the choices of these data were related to the five sub-questions of the research question. At last, the method of analysis of the various data is described.

In **chapter 8** the cyclic phase of the research is reported. First, an extensive description is given of a comparison between the last developed scenario and the actual course of the last case study from the third version of the design. To cope with issues arising from a confusion of the roles of the teacher and the investigator (because the investigator did also the teaching) a co-researcher was invited to participate in the analysis of the material, which can guarantee the reliability of the analyses. For each lesson, the various activities are described, with aberrations from the scenario and their possible cause.

After that, for all five sub-questions, making use of conditions which are derived from the eight design criteria, is described whether the designed learning and teaching strategy is succesfull and if not, which attempts have been done for improvement.

Sub-question 1: *Which ecology-related authentic practices seem appropriate for enabling students to grasp and value the role of systems thinking and modelling?*

For this sub-question it is concluded that the three selected authentic practices are appropriate. They are clear and relevant for most students and offer them enough possibilities for active involvement, which is a prerequisite for getting seriously involved in systems thinking and modelling. The chosen sequence was not the sequence that the students preferred, but they accepted it after a discussion and worked without further objections.

Sub-question 2: *What are the opportunities for systems theory to clarify complexity at various levels of organization such as the organism, population, and ecosystem?*

For this sub-question it is concluded that systems thinking offers opportumies. There is no unambiguous answer to the second sub-question. Most abilities are successfully used by the students. However, the ability 'organize the systems' components and processes within a framework of relations' seems to be difficult. This is the ability which is also very important in modelling. There is only an improvement in the ability 'recognition of the systems' boundaries and of the open or closed character of the system' in the subsequent case studies.

Sub-question 3: *What are the opportunities for computer modelling to clarify dynamics at various levels of organization such as the organism, population or ecosystem?*

Modelling has opportunities to clarify dynamics. However, there appear to be some complicated abilities for students. Despite the rather successful introduction of emergent modelling in the second version of the design, especially the sketching, which requires goal orientated modelling behaviour, and the actual building, which requires an overview of the components of the system and the relations between them, expressed in formal (mathematical) language, cause problems. The students are aware of the relation between their model and empirical data, but sometimes they seem to be too involved with modelling to think about these links constantly and validate their models with real world knowledge.

Sub-question 4: *Which pedagogical approach is helpful for students in using modelling and systems thinking?*

Some understanding of the problems posed has been reached. However, the students still have difficulties realizing the various learning activities to continue, especially in the modelling activities. The teacher's ability to detect modelling problems, to suggest solutions and to divide time between personal attention and group reflection seems necessary to keep the students involved and continuing their activities.

Sub-question 5: *Which pedagogical approach is helpful for students in developing scientific ecological concepts starting from concepts embedded in authentic practices?*

My approach did not succeed in developing real understanding of complexity and dynamics of an ecosystem. Especially the fulfilment of the conditions 'the students recognize that used concepts can have (slightly) different meanings in other practices' and 'the students use the concepts in an adequate way in still another practice without help' appeared to be problematic.

In my learning and teaching strategy I went bottom-up towards the level of the ecosystem. From there an overview can be given from all three levels of organization, which makes it possible to perform the necessary yo-yoing activities between these levels. This gives the possibility to find out effects from one level on the other. However, the construction of models has been so time consuming that there has not been enough time to reach 'the top of the mountain'. In all case studies there have been problems with completing the content that was offered. All teachers responded to this lack of time by concentrating on the models, trying to get the students on the same level again. They did this at the cost of the time reserved for reflection on what the students had learned and for re-contextualisation. Therefore there was not much progress in concept development. Relatively much time has been spent on the first practice, not enough time was left for the second. And it was this second practice where the complexity and dynamics of the ecosystem were in focus, because in this practice the related ecosystem was more complex and dynamic.

It is not surprising that the comparison of a pre-test and post-test, which could give an idea of the view on ecosystems (see also chapter 5), does not show a substantial change in the view of the students in our case studies.

In chapter 9 the research question is answered. My learning and teaching strategy is valid, in terms of introducing adequate ecosystem-related practices where dynamics and complexity are important sub-concepts, enabling students to understand ecosystem behaviour. My strategy is feasible, in terms of the characteristics of a realistic, clear and relevant use of practices, with a transparent role for systems thinking; where there is a problem that elicits students' ideas; and where the LT-strategy is clear to the students. However, in terms of the characteristics of the (open) systems character of an ecosystem, the modelling activities and the plausibility of the sequence of the selected practices, the strategy is not (completely) feasible.

In some aspects our learning and teaching strategy appears to be *effective.* Most students performed rather well on discriminating levels of organization, exploring models and getting an idea of complexity and dynamics, although on the last subject their understanding appeared to be rather superficial. A number of the ten intended learning outcomes have been realised. However, three outcomes were certainly not (completely) attained, where 'exemplify the relation between complexity, dynamics, stability and diversity' is an outcome which is central in my opinion.

When I reflect on the eight design criteria I used for the construction of my learning and teaching strategy, I can say that all criteria have been used in the learning and teaching strategy, with a problematic filling-in of the criteria 3 ('The practice should rely on the use of 'ecosystem' as a recognizable and functional key concept, interpreted as an open system with interrelated factors. Besides, population, organism, dynamics and complexity have to be recognizable sub-ordinate concepts'), 5 ('In the practice modelling activities should have a necessary role to gain a quantitative insight into the dynamics of the system over time and space') and 6 ('There should be a sequence of three practices of increasing complexity. This sequence should be plausible for the students').

There has been made progress in education about ecosystems. However, there are some bottlenecks that have to be solved. There are not yet complete concepts of dynamics and complexity in an ecosystem. Partly, because there has been too less time (used) for reflection and re-contextualisation. Besides, modelling appeared to demand a lot of time and the students sometimes lost contact with the real world.

Most students said they liked the approach, because it is about the real world, and the problems posed are real problems, while their schoolbooks are not experienced in the same way. What they stated to be difficult in practice based lessons is what they had to learn. Where the students react positively to the idea of introducing concepts in a meaningful authentic practice (context), these experiences can be used as an example in Dutch upper secondary biology education where an experiment with the use of authentic practices (known as the concept-activity-concept approach) is ongoing.

Students understood the systems character of the organism, population, and ecosystem and most of them were able to determine the correct level or levels that were involved in the presented practices and to yo-yo between these three levels. However, they had difficulties with the idea of systems boundaries, especially at the rather abstract level of the population.

When the students were modelling, most of them did not have difficulties in exploring and running computer models. However, being asked to construct models all by themselves, they found it very difficult to feed in data from natural phenomena and also to relate the components (most of which they understood) to each other in their model. In the first place they had problems in model development while keeping in touch with natural phenomena. It is difficult to link natural phenomena with model output, if you do not have any idea of the nature of these phenomena. But also, some of the students were inclined to lose contact with the real word at all. This could be a result of lack of understanding of the abstract structure of the model. Other problems for the students are the understanding of symbolic computer language and describing the relation between two components in a formula. These difficulties are not easy to be solved, also because many of their teachers experienced the same problems. For modelling to become a success, it is necessary that the teachers get familiar with the used modelling tool. An intense teacher training programme in this subject will be needed. This programme should enable the teachers to use their biological knowledge in a 'language' which is not yet very familiar, a language with very specific difficulties.

In the end of this chapter there is attention for further research and for the personal experiences of the investigator who is also a teacher, with special attention for two questions. What aspects of being a teacher were of help during this investigation? On the other hand, what aspects of this investigation during the last four years were of help for the further career as a teacher?

Samenvatting

Dit proefschrift beschrijft ontwikkelingsonderzoek dat werd uitgevoerd van juli 2003 tot juli 2007 bij het Centrum voor Didactiek van Wiskunde en Natuurwetenschappen (nu Freudenthal Instituut voor Didactiek van Wiskunde en Natuurwetenschappen) aan de Universiteit Utrecht. Dit onderzoek richtte zich op een geschikte aanpak van de modernisering van het onderwijs over ecosystemen in de bovenbouw van het VWO. Het doel van het onderzoek was de ontwikkeling van een theoretisch gefundeerd en empirisch getest ontwerp van een onderwijsleerstrategie om die modernisering te bereiken. De centrale onderzoeksvraag luidt als volgt:

Wat zijn kenmerken van een valide, uitvoerbare en effectieve onderwijsleerstrategie over het gedrag van ecosystemen, met gebruikmaking van modelleren en systeemdenken in authentieke praktijken?

Hoofdstuk 1 beschrijft de aanleiding voor dit onderzoek. Een ecosysteem is complex en dynamisch. Kennis van en inzicht in zulke dynamiek en complexiteit is van maatschappelijk belang. Echter, het ontbreken van dergelijke kennis en inzichten in het voortgezet onderwijs geeft leerlingen niet de mogelijkheid om ecologisch geletterd te raken. Zulke geletterdheid is, naar mijn opvatting, belangrijker dan het verwerven van een grote hoeveelheid ecologische kennis.

Door gebruik te maken van activiteiten als systeemdenken en modelleren kunnen complexe en dynamische verschijnselen voor de leerlingen duidelijker worden. Maar leerlingen zullen deze activiteiten wel zelf moeten uitvoeren, waarbij ze het belang daarvan inzien. Daarom wordt een onderwijsleerstrategie ontwikkeld waarin contexten in de vorm van ecosysteem- gerelateerde authentieke praktijken zijn ingebed en waarin concepten als ecosysteem, dynamiek en complexiteit op functionele wijze worden benaderd. De ontwikkelde strategie levert nadat hij in de klas getest is, een antwoord op de bovengenoemde onderzoeksvraag. Daarbij worden vijf deelvragen rond de validiteit, uitvoerbaarheid en effectiviteit van die strategie beantwoord.

1. *Welke ecosysteem- gerelateerde authentieke praktijken lijken geschikt om het de leerlingen mogelijk te maken om de rol van systeemdenken en modelleren te gebruiken en waarderen?*

2. *Wat zijn de mogelijkheden van systeemdenken om complexiteit duidelijk te maken op de verschillende organisatieniveaus zoals organisme, populatie en ecosysteem?*
3. *Wat zijn de mogelijkheden van computermodelleren om dynamiek duidelijk te maken op de verschillende organisatieniveaus zoals organisme, populatie en ecosysteem?*
4. *Welke didactische aanpak helpt leerlingen bij het gebruik van systeemdenken en modelleren?*
5. *Welke didactische aanpak helpt leerlingen om wetenschappelijke ecologische concepten te ontwikkelen, uitgaande van concepten die zijn ingebed in authentieke praktijken?*

Hoofdstuk 2 gaat vooral in op de deelvragen 4 en 5. Er wordt beschreven hoe leren op school meestal plaatsvindt. Er is in Nederland een ontwikkeling geweest van een connectionistisch- behavioristische aanpak naar een constructivistische. De aandacht verschuift daarbij, waarbij de rol van de leraar verschuift van kennisoverdrager naar begeleider van de kennisopbouw door de leerling. De cultuurhistorische benadering heeft zowel aandacht voor de rol van de leraar als begeleider als als 'mediator' tussen leerling en cultuur. De constructie van kennis door de leerling kan worden beschreven als een ontwikkelingsproces, dat cultuurhistorisch is bepaald. Leren is geen individueel proces, maar vindt plaats in de interactie tussen de leerling, zijn medeleerlingen en de leraar. Ook het gebruik van (leer)middelen is essentieel.Vooral de nadruk op leeractiviteiten van de leerlingen en de prominente rol van de leraar als vertegenwoordiger van de cultuur die de leerlingen uitdaagt, zijn belangrijke punten. Leren vereist in deze benadering een praktijk die studenten uitnodigt om deel te nemen aan allerlei verschillende sociale activiteiten. De leerlingen werken samen, praten met elkaar, discussiëren en reflecteren op hun activiteiten. De authenticiteit van een praktijk kan de leerlingen, die interesse hebben in de verschijnselen uit het 'echte leven', motieven aanreiken tot leren. Gebruikte concepten hebben een specifieke praktijkgebonden betekenis. Dat betekent dat een concept in een andere praktijk (hier aangeduid als een context) een andere betekenis kan hebben. Dat betekent dat leerlingen een concept moeten aanpassen, alvorens zij het in een andere praktijk (context) kunnen gebruiken. Dit proces staat bekend als recontextualiseren.

Om effectief te zijn voor het leren is het belangrijk dat leerlingen bereid en in staat zijn tot deelname in een serie leeractiviteiten. Daarvoor is het gebruik van authentieke praktijken niet voldoende. De probleemstellende benadering is een didactische strategie die mikt op het actief betrekken van de leerlingen bij het leerproces. Leerlingen weten in een dergelijke benadering wat ze doen, waarom ze dat doen en hoe ze verder moeten gaan.

In de ontwikkeling van een onderwijsleerstrategie wordt de concept-context-benadering, waarbij de context cultuurhistorisch als een authentieke praktijk is omschreven, verbonden met een probleemstellende benadering. De activiteiten die de leerlingen uitvoeren zijn verbonden door een serie vragen die worden beantwoord als de activiteiten worden uitgevoerd. Aan het einde dragen alle antwoorden bij aan het oplossen van het centrale probleem in de lessenserie.

Hoofdstuk 3 gaat ook vooral in op de deelvragen 4 en 5. Het beschrijft de onderzoeksaanpak. Het gaat hier om ontwikkelingsonderzoek. In ontwikkelingsonderzoek worden theoretische, creatieve en praktische oplossingen voor onderwijsleerproblemen ontwikkeld in nauw overleg met ervaren leraren en uitgetest in de klas. Daardoor kan een domeinspecifieke onderwijsleertheorie worden ontwikkeld, die bruikbaar is voor gebruik in de klas. In ontwikkelingsonderzoek zijn twee fasen te onderscheiden: de verkennende fase en de cyclische onderzoeksfase.

In de verkennende fase worden criteria voor een vermoedelijk effectieve onderwijsleerstrategie vastgesteld. Dat gebeurt na het vaststellen van de belangrijkste kenmerken van het moderne concept ‘ecosysteem’ en de daarmee verbonden subconcepten ‘dynamiek’ en ‘complexiteit’ (zie verder hoofdstuk 4). Vervolgens worden de mogelijke leerproblemen die zich bij introductie van die concepten kunnen voordoen (zie verder hoofdstuk 5) geanalyseerd. Daarna wordt (in hoofdstuk 6) de gewenste structuur vastgesteld van de onderwijsleerstrategie, die mede bepaald wordt door de gekozen onderwijsleerfilosofie (zie hoofdstuk 2).

Na de verkennende fase volgt de cyclische onderzoeksfase. Eerst wordt de onderwijsleerstrategie omgezet in een contextspecifiek scenario (zie verder hoofdstuk 6). Daarna wordt in drie onderzoeksrondes dit scenario uitgetest (zie verder hoofdstuk 7). Na iedere ronde wordt het scenario met behulp van verschillende verzamelde datasets geanalyseerd. Evaluatie van en reflectie op het uitgevoerde scenario geven aanwijzingen voor verbetering (zie verder hoofdstuk 8). Ontwikkeling en onderzoek in de klas wisselen elkaar af en leiden uiteindelijk tot een theoretisch gefundeerde en empirisch geteste onderwijsleerstrategie (zie verder hoofdstuk 9).

Hoofdstuk 4 gaat vooral in op de deelvragen 2 en 3. De wetenschappelijke inzichten rond het concept ecosysteem komen aan de orde. Er hebben zich verschillende visies op het concept ontwikkeld, afhankelijk van het perspectief van mensen. Vier visies met hun specifieke kenmerken worden beschreven: de holistische, cybernetische, dynamische en chaotische visie. De dynamische en chaotische visie zijn momenteel dominant in de wetenschap. Daarbij is er sprake van voortdurende dynamiek, evenwicht is slechts een tijdelijk verschijnsel. Voorspellingen hebben slechts een beperkte waarde.

Binnen de wetenschappelijke wereld is geen consensus over bepaalde subconcepten zoals (tijdelijk) evenwicht, complexiteit en stabiliteit en de relatie daartussen.

Om vat te krijgen op complexe verschijnselen is systeemdenken geschikt. Daarbij is er expliciete aandacht voor de organisatieniveaus en voor de manier waarop de onderdelen (populaties, allerlei abiotische factoren) elkaar wederzijds beïnvloeden op een niet-lineaire multicausale manier, waardoor dynamische patronen ontstaan. In deze studie beperk ik me (beargumenteerd) tot drie organisatieniveaus: organisme, populatie en ecosysteem Verschillende modellen die binnen het systeemdenken worden gebruikt, zoals 'black box' en 'glass box' modellen, wiskundige modellen en computermodellen komen aan de orde. Modelleren heeft zich vanuit een wiskundige formulering van ecologische relaties ontwikkeld tot een belangrijke computergestuurde activiteit bij de studie van ecosystemen. Daardoor kunnen complexe verschijnselen worden gesimuleerd en doorgerekend, wat voorspellingen over (mogelijke) ontwikkelingen mogelijk maakt.

Ook in **hoofdstuk 5** komen vooral de deelvragen 2 en 3 aan bod. De huidige stand van zaken in het voortgezet onderwijs staat centraal. Het ecologie- onderwijs gaat veelal uit van statische modellen (bij voorbeeld voedselketens of -webben) die de leerling geen mogelijkheid bieden inzicht te krijgen in dynamische ontwikkelingen. Het vermoeden dat in het Nederlandse onderwijs vooral de holistische en cybernetische visie aandacht krijgen werd getoetst. Daartoe werden de VWO-examensyllabus, drie verschillende leerboeken en een aantal lessen over ecologie geanalyseerd. Ook werden de visies van docenten vergeleken met die van ecologen die als onderzoeker werkzaam zijn. In de examensyllabus, in de leerboeken en in de lessen zijn nauwelijks sporen van de moderne ecologische theorievorming te vinden. Tussen docenten en wetenschappelijke ecologen bestaan flinke verschillen in de visie op het concept ecosysteem. Leraren neigen meer naar verouderde visies en zijn veel minder consistent in hun visie dan ecologen. De keuzes van leraren en ecologen over belangrijke concepten die moeten worden onderwezen komen slechts gedeeltelijk overeen.

Hoofdstuk 6 gaat vooral in op de deelvragen 1, 4 en 5. De onderwijsleerstrategie wordt ontwikkeld na de exploratieve fase, die na hoofdstuk 5 is afgesloten. Allereerst worden de leerdoelen die afgeleid zijn uit de analyse van het moderne concept 'ecosysteem' vastgesteld. Daarna worden acht ontwerpcriteria voor de onderwijsleerstrategie geformuleerd. Vervolgens wordt een selectie van geschikte authentieke praktijken gemaakt. De drie geselecteerde praktijken worden behandeld: ecologen die werken aan optimalisatie van mosselkweek in de Oosterschelde, duinbeheerders die werken aan het beheer van de konijnenpopulatie in het Noordhollands duinreservaat en wetenschappers die samen beslissen over hoe te handelen in een situatie van overbevolking bij olifanten in Zuidelijk Afrika.

De voorlopige structuur voor de onderwijsleerstrategie wordt geschetst. Uit deze structuur wordt een scenario afgeleid dat na omzetting in lesmateriaal (werkboek en computermodellen) zal worden getest in de eerste onderzoeksronde.

Hoofdstuk 7 toont de opzet van de cyclische fase van het onderzoek. Na de gegevens over de deelnemende scholen in de drie onderzoeksrondes wordt behandeld op welke wijze data zijn verzameld en hoe de keuze van te analyseren data werd gerelateerd aan de vijf deelvragen van de algemene onderzoeksvraag. Tenslotte wordt uitvoerig ingegaan op de wijze van analyse van de verschillende data.

In hoofdstuk 8 volgt de rapportage van de cyclische onderzoeksfase. Allereerst wordt uitvoerig verslag gedaan van een vergelijking van het laatst ontwikkelde scenario en het eigenlijke verloop van een lessenserie in de derde onderzoeksronde. Doordat daarbij de onderzoeker een dubbelrol heeft (zowel onderzoeker als leraar) wordt een mede- onderzoeker ingeschakeld, zodat de betrouwbaarheid van de analyses kan worden gewaarborgd. Per les passeren de verschillende activiteiten, met een vergelijking van het bedoelde en het eigenlijke verloop, de revue. Steeds wordt verslag gedaan van afwijkingen van het scenario en de mogelijke oorzaak van die afwijkingen.

Vervolgens wordt voor elk van de vijf deelvragen, met behulp van uit de acht ontwerpcriteria afgeleide voorwaarden, beschreven of de ontwikkelde onderwijsleerstrategie succesvol is en zo nee, welke pogingen zijn gedaan in de onderzoeksrondes om verbeteringen aan te brengen.

Deelvraag 1: *Welke ecosysteem- gerelateerde authentieke praktijken lijken geschikt om het* *de leerlingen mogelijk te maken om de rol van systeemdenken en modelleren te gebruiken en waarderen?*

Bij de eerste deelvraag is de conclusie dat de gekozen authentieke praktijken duidelijk en relevant zijn voor de meeste leerlingen en hen genoeg mogelijkheden geven voor actieve deelname, wat een voorwaarde is om serieus bezig te zijn met systeemdenken en modelleren. De volgorde waarin de drie praktijken werden aangeboden was niet de volgorde die de leerlingen zouden kiezen, maar na een discussie accepteerden zij dat zonder verdere bezwaren.

Deelvraag 2: *Wat zijn de mogelijkheden van systeemdenken om complexiteit duidelijk te maken op de verschillende organisatieniveaus zoals organisme, populatie en ecosysteem?*

Bij de tweede deelvraag is de conclusie dat er mogelijkheden liggen. Er is echter geen eenduidig antwoord op deze vraag. De meeste onderdelen worden succesvol gebruikt door de leerlingen. Maar het 'organiseren van systeemcomponenten en processen in een relatieschema' is een moeilijk onderdeel binnen het systeemdenken. Dit onderdeel is ook belangrijk bij modelleren. Verder blijkt dat er slechts in het onderdeel 'herkennen van het systeemkarakter en de systeemgrenzen' enige verbetering optreedt in de loop van de drie onderzoeksrondes.

Deelvraag 3: *Wat zijn de mogelijkheden van computermodelleren om dynamiek duidelijk te maken op de verschillende organisatieniveaus zoals organisme, populatie en ecosysteem?*

Modelleren blijkt mogelijkheden te hebben. Echter, sommige aspecten blijken heel gecompliceerd voor de leerlingen. Ondanks het tamelijk succesvol inzetten van emergent modelleren in de tweede onderzoeksronde blijven vooral het schetsen van een model, dat doelgericht modelleergedrag vereist en het zelf bouwen, dat een overzicht vraagt van de componenten en de relaties daartussen, uitgedrukt in formeel-wiskundige taal, problematisch. De leerlingen zijn zich bewust van de relatie tussen hun model en empirische data, maar zijn vaak zo bezig met hun model dat ze deze relatie soms uit het oog verliezen en hun model niet altijd valideren.

Deelvraag 4: *Welke didactische aanpak helpt leerlingen bij het gebruik van systeemdenken en modelleren?*

Begrip van de problemen die aan de orde komen is zeker ontstaan. Maar de leerlingen houden grote problemen met het doorlopen van de leeractiviteiten, vooral als ze moeten modelleren. De bekwaamheid van de leraar om modelleerproblemen op te sporen en oplossingen te suggereren is vereist om de leerlingen betrokken te houden, zodat ze hun activiteiten voortzetten.

Deelvraag 5: *Welke didactische aanpak helpt leerlingen om wetenschappelijke ecologische concepten te ontwikkelen, uitgaande van concepten die zijn ingebed in authentieke praktijken?*

Mijn aanpak slaagde er niet in, een werkelijk begrip te ontwikkelen van complexiteit en dynamiek. Vooral aan de gestelde voorwaarden dat 'leerlingen inzien dat concepten in een andere praktijk een andere betekenis hebben' en dat 'leerlingen de concepten in een nieuwe praktijk zonder hulp concepten adequaat kunnen gebruiken' werd niet volledig voldaan.

In deze onderwijsleerstrategie werd een ontwikkeling van organisme naar ecosysteem beschreven. Vanuit het ecosysteem kan een overzicht worden gegeven van alle drie gebruikte organisatieniveaus. Dit biedt de mogelijkheid om te jojoën tussen de organisatieniveaus en daardoor effecten van het ene niveau op het andere te ontdekken. Maar het bouwen van modellen is zo tijdrovend geweest dat dit niet volledig gehaald is. In alle onderzoeksrondes ontstonden tijdproblemen. Alle docenten reageerden hierop door zich te concentreren op de modellen, waarbij ze probeerden alle leerlingen weer 'bij te krijgen'. Dat ging ten koste van de tijd die bestemd was voor reflectie en recontextualisatie. Daardoor ontstonden problemen bij de ontwikkeling van een complex en dynamisch concept van 'ecosysteem'. Het is niet verrassend dat de leerlingen in een posttest, die een idee kan geven van hun visie op ecosystemen (zie ook hoofdstuk 5) niet veel anders (beter) scoorden dan in de pretest.

In hoofdstuk 9 wordt eerst de onderzoeksvraag beantwoord. Mijn onderwijsleerstrategie is *valide*, omdat adequate ecosysteem- gerelateerde praktijken worden geïntroduceerd waar complexiteit en dynamiek belangrijke subconcepten zijn. Wat betreft de *haalbaarheid* concludeer ik dat dit geldt voor een aantal kenmerken. Dat zijn de keuze voor realistische, begrijpelijke en relevante praktijken, met een duidelijke rol voor systeemdenken. Daarnaast is het stellen van een probleem dat de leerlingen uitdaagt tot zelfstandig denken en de duidelijke onderwijsleerstrategie succesvol.

Maar voor de kenmerken die te maken hebben met het begrijpen van het (open) systeemkarakter van een ecosysteem, met modelleren en met de plausibiliteit van de volgorde van de drie aangeboden praktijken was de strategie niet (geheel) haalbaar.

Veel leerlingen presteerden goed op het onderscheiden van organisatieniveaus, het exploreren van modellen en het ontwikkelen van begrip van complexiteit en dynamiek, hoewel dit laatste erg oppervlakkig blijft. Een aantal van de tien gestelde leerdoelen is gerealiseerd, maar andere niet of slechts gedeeltelijk, waaronder de belangrijkste: de relatie tussen complexiteit, dynamiek, stabiliteit en diversiteit met voorbeelden duidelijk maken.

Terugkijkend op de acht ontwerpcriteria kan ik vaststellen dat ze allemaal aan de orde zijn gekomen en dat er vijf goed hebben gefunctioneerd. Maar de invulling van de criteria 3 ('De praktijk moet gebaseerd zijn op het gebruik van 'ecosysteem' als herkenbaar functioneel concept, opgevat als een open systeem. Daarnaast moeten populatie, organisme, dynamiek en complexiteit herkenbaar zijn als deelconcepten'), 5 ('In de praktijk moeten modelleeractiviteiten een hoofdrol spelen om kwantitatief inzicht te geven in de dynamiek van het systeem in ruimte en tijd') en 6 ('Er moet sprake zijn van een toename in complexiteit in de volgorde van de praktijken. Voor leerlingen moet die volgorde plausibel zijn') was problematisch.

Er is vooruitgang geboekt bij het onderwijs over ecosystemen. Maar er zijn nog belangrijke knelpunten op te lossen. Er zijn nog geen volledig doordachte concepten ontwikkeld voor dynamiek en complexiteit in een ecosysteem. Voor een deel komt dat doordat er te weinig tijd was (gereserveerd) voor reflectie en recontextualisatie. Daarnaast blijkt het modelleren erg veel tijd te kosten en raken de leerlingen daarbij vaak het contact met de 'echte wereld' kwijt.

Bij het gebruik van authentieke praktijken bleek dat de leerlingen het werken daarmee op prijs stelden, omdat het over echte situaties en echte problemen gaat, iets dat ze in hun schoolboek niet ervaren. Maar het was hen niet altijd precies duidelijk, wat er geleerd moet worden. Deze voornamelijk positieve ervaring met praktijken kan als voorbeeld gebruikt worden in de verdere ontwikkeling van het experiment van de CVBO (de context-concept-benadering) in het voortgezet onderwijs.

De leerlingen begrepen het systeemkarakter van organisme, populatie en ecosysteem en velen van hen bleken in staat om vast te stellen welk niveau centraal staat in de verschillende praktijken en tussen de niveaus te jojoën. Maar ze hadden moeite met de systeemgrenzen, vooral bij de populatie.

Bij het modelleren waren er weinig problemen met exploreren en laten doorrekenen, maar verloren een aantal leerlingen het contact met de werkelijkheid. Als de leerlingen zelf een model moesten bouwen, vonden ze het vaak moeilijk om data uit die werkelijkheid in te voeren in het model en om de verschillende componenten met elkaar te verbinden. Op de eerste plaats ondervonden de leerlingen moeilijkheden met dat verbinden. Maar daarnaast is er de neiging om het contact met de werkelijkheid totaal los te laten. Dat kan een gevolg zijn van het niet goed begrijpen van de abstracte structuur van een model en van problemen met de symbolische taal van het modelleerprogramma of met het in een formule weergeven van het verband tussen twee componenten. Deze problemen zijn niet eenvoudig op te lossen, omdat ook leraren tegen deze problemen oplopen. Voor het moderniseren van het onderwijs over ecosystemen zouden leraren een gedegen training moeten krijgen, die hen inwijdt in zowel de programmataal als in de manier om biologische relaties in formules uit te drukken. Aan het eind wordt ingegaan op mogelijk verder onderzoek op dit gebied en op de persoonlijke ervaringen van de onderzoeker die tevens een ervaren leraar is. Wat hielp die ervaring bij het onderzoek en wat neemt de leraar mee naar de lessen van dit onderzoek?

Appendices

1. Learning objectives in the ecology part of the Dutch syllabus for the national written examination

(from Timmermans, 1996)

Domain B: Structures

Sub-domain B1: Structures of ecosystems

The candidate will be able to

1 describe relations in an ecosystem.

2 explain that differences between and diversity in ecosystems originate from abiotic and biotic factors;
in particular:
- abiotic factors: light, temperature, air, humidity, water, composition and structure of the soil, composition and temperature of (surface)water;
- biotic factors: populations from different species of plants, animals, fungi and bacteria; human influence.

3 explain that abiotic and biotic factors limit the possibilities for growth, development and functioning of organisms;
in particular:
- tolerance borders;
- limiting factors;
- microclimate.

4 nominate in a described ecosystem various relations between species and individual from one species:
- competition;
- food relation;
- predation;
- symbiosis;
- mutualism;
- commensalism;
- parasitism;
- reproductive relation.

5 use the concept niche from a certain species in a described ecosystem.

6 recognize and describe the place (habitat) that a specific species has in a described ecosystem.

Sub-domain 2: Structures of species and population

The candidate will be able to

7 indicate the relations between the concepts species, population and ecosystem.

Domain D: Metabolism

Sub-domain 1: Energy and matter

The candidate will be able to

69 explain that the sun is the most important energy source for life on earth.

70 represent in graphic form the energy content and the biomass of the trophic levels of a food chain.

71 indicate what the reason is that in a link in a food chain not all produced or assimilated biomass is conserved.

72 indicate that a food chain can be interpreted as a whole of supplies and flows of matter.

73 indicate which production of organic matter takes place in an ecosystem, using concepts like gross primary production, net primary production and productivity.

74 indicate that cycles in an ecosystem can be interrupted or disturbed because of separation of production and consumption, the use of fossil fuels and harvesting,
in particular by:
- removing or adding of elements in cycles.

75 indicate that materials for the construction of organisms originate from the abiotic environment or from other organisms.

76 nominate in a description or illustration of an ecosystem examples of organisms which belong to respectively:
- producers, consumers and reducers;
- autotrophic and heterotrophic organisms.

77 apply the concept 'limiting factors' in various concrete situations
in particular:
- optimizing circumstances in modern forms of composting and water purification;
- the necessity of separately collection of litter.

78 explain the role of producers, consumers and reducers in the cycles of carbon and nitrogen with the use of schemes of these cycles,
in particular:
- photosynthesis;
- conversion of glucose in other organic substances;
- formation of nitrogen containing organic substances;
- decay of organic substances into simple inorganic substances.

79 indicate the role of micro-organisms in the carbon cycle
in particular:
- yeast;
- acetic acid bacteria;

and in the nitrogen cycle
in particular:
- nitrifying bacteria;
- decomposing bacteria;
- nitrogen fixing bacteria;
- denitrifying bacteria.

80 nominate human acitivities which:
- cause the 'acid rain'- problem (a.o. eutrofication);
- cause the greenhouse-effect (a.o. combustion of fossil fuels).

81 describe examples of human behaviour which contribute to solutions for environmental problems.
82 indicate what is meant by biological degradable.
83 indicate the effect of human activities on the carbon cycle and the nitrogen cycle.

Domain E: Dynamics and homeostasis

Sub-domain 1: Dynamics in ecosystems

The candidate will be able to
153 recognize the mechanisms which are mentioned in this sub-domain and which cause the maintenance, development and disturbance of an ecosystem, using the mentioned mechanisms on the basis of illustrations or descriptions of ecosystems.
154 explain which role competition in and between populations plays in the maintenance and development of an ecosystem.

155 explain how growth and equilibrium of populations are determined by population density, emigration /immigration, birth rate and death rate.
156 explain what influence the change in the size of a certain population has on other populations in a given food web with various food chains
157 explain and predict how the growth of a population will develop with limited and unlimited supplies
in particular:

- S-like and J-like growth curves;
- the collapse of a population.

158 nominate the significance of the following factors related with succession:

- change in the abiotic factors;
- influence of organisms or abiotic factors;
- extinction or disappearance of species;
- immigration or import of species;
- influence from organisms on each other.

159 indicate that succession in ecosystems goes into the direction of a climax-ecosystem and explain which role climate and natural selection play here.
160 characterise a pioneer and a climax ecosystem using the following properties:

- open or closed cycles;
- the amount of biomass;
- extent of stratification;
- diversity in species;
- extent of specialization of the niches
- extent of complexity of the food web;
- the ratio between production and decay;
- rate of development of the succession.

Sub-domain 2: Origin and maintenance of diversity

The candidate will be able to
161 indicate the significance of variability in a population for the maintenance of this population.
162 explain the role which selection plays in the constancy or change of the variability in a population
163 calculate the gene frequencies with the help of Hardy-Weinberg's rule
164 indicate that evolution theory is used to explain the origin of the different life forms, by making use of the following points of departure:

- mutations cause variability within a population;
- more offspring is produced than corresponds with the carrying capacity;
- by natural selection the best adapted individuals have more chances to survive;
- this causes the gene frequencies to shift.

2. Questionnaire ecology education

Dear madam / sir
Within the framework of my Ph.D. study on the teaching and learning of ecology in upper secondary school in the Netherlands, I would appreciate it if you, as an ecologist / teacher, could answer a number of questions that I also have presented to students and teachers in upper secondary schools.
The definition of my problem is:
What is an adequate way in which upper secondary school students can acquire the concept 'ecosystem', emphasizing its complexity and dynamics?
Thank you in advance for taking the trouble to fill in this paper!

René Westra
Centre for Science and Mathematics Education
Utrecht University (The Netherlands)

1. Which place has man in nature, in your opinion?
   - ❑ Score 1 Man is part of the ecosystem
   - ❑ Score 2 Man is no part of the ecosystem
   - ❑ Score 3 Otherwise, sometimes man places himself outside of the ecosystem

2. What do you think is the balance of nature?
   - ❑ Score 1 It means that an ecosystem goes automatically back to the point of departure after a disturbance
   - ❑ Score 2 It means that in an ecosystem the present populations have only limited oscillations in numbers.
   - ❑ Score 3 Something else, for example a combination of score 1 and 2, or the origin of a new equilibrium
   - ❑ Score 4 The balance of nature does not exist

3. What do you expect to happen in an ecosystem that is not disturbed?
   - ❑ Score 1 Development (succession towards climax) and in the long run evolution
   - ❑ Score 2 It will stay in an equilibrium, with oscillations
   - ❑ Score 3 Such ecosystems do not exist, there are always fluctuations in the environment

4. What is the relation between stability and (bio) diversity (the number of different species) in an ecosystem?
   - ❑ Score 1 The more biodiversity, the more stability
   - ❑ Score 2 The more biodiversity, the less stability
   - ❑ Score 3 There is no fixed relation between both
   - ❑ Score 4 The relation is shown by an optimum-curve

You will now read a number of statements, some of which are factual, others are based on a personal view or appreciation.
Could you put a cross in the square that, according to you, is correct or corresponds most closely with your view?

5. Equilibrium is maintained in an ecosystem by means of feed-back mechanisms.
   - ❑ Score 1 I agree
   - ❑ Score 2 I do not agree
   - ❑ Score 3 I doubt, I do not know

6. In an ecosystem, extinction of species is a usual phenomenon.
   - ❑ Score 1 I agree
   - ❑ Score 2 I do not agree
   - ❑ Score 3 I doubt, I do not know

7. How an ecosystem develops as to composition of species and numbers of those species can not be predicted.
   - ❑ Score 1 I agree
   - ❑ Score 2 I do not agree, it can be predicted (for example with models),but the predictions do not always work out
   - ❑ Score 3 I doubt, I do not know

8. The development of an ecosystem has neither direction nor goal.
   - ❑ Score 1 it has a direction, but no goal
   - ❑ Score 2 it has a direction and a goal
   - ❑ Score 3 it has no direction, but it has a goal
   - ❑ Score 4 it has no direction and no goal either
   - ❑ Score 5 I doubt, I do not know

9. Man can create desired ecosystems by development of nature.
   - ❑ Score 1 I agree
   - ❑ Score 2 I do not agree
   - ❑ Score 3 Only ecosystems that are not too complex
   - ❑ Score 4 I doubt, I do not know

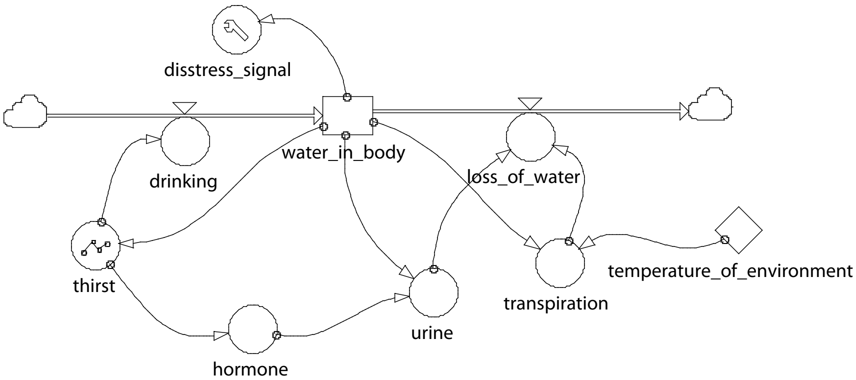
10. More than a prescribing science, ecology is a describing science.
   - ❑ Score 1 I agree
   - ❑ Score 2 I do not agree
   - ❑ Score 3 just in some cases
   - ❑ Score 4 I doubt, I do not know

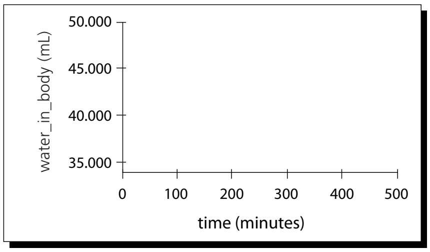
11. For an ecosystem to function, all species are equally important.
    Score 1 I agree
    Score 2 I do not agree
    Score 3 I doubt, I do not know

12. The larger an ecosystem, the less chance there is of a disturbance of the numbers of all kinds of species.
   - ❑ Score 1 I agree
   - ❑ Score 2 I do not agree
   - ❑ Score 3 I doubt, I do not know

3. Questions from the Compex national examination 2004

Thirst at the 'Vierdaagse Walk'





*Click on Water economics. You see the mode*l water21.sim.

In this model the regulation of the water balance of a woman is involved who takes part in a walking tour of four days. Every day she walks 40 km in about 7 hours. Any time she gets thirsty, she drinks 50 mL water. In the model, this is settled by means of a Pulseif –function: if thirst has a value of more than 1.48, she drinks 50 mL (see the formula of drinking: PULSEIF(thirst>1.48,50).

Control by running the simulation that by drinking this amount of water the water volume of this woman (water_in_body) during the walk will be sufficient.

In the model a. o. the production of urine and the secretion of a hormone are influencing the water economics.

Make a graph, with help of the simulation, in which the change of the amount of urine and the amount of secreted hormones during the walk can be followed.

2p 1 ■ – Explain on the basis of the graph whether the hormone stimulates the back-resorption of water in the urine or not.

– What hormone is involved here?

The temperature of the environment has also influence on water economics. When it is very hot, a walk of seven hours is a problem. In the 'Vierdaagse Walk' of 2003 at Nijmegen, there was a heat wave. Therefore the walking distance was strongly reduced.

When it is very hot, the woman will lose too much water to finish her walk, when she does not drink extra.

Investigate the following with the model.

2p 2 ■ – After how many minutes does the body of the woman get problems if it is 30 °C during the walk?

– How many liters of water less than normal does her body contain at that moment? Give your answer with an accuracy of one decimal.

It is sensible to drink constantly in a heat wave and not to wait until one is thirsty, as in this model.

It would be more practical to have a constant inflow of water via e.g. a hose from a special backpack.

Change the model so as to give the walking woman a continuous inflow of water. Name the addition "backpack" and choose an initial value. Eliminate the pulseif-function at 'drinking' by putting the water volume at 0 mL. Add to the formula: + backpack.

Determine how much the continuous inflow of water has to be, to make it possible for the woman to finish her walk in *a temperature of 30 °C without problems.*

2p 3 ■ – Describe or draw the changes you have introduced into the model.

– Determine how many liters of water should be in the backpack at minimum to make it possible for this woman to accomplish her walk. Give your answer in an accuracy of one decimal.

Acknowledgements

When I started this investigation four and a half years ago, I was full of plans and dedicated to help improve ecology education for upper secondary school. Now, at the end of a long road, I realize I have just done some little parts of this improvement. As a marathon runner I am used to long roads, but for me this investigation felt heavier than a marathon. Like in the marathon, the man with the hammer comes in the last part, in this case in the last year, when all thoughts and collected data have to be written in an orderly way. For me as a rather chaotic person this was a very heavy part. What has helped me a lot was that, like in all those years where my supervisors have always supported my plans, they have also supported me strongly to get to the finish. Sometimes they tried to change parts of these plans and always they looked for the main road, saving me from going to all kinds of interesting and promising small side streets. I want to thank my first promotor, Kerst Boersma, for his persisting enthusiasm for this project and for his never-ending efforts to improve the texts I wrote. I felt always his support and always he knew exactly what I had been doing and wanted to do more. I want to thank my second promotor, Arend Jan Waarlo, for his cautious reading of the texts and for the personal interest and warmth I always felt when we were deliberating. When I had low spirits about my work, after a meeting with him I always had found again the feeling to go for it. I want to thank my co-promotor, Elwin Savelsbergh, for his bright remarks and his support, especially on the modelling part. We have discussed about a lot of subjects; it was always a delight to talk with him about reductionism and holism, the basics of modelling, and the special characteristics of biological models. Further, there are so many people who helped me on this long road to the finish. The other PhD.'s, Gjalt, Marjon, Bart, Marijn, Katrina and Mariska, with whom I shared my hopes and sometimes my despair, with whom I visited conferences in Mülheim, Barcelona, London and Malmö. My biology colleagues Kris, Sonja, Paul, Roald, Dirk-Jan, Geertemarie and Dieuwke, with whom I had various interesting meetings about biology didactics. Koos, who in his very quiet and humoristic way, really taught me to look as a science educator to my series of lessons and to the observed students. Kees, who kept me sharp by his very keen and deep digging remarks. The supporting people, such as our secretaries Hanneke, Wilma, Rita and Tine who always helped me with administrative matters, Ben who helped me with computer business and Erik-Jan who put all my video-recordings on DVD. Also I want to thank Emy Franck from the Department of Communications & Design who was responsable for the lay-out of this thesis. I worked in the Institute for Science and Mathematics Education (now

Freudenthal Institute for Science and Mathematics Education) for six years, two years as a project co-worker in the project "Computer based Modelling" and four years as a Ph.D. During all those years I felt welcome and enjoyed being there. There were also nice parties and I remember running several times as a group of 'CD-Beta Runners' in the Pheidippides Marathon.

I also got much help and made new friends outside of the Institute. I was hospitably received by Ulrich Kattmann on the Carl von Ossietzky Universität in Oldenburg (Germany) and by Gustav Helldén on the Högskolan in Kristianstad (Sweden), where I worked together with my friend Ola Magntorn. I visited the NIOO-departments in Nieuwersluis and in Yerseke (the Netherlands), where especially Louise Vet, Peter Herman and Marcel Klaasse spent time to help me with the ecological part of my work. Froukje Rienks from NIOO did almost everything to arrange contacts, questionnaires and visits to conferences for me. My dear school colleague and teacher in English Henk de Geus generously helped me with the heavy and time consuming task to improve the quality of the English language in this manuscript. When I looked for schools to carry out my case studies, it was no problem at all to find teachers. Many of them were willing to receive me, which I remember with warm feelings. Those feelings are even stronger for the teachers with whom I eventually worked with: Sandra Elzinga and Dirk van der Wulp from Jac.P. Thijsse College Castricum, Dirk Slagter from Stedelijk Gymnasium Haarlem, Gee van Duin and Niek van Lieshout from Het Baken Park Lyceum Almere and Ria Snippe from Petrus Canisius College Alkmaar. Thanks to them and not to forget to all those girls and boys who did not bother to be interviewed, surveyed and video- and audio-taped, it was possible for me to do my investigations.

I am glad that Sandra Elzinga and Froukje Rienks will be my 'paranymphs', which will give me the support of a teacher and an ecologist, on the crossing of which I 'occupy my niche'. Last but not least, I could not have done all this work without the everlasting support from home. From the beginning till the end, my beloved Ellen, with whom I share more than 35 years of my life, 'min brinnande kärlek' (as I would call her in Sweden, our second homeland where I write these words) has been my everlasting support and help, yelling with me when there were good results, comforting me when I was in despair. She was the one who pointed out to me Vygotsky as an inspiring learning psychologist. Darling, now the job is finished, up for another 35 years, but without science investigations!

Curriculum vitae

by Ellen Westra-Versteeg

René Westra was born in Leeuwarden (Friesland) on a Sunday in February 1950 and he has always been a 'Sunday child.' After visiting primary and secondary school he moved to Groningen in 1967 to study biology on the Rijks Universiteit. In 1971 we fell in love with each other and since then we share our lives. Between all our activities we managed to raise five children: three daughters, an adopted son and at last another son.

After finishing his study (cum laude) with as main subject mathematical ecology, René decided to become a teacher in secondary school, though he was asked for a Ph.D. route. He got a job at Petrus Canisius College in Alkmaar, where he still works as a skilled and enthusiastic teacher.

Besides his job as a teacher, René had many other jobs. He worked from 1978-1981 as educator for biology teachers (3rd grade) and was co-author of schoolbooks for the publisher Malmberg in 's-Hertogenbosch ('Levenstekens' for biology, 1986 and 'Scala' for general science, 1996). From 1995 until 2004 he worked at the institute Cito Arnhem in a group who prepares questions for the national written biology examination and in a group who prepares questions about nature and technology for the 'End of primary school test'. He also works as an examiner for upper secondary students who apply for a state examination, from 1982 until now.

Further he is a volunteer member of the group that constructs the questions for the first selection round of the National Biology Olympiad and of the group that organizes the annual Nibi Biology Education Conference in Lunteren.

From 2001-2003 René worked in a computer modelling project for the Centre for Science and Mathematics Education (now the Freudenthal Institute for Science and Mathematics Education). During this period the director of the Institute, professor Kerst Boersma, asked him to carry out a promotion investigation under his directory, which has lead to this thesis. During the investigation period René kept teaching in upper secondary school on halftime basis.

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