Promoting conceptual coherence within biology education based on the concept-context approach

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Table of contents

List of papers

The following three papers are presented in this thesis:

First paper:

The development of conceptual coherence within biology education based on the concept-context approach. Ummels, M. H. J., Kamp, M. J. A, de Kroon, H., & Boersma, K. Th. (2013). Published in *Pedagogische Studiën*, 90, 19-32.

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Third paper:

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1

General introduction

1.1 Problem statement

In secondary biology education, students must study the dynamic, synthesising, organising and energy-consuming nature of living systems. The characteristics of these living systems are self-regulation, maintenance of a steady state, development and reproduction (Miller, 1973). These characteristics refer to several hierarchical levels of organisation (such as molecules, cells, tissues, organs, organ systems, organisms, populations, communities, ecosystems and biospheres), each with its own emergent properties (Mayr, 1982). According to the national Dutch exam standards, students are expected to understand the characteristics of living systems in relation to these different levels of biological organization (College voor Examens, 2012). Moreover, they must acquire the notion that each biological system is more than "the sum of its parts."

However, many studies on biology education reveal that, despite the best efforts of teachers, students of all ages and different educational levels have problems in understanding how these systems function. In particular, students are often not able to retrieve and interrelate the biological concepts that are involved in these systems (e.g., Wandersee, Fisher, & Moody, 2001; Wandersee, Mintzes, & Novak, 1994). This mainly concerns concepts that are theoretical, such as respiration, photosynthesis, osmosis, protein synthesis, meiosis and mitosis (Lazarowitz & Penso, 1992). Such theoretical concepts can be characterised as part of scientific theories and as functional to explain natural phenomena (Lawson, Alkhoury, Benford, Clark, & Falconer, 2000). This problematic understanding of concepts is often manifested by alternative conceptions that students reveal when they are asked to reason about natural phenomena or events (Mintzes, Wandersee, & Novak, 2005). A review of more than 3,000 studies showed that alternative conceptions develop easily in relation to biology-related issues due to the strong influence of personal experiences, intuition and everyday ways of talking and reasoning (Wandersee et al., 1994). These findings suggest that, within the given circumstances, education does not succeed to prepare students to acquire the competence to use or deal with the appropriate theoretical concept(s) needed to explain or reason about natural events and phenomena. For instance, in relation to explaining how energy is generated from human nutrition, many students ignore the cellular organisation of the body (Mortimer & Scott, 2003) or do not display an understanding of the chemical transformation of food (Ramadas & Nair, 1996). As a consequence, students often leave secondary school with a limited view or naïve understanding of biological subjects (Mintzes, Wandersee, & Novak, 2001). For example, with respect to understanding carbon transforming events in living systems, only 10 percent of 12th grade students at the end of secondary school appeared to be able to reason consistently with American national standards (Mohan, Chen, & Anderson, 2009). This research project is based on the generally accepted view that learners' cognitive networks of concepts are essential for their ability to reason about natural phenomena and events (Pearsall, Skipper, & Mintzes, 1997). This corresponds with studies on expert learning that provide evidence that the knowledge of experts is organised around a cognitive network of core concepts (Bransford, Brown, & Cocking, 2000; Chi, Feltovitch, & Glaser, 1981). Because a person's cognitive network of concepts is unobservable, we focus on the observable manifestations of such cognitive networks: spoken or written remarks of conceptual knowledge (Gomez, Benarroch, & Marin, 2006). If a learner is able to mention concepts in a coherent way, we regard this as an indication of coherent conceptual understanding. In addition, if students show an increase in mentioned connections between concepts, this indicates a development of conceptual coherence (Martin, Mintzes, & Clavijo, 2000). To qualify a connection as coherent we consider two criteria: First, the connection should be consistent (and not in contradiction) with accepted scientific theories. Second, the connection should be meaningful in the sense that it adds value to understanding a given situation. It is worth noticing that the use of concepts is dynamic: The situation determines which concepts are required and which connections between them are more relevant than others (Scott, Mortimer, & Ametller, 2011). Therefore, we refer to the term *conceptual coherence* as the ability of a person to establish scientifically accepted and meaningful connections between concepts.

Context-based approaches have been proposed to contribute to solving the problematic coherent conceptual understanding in biology, as well as in other natural sciences (Boersma et al., 2007; Bulte, Westbroek, de Jong, & Pilot, 2006; Gilbert, 2006). These approaches generally improve students' engagement by situating the learning of science in contexts that represent the real world (Bulte et al., 2006), which helps students to appreciate the role science plays in their own lives and in society (King & Ritchie, 2012). Up to now, there has been limited empirical evidence that relates context-based education to an enhancement in the development of conceptual coherence (Bennett, Lubben, & Hogarth, 2007). Tsai (2000) found that a Science-Technology-Society (STS) instructional approach, which relates to a context-based approach, improved the extent, richness and connectivity of students' cognitive structures, compared to traditional teaching. Barker and Millar (2000) found in a comparative longitudinal study on the Salters Advanced Chemistry course that students who experienced a gradual introduction and revisiting of chemical ideas in different contexts appeared to develop a better understanding of these ideas than students who followed more conventional courses. This latter study assumes that when various concepts come together within a context and reappear in other contexts, the transfer of concepts is promoted, which provides a basis for further conceptual understanding (Gilbert, 2006). There are two other assumptions regarding why a context-based approach can improve a coherent conceptual understanding. First, contexts intend to evoke students' preconceptions, which forms a starting point for the learning of new concepts (Scott, Asoko, & Leach, 2007). This is also promoted when contexts raise questions in students, which enables them to see a reason for extending their knowledge (Bulte et al., 2006). Second, contexts can help students to relate concepts from separate fields of biology, such as molecular biology, genetics, ecology and evolution.

In conventional biology education, these fields are often presented in separate chapters or themes. Although these assumptions suggest that context-based courses *can* facilitate the development of conceptual coherence, the underlying learning and teaching mechanism that describes how this development proceeds are still—to a large extent—unclear. For example, such a mechanism describes how, during a learning-teaching activity, the teacher facilitates students to link a set of concepts to a given context in a meaningful way or how students develop a more profound understanding of these concepts in relationship to each other and to a new context. By unravelling this mechanism, the factors related to context-based education that contribute to students' development of conceptual coherence can be identified. Providing insight regarding such a mechanism has been recognised as one of the major challenges in research on context-based education (Gilbert, Bulte, & Pilot, 2011; Pilot & Bulte, 2006). This challenge is addressed in this research project.

In the next section (1.2), we explain how the concept-context approach intends to contribute to solving this research problem. This leads to the formulation of the objective of the research project and the main research question (1.3). Next, we elaborate on a theoretical framework related to the development of conceptual understanding (1.4). The chosen design research approach is explained and important elements for the design of a lesson sequence are presented: design principles and promising learning-teaching activities (1.5). Then, we focus on a domain-specific topic in biology that was chosen for this lesson sequence: energy and matter transformation in metabolic cell processes. Subsequently, a set of concepts related to this topic is presented in a reference concept map and relevant contexts for this topic are described (1.6). The introduction ends with an overview of the phases in this research project and the specification of four sub-questions (1.7). These sub-questions structure the outline of this thesis (1.8).

1.2 The concept-context approach

In this section, we focus on one specific form of context-based education: the concept-context approach. In the beginning of the 21st century, the Royal Netherlands Academy of Arts and Sciences recommended that the Minister of Education should focus on more coherent biology education and adapt the biology curriculum and the examination programs (KNAW, 2003). Following this recommendation, a Committee for the Innovation of Biology Education (CVBO) in the Netherlands was established in 2004. Three problems were defined in Dutch biology education: an overload of biological concepts in the curriculum, a lack of relevance of biological concepts for students' everyday lives and a lack of coherent conceptual understanding. In 2007, the CVBO proposed a learning line for biology education from elementary school to upper secondary education (Boersma et al., 2007). This learning line was based on the *con-*

cept-context approach, which stems from the cultural-historical activity theory (Van Oers, 1998; Vygotsky, 1978, 1987). According to this approach, a context is defined as a representation of an existing scientific, professional or real-life community of practice in which participants perform goal-oriented activities (Boersma et al., 2007). Within such contexts, students perform activities in social interactions and deal with biological concepts from the perspective of these participants. This definition of a context corresponds with the most promising model, which was described by Gilbert (2006, p. 969) as: “context as the social circumstances.” In this model the social dimension of a context is essential. The learning line that was proposed by the CVBO is intended to contribute to a more coherent understanding of biological knowledge because students perform activities in social interactions using (a network of) concepts in a meaningful way. One way to make these activities meaningful for students is to follow a problem-posing approach (Klaassen, 1995). In this approach, problems that are recognisable to students are introduced. It is expected that students will be motivated to find solutions to these problems within contexts and that they will provide a reason to acquire domain-specific concepts.

The feasibility of drafts of examination programs that were based on the new learning line were tested in seven experimental secondary schools in the Netherlands. These so-called biology developmental schools (BOS-schools) developed and conducted lesson sequences in practice. In 2010, a final report was presented to the Minister of Education with the conclusion that the new examination programs based on the concept-context approach were feasible and necessary to contribute to a solution to the three main problems (Boersma, Kamp, Van den Oever, & Schalk, 2010). In 2013, the Minister of Education decided to introduce a new curriculum for senior general (havo) and pre-university (vwo) secondary biology education, with the first exams to take place in 2015 and 2016, respectively.

At present, the challenge is to change the educational practice towards the intended context-based innovation. So far, several new editions of biology textbooks have been introduced with a rich variety of sources that refer to authentic social practices. To really engage students in meaningful educational learning tasks in which they deal with (a network of) concepts, the authentic social practices must be transformed into usable contexts adapted for classroom use. We call this transformation process *contextual transposition* (Boersma, 2011, p. 45). This implies that the social practice is adapted in such a way that the learning goals are realistic and achievable. Important elements of contextual transposition are: simplifying a complex social practice (Westbroek, 2005); choosing a focus on that part of the social practice that matches the intended learning goals; and developing a motive for learning, for example, by structuring a context according to the problem-posing approach (Klaassen, 1995) or a “need-to-know” principle (Bulte et al., 2006). Our research project generates input for the choices to be made during this process of contextual transposition. It complements other PhD studies in this field, such as that of

Wierdsma (2012), which focuses on the mechanism of the recontextualisation of concepts related to cellular respiration, that of Mazereeuw (2013), which focuses on the use of biological knowledge about reproduction in authentic practices, and that of Westra (2008), which relates the learning and teaching of ecosystems to modelling and systems thinking in authentic practices.

1.3 Objective of research project and main research question

The objective of this study is to find empirically grounded guidelines for students' development of conceptual coherence within biology education based on the concept-context approach. Therefore, this research project focuses on learning-teaching mechanisms that occur when contexts and (a network of) concepts are offered in relation to each other. To understand such a mechanism, an in-depth design study is required that examines if and when the design and the administration of a context-based lesson sequence about a domain-specific topic meet its intended learning goals or if they do not. By determining changes that occur in students' abilities to relate concepts at specific moments during this lesson sequence, we expect that factors that hinder or promote the development of conceptual coherence can be identified. Eventually, this will result in recommendations for context-based lesson sequences about the domain-specific topic, as well as other topics in biology. These recommendations will be formulated as design principles. Such information will be valuable for educational researchers who examine how context-based lesson sequences work in practice, for educational designers of context-based lesson sequences in similar settings, and for teachers who conduct these lesson sequences. The fundamental assumptions of our research project are that a context is a representation of an authentic social practice in which participants interact, that learning takes place in such social interactions and that dealing with biological concepts and the connection between different concepts is required within such contexts. In line with these assumptions, the main research question in this research project is:

How can the development of students' conceptual coherence be promoted within biology education based on the concept-context approach?

To address this question, a design research approach was adopted. Before we describe this approach (1.5), some theoretical insights on conceptual learning are explored in the next section (1.4).

1.4 Theories on conceptual learning that focus on coherence

In this thesis, there is an emphasis on the learning of concepts. Concepts are considered to be the fundamental units of knowledge and can be defined as "perceived regularities in events or objects, or records of events or objects, designated by a label" (Mintzes et al., 2005, p. 2). Two such interconnected concepts can be referred to as a *proposition* (Mintzes et al., 2005). In this section, we describe the learning theories that were used as a theoretical foundation for our views on conceptual learning.

This research project is based on the learning theory of the cognitive psychologist Ausubel (1968). He argued that conceptual learning can occur in two ways, with a continuum between *rote learning* and *meaningful learning*. Rote learning is considered to be memorisation without the use of meaning as a basis to connect new concepts to available concepts. Meaningful learning occurs when learners connect new concepts to relevant available concepts. Consequently, this results in the formation of new propositions in the learner's cognitive structure, a process that is called *assimilation*. Such connections can be depicted in concept maps. Concept maps represent the way in which concepts and propositions are organised in the cognitive structure of a learner (Novak, 1991). The hierarchical structure of concept maps is intended to parallel the way in which the brain stores conceptual knowledge (Wandersee, 1990). It is expected that, in the course of meaningful learning, the concept maps that learners construct become more complex, more elaborate and well differentiated (Novak & Cañas, 2008; Pearsall et al., 1997). It is assumed that concept construction proceeds in an "up and down" manner (Mintzes et al., 2005, p. 6). After learners have acquired a concept of average generality and inclusiveness (e.g., plant), they proceed to an understanding of this concept with greater precision and specificity (e.g., plant species) and an understanding of this concept by relating it to other more general and inclusive concepts (e.g., ecosystem or photosynthesis). Another aspect of the construction of concepts in a meaningful way is the context or situation in which the concepts to be learned are embedded. This refers to the theory of "situated cognition" (Henessy, 1993; Lave, 1988). It is expected that the more connections there are between concepts, and the more systematically or hierarchically these concepts are organised in someone's cognition, the greater are the chances that these concepts can be retrieved (Fisher, 2001). As a consequence, concepts that are acquired by meaningful learning are retained longer (compared to concepts that are acquired by rote learning) and serve as a basis for subsequent learning (Pearsall et al., 1997). Moreover, because students are actively involved in integrating new concepts into their available conceptual structure, it is expected that fewer alternative conceptions are induced (Nuñez & Banet, 1997).

Current constructivist approaches on learning are in line with the assimilation theory of Ausubel (1968). Educational constructivists consider learning to be a process in which students construct conceptual knowledge in an active and goal-oriented way. Learning starts from shared conceptual understanding and, subsequently, relationships between existing and new concepts are formed (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Ogborn, 1997). In this way, students extend their own prior knowledge towards the accepted scientific knowledge that must be acquired (Mintzes, Wandersee, & Novak, 1998). The teacher facilitates this process and addresses difficulties that may arise from how students imagine things to be (Ogborn, 1997). Social constructivism extends constructivism by emphasising that learning is embedded in a social context and that learning takes place because people interact in a group (Leach & Scott, 2003). In the classroom, this social perspective on constructivism entails discussions in which the teacher guides the construction process between students' preconceptions on one side and the accepted scientific conceptions on the other side.

A theory that is in line with social constructivism is the cultural-historical activity theory (Vygotsky, 1978, 1987). The concept-context approach, on which the biology curriculum innovation in the Netherlands rests, is based on the cultural-historical activity theory (Boersma et al., 2007). The basic principle of this theory is that learning is not an individual process, but requires interaction between people. So far, this corresponds to social constructivism. Specific to the cultural-historical activity theory is that this interaction and the use of tools, including (conceptual) knowledge, take place during activities that people perform within social practices. For instance, in a medical practice, the activities of a doctor are measuring the blood pressure of patients and informing these patients about the outcomes and a healthy life-style. These activities, which are of a social nature, are culturally-historically determined and have a particular collective purpose. The conceptual knowledge that is needed during these activities is situated (e.g., Henessy, 1993; Lave, 1988). This means that this conceptual knowledge is embedded in the activity, and therefore, in the context. According to Vygotsky (1978, 1987), the learning of (conceptual) knowledge takes place from social interactions (within a social context) to a personal plane inside the learner. This is the process of *internalisation*. Because every learner makes sense of new ideas in terms of available ones, a structure of concepts and propositions is not absorbed fully formed but is reconstructed during this internalisation step. Internalisation is in line with the process of assimilation. The teacher has the task of adapting the educational setting of the social practice to the *zone of proximal development* of the student. For instance, the teacher offers scaffolds tailored to the level of conceptual understanding of the individual student. Moreover, the teacher needs to help students to develop a flexible perspective on concepts that allows students to use concepts in different contexts, because the meaning of concepts may differ in different contexts. The process in which a student transfers concepts from one context to another is called *recontextualisation* (Van Oers, 1998).

1.5 Design research approach

This research project is concerned with the difficulty in learning biological concepts and the way in which a lesson sequence based on the concept-context approach could be designed and conducted to partially solve this problem, as presented in section 1.1. To address this problem adequately, with a focus on the mechanism that is involved in students' development of conceptual coherence within contexts, a design research approach was adopted (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). Following this approach, a lesson sequence on a domain-specific topic in biology was designed and tested in a cyclic way. Through close cooperation between researchers and teachers, it was expected that, as a result of two case studies, a workable and effective lesson sequence would be constructed. The first design was tested in the first case study in two classes. This evaluation focused on the *practicability* of the design. This means that the actual performance of teacher and student activities was compared with the intended performance. Furthermore, a measuring instrument was developed to assess students' ability to mention intended propositions before during and after the administration of the lesson sequence. The revised design was tested in the second case study in one class. This enabled us to evaluate the design and its administration with a focus on the *effectiveness* of the design. This evaluation focused on students' learning outcomes in terms of students' ability to mention propositions. We intend to generalise the findings of these case studies to be useful for other lesson sequences in biology education that are based on the concept-context approach.

Design principles are important in the conduction of design research. Design principles can be considered to be rules of thumb that support conversations about design decisions (Kali, Fortus, & Ronen-Fuhrmann, 2008). Following Van den Akker et al. (2006), we define design principles as theoretically and empirically grounded constructs that link learning-teaching strategies with intended learning outcomes. In this research project, initial design principles that focused on promoting conceptual coherence within contexts were formulated and adjusted during the research process. These design principles were used in two ways. First, they guided the design of learning-teaching activities within a context-based lesson sequence by underpinning the decisions to be made. Second, they were used to reflect on the theoretical insights that were abstracted from the empirical findings. In this way, the findings can be generalised and can potentially contribute to a body of knowledge that is useful to others outside of the research setting (McKenney & Reeves, 2012). In the next section (1.5.1), the design principles that evolved in our design research are presented. In the discussion section, we reflect on these design principles. In order to use the empirical data that are generated in our research project for the adjustment of the design principles in a valid and systematic way, we combined the design research approach with a model of curriculum representations (Goodlad, Klein, & Tye, 1979; Van den Akker, 2003). This model (Table 1.1) functions as a helpful analytic tool to bridge the gap that often exists between the ideal and the attained curriculum.

Table 1.1 Model of curriculum representations constructed by Goodlad et al. (1979) and adapted by van den Akker (2003).

Ideal curriculum	The original vision or rationale underlying the curriculum
Formal curriculum	Elaboration of vision in curriculum documents like text books, teacher and student manuals.
Perceived curriculum	The way the curriculum is perceived by the teacher
Operational curriculum	Actual instruction process in the classroom by the teacher
Experiential curriculum	Actual learning activities of the students
Attained curriculum	Learning outcomes of students

Van den Akker and Voogt (1994) state that if the actions that actually occur in the classroom are out of sight, no conclusions about the nature of causes can be drawn and the mechanism of teaching and learning cannot be revealed. The teacher plays a crucial role here. This was also recognised by Leach and Scott (2002), who argued that claims about the effectiveness of teaching sequences are often made while giving little explicit attention to the teacher's role in staging those teaching activities in the social context of the classroom. Therefore, we used the model (Table 1.1) as a theoretical construct for the design of a so-called *research scenario*. A research scenario consists of a detailed prediction and theoretical justification of the hypothesised learning-teaching process. It shows, systematically, how and where the underlying theory of the concept-context approach (ideal curriculum) is elaborated in the teacher and students' manuals (formal curriculum), how this leads—with high probability—to the actions that take place in the classroom (perceived and operational curriculum), and how it is expected that this results in students' learning outcomes (experiential and attained curriculum). Next, we present two important elements for the design of our lesson sequence, design principles (1.5.1) and promising learning-teaching activities (1.5.2), through which these design principles can be elaborated.

1.5.1 Design principles

A set of initial design principles was formulated that was specific for the promotion of conceptual coherence in education based on the concept-context approach. They originate from the theories on conceptual learning that underpin our research project (as described in section 1.4), as well as from empirical observations. These design principles were used to give direction to the design of a context-based lesson sequence. The design refers to both the teacher and student manuals and the accompanying research scenario. In particular, the design principles were used for contextual transposition, i.e., to adjust the social practice to students' (conceptual) learning goals. The following four design principles evolved during the course of this research project. Although there is no prescribed order in which these design principles should be applied, it seems natural, at least for the first design principle to be elaborated at the beginning of a context and the fourth design principle to be elaborated at the end of a context. In Chapters three and four, slightly different versions of these design principles are presented. In the discussion section, we will reflect upon these design principles and indicate points of interest when they are elaborated in concrete settings.

1. **Building on familiar concepts**
   It is assumed that sharing prior conceptual understanding forms the starting point for further conceptual development (e.g., Driver et al., 1994; Scott et al., 2007). This could imply that when a context is introduced in the classroom, the initial focus should be on concepts with which students are expected to be familiar from prior education or personal life (Mintzes et al., 1998). Such concepts are often perceived by students as concrete and are associated with their own empirical knowledge (Boersma, 2011). These concepts can function as "stepping stones" to connect to concepts that are more inclusive and theoretical.

2. **Focusing on core concepts**
   One essential element of the activity theory (Vygotsky, 1978, 1987) is that concepts are embedded in activities. It appears difficult to align such activities with concepts that consist of the intended conceptual structures of the curriculum (the learning goals). This mainly accounts for *core concepts* that are based on theories and are often perceived by students as abstract, and therefore, difficult to learn (Boersma, 2011). Moreover, in most social practices, many concepts are involved, including concepts that do not match the learning goals. For instance, this refers to concepts that participants use to communicate with each other. Students might be confused by an overload of such concepts. Therefore, it is essential that a context and its learning-teaching activities are designed in such a way that students' learning process is guided in the direction of the underlying core concepts to be learned. These core concepts lie at the heart of biological reasoning and are essential to understand a wide range of natural phenomena. By explicitly focusing on activities in which core concepts are functional, students are helped to see how a context is related to these core concepts and vice versa.

3. **Stimulating students to interconnect concepts**
   To promote conceptual coherence, students should be stimulated to interconnect concepts actively and frequently (Fisher, 2001; Novak & Cañas, 2008). This calls for learning-teaching (LT) activities that trigger students to formulate propositions, such as

concept mapping (Nesbit & Adesope, 2006; Novak & Cañas, 2008), writing assignments (Keselman, Kaufman, Kramer, & Patel, 2007) and classroom conversations (in which students answer teachers' questions) (Chin, 2007). An important element of these LT activities is that students' conceptual thinking is made explicit. This facilitates productive student-student and student-teacher interactions about the quality of established propositions. One way to structure these LT activities within a context is by aligning them with "authentic" activities that participants perform in a social practice. During these interactions, the teacher can scaffold the learning process and give students adequate feedback on the way that they have established propositions.

4. **Reflecting on conceptual relationships within a context**
   To reinforce the first fragile relationships that students have established between concepts, it is important to reflect on them with an emphasis on the functionality of these relations within the context. We expect that focussing on the way in which participants of a context deal with concepts could be a useful perspective to start a moment of reflection. Moreover, paying attention to the recontextualisation of concepts from one context to another is expected to reinforce the flexibility of students' conceptual coherence (Van Oers, 1998; Wierdsma, 2012). Therefore, during moments of reflection, students need to be helped to see which concepts were connected and why these connections are functional within the given context, and possibly, in the next context as well.

1.5.2 Promising learning-teaching activities

Design principles can be elaborated in LT activities of a lesson sequence. We define LT activities as delimited educational units that consists of an introduction phase, an action phase and a reflection phase in which students and teacher perform activities. Three LT activities were selected because they can be connected to the aforementioned learning theories (see section 1.4) and are promising to help students to mention concepts and propositions in relation to contexts. These LT activities are: classroom conversations (with a focus on teacher's questioning), concept mapping and writing activities. We explain how these LT activities might promote the development of students' conceptual coherence. By referring to the design principles (1.5.1), we indicate, when possible, how these LT activities can be elaborated in the design of contexts in a lesson sequence.

Classroom conversations (focusing on teacher's questioning)

Teacher-student conversations play an important role in developing students' conceptual understanding in the social context of the classroom (Duit & Treagust, 1998). The teacher has the task of guiding the learning environment to the student's zone of proximal development (Vygotsky, 1987). Therefore, the kinds of questions the teacher asks and the way in which the teacher articulates these questions can influence the cognitive processes of students during the construction of scientific knowledge (Chin, 2007). Mortimer and Scott (2003) distinguished two types of interactive conversations (discourses) in which teachers and students participate: authoritative conversations and dialogic conversations. In an authoritative conversation, the teacher predominantly conveys information and the posed questions invite students to respond with short answers (single words). Because the teacher focuses on the scientific conceptions, there is less attention to students' own conceptions. In a dialogic conversation, the teacher encourages students to explore (e.g., argue and justify) their own conceptions, even though they may be different from the scientific conceptions. We expect that a successful strategy to develop students' conceptual understanding within contexts consists of a combination of both types of conversations. The dialogic conversation seems suitable to elaborate the first design principle and the authoritative conversation seems to provide a suitable elaboration of (at least) the second and fourth design principles.

Furthermore, an essential feature of classroom conversations is the type of questions the teacher asks (Chin, 2007). Chin (2007) proposed a framework of questioning approaches that are intended to scaffold students' thinking. Four types of productive questioning approaches were included in this framework: Socratic questioning, verbal jigsaw, semantic tapestry, and framing. The features of these approaches and their purposes are summarised in Table 1.2. We adapted this table to the development of conceptual coherence. Presumably, most teachers ask questions intuitively and are unaware of the type of conversation and the questioning approach they are following. In this research project we intend to point out which type of conversation or questioning approach is (or are) more suitable during a specific moment in a context than the others. By offering a list of questions and follow-up questions, the teacher is helped to conduct such conversations or questioning approaches in classroom. Socratic questioning seems to be suitable for the elaboration of the first design principle, verbal jigsaw and semantic tapestry, for the elaboration of both the second and third design principles, and framing, for the elaboration of the fourth design principle.

Concept-mapping

Concept maps are diagrams that organise and represent knowledge. They consist of concepts and relationships between concepts that are indicated with arrows that are labelled. Such a relationship is referred to as a proposition and it forms a meaningful statement. A meta-analysis of learning with concept maps showed that constructing concept maps is strongly associated with increased knowledge retention and transfer (Nesbit & Adesope, 2006). This can be explained because the brain organises concepts in a parallel way (See 1.4). Novak and Cañas (2008) described four guidelines to be taken into account when designing concept mapping activities:

- There should be a hierarchical structure with more general concepts at the top and more specific concepts at the bottom.

Table 1.2 Teacher questioning approaches that stimulate students' conceptual understanding in science education.

Approach	Features	Purpose
Socratic questioning	A series of questions builds on students' previous answers and is aimed at prompting and guiding students' thinking.	Encourages students to generate ideas about concepts based on their reasoning and prior conceptual knowledge.
Verbal Jigsaw	The questions are aimed at answers that require the use of scientific terminology and the expression of interrelations between concepts.	Reinforces students' vocabulary and helps students to master concepts in a systematic way.
Semantic tapestry	The questions are aimed at producing answers that weave students' disparate ideas together meaningfully into a coherent conceptual framework. These questions can zoom in and out, alternating between biological levels of organisation.	Helps students to focus on abstract concepts and to view a concept from different perspectives.
Framing	The questions are aimed at framing or structuring a problem or topic.	Helps students to recapitulate or reflect on concepts at the end of a lesson.

Note. These approaches are adopted from Chin (2007) and adjusted to the development of conceptual coherence.

- There should be a focus question that guides the way that students organise concepts. For the purpose of this research project, the focus question is essential to link this LT activity to a context.
- There should be attention to the establishment of cross-links, which are relations between different segments of the concept map.
- There should be an opportunity for students to relate each concept to a specific example of an event or object (associated with personal experiences) that helps students to clarify the meaning of this concept.

Concept mapping seems suitable for the elaboration of each of the four design principles.

Writing activities

Writing activities stimulate students to brainstorm, which activates associations among the concepts that are stored in their long-term memories (e.g., Galbraith, 1999). Furthermore, writing prompts students to organise their (conceptual) knowledge and to express relationships between concepts when formulating sentences. Therefore, this LT activity is promising for the promotion of the development of conceptual coherence. This is supported by a study in which seventh grade high school students perform writing activities around authentic tasks. It appeared that after writing, the ability of these students to integrate knowledge and apply knowledge to real-world problem solving improved significantly (Keselman et al., 2007). Based on this study, the following effective components of a writing activity were proposed:

- Students should work together and should have discussions about a realistic scenario for their writings that is situated within a context that uses the biological concepts they learned during preceding activities.
- Students should have the opportunity to evaluate their written products on contents and writing process.
- The writing assignment should consist of different phases that result in several drafts.

Writing activities seem suitable for the elaboration of each of the four design principles.

1.6 Focus on a domain-specific topic: energy and matter transformation in cellular processes

To investigate the degree in which students develop conceptual coherence during a lesson sequence based on the concept-context approach, a domain-specific topic in biology was chosen. This topic was carbon and energy transformation in metabolic cell processes: photosynthesis, cellular respiration and biosynthesis. Photosynthesis, a process that occurs in plant cells, transforms (radiant) energy from sunlight into chemical energy stored within carbohydrate molecules such as glucose. The carbon atoms of these molecules originate from carbon dioxide. Cellular respiration, a process that occurs in all living cells, transforms the chemical energy of glucose into smaller units of energy within ATP molecules. This chemical energy is partly transformed into heat. The carbon atoms of glucose are transformed to carbon dioxide molecules. The glucose, produced from photosynthesis or taken up from the environment, is used for biosynthesis. Biosynthesis is the process that forms larger carbohydrate molecules, for instance, for the growth of the organism. The chemical energy that is stored in these carbohydrate molecules can also be transformed into energy for cellular activity (Campbell et al., 2008). This topic was chosen because of its complexity and its relevance. People who understand this mechanism of energy and matter transformation in chemical reactions of biological systems are able to tie together seemingly unrelated phenomena relevant in socio-scientific issues (e.g., Brown & Schwartz, 2009). This refers to energy conversion in relation to food production and consumption (McMichael, Powles, Butler, & Uauy, 2007) or carbon cycling in relation to climate change and global warming (Mohan et al., 2009). Next, we present a literature study that specifies the learning and teaching difficulties related to this topic.

Biological education research of the last three decades reveals that students experience problems with the concept of photosynthesis (Domingos-Grilo, Reis-Grilo, Ruiz, & Mellado, 2012; Eisen & Stavy, 1993; Ozay & Oztas, 2003; Stavy, Eisen, & Yaakobi, 1987; Waheed & Lucas, 1992) and the relation between photosynthesis and cellular respiration (Amir & Tamir, 1990; Brown & Schwartz, 2009; Cañal, 1999; Kose, Usak, & Bahar, 2009; Songer & Mintzes, 1994). For example, students often think that photosynthesis and cellular respiration do not occur simultaneously in plant cells, are exactly opposite biochemical processes or are purely "gas exchanging" processes. In addition, students are not used to seeking explanations at the (sub-)cellular level of biological organisation when they are asked to explain observable phenomena in plants or animals (Flores, Tovar, & Gallegos, 2003; Songer & Mintzes, 1994). Furthermore, understanding energy flow and matter cycling in living systems appears to be problematic (Asshoff, Riedl, & Leuzinger, 2010; Barak, Gorodetsky, & Chipman, 1997; Jin & Anderson, 2012; Lin & Hu, 2003; Mohan et al., 2009; Öztaş, 2009). Students often experience problems in linking the living world to the non-living world and often do not grasp the idea that, in living cells, energy can be captured, transferred or released and chemical elements (like carbon) can be transformed in a cyclic way from one molecule to another (Amir & Tamir, 1990; Lin & Hu, 2003; Mohan et al., 2009). This might partially be caused by the way that this topic is presented in textbooks. Textbooks do not convey the idea that the metabolic processes in living cells are instances of matter and energy conservation and transformation (Roseman, Linn, & Koppal, 2008). It is worth noticing that there are many indications in the literature that, in all natural sciences, the concept of energy is difficult (Barak et al., 1997; Chabalengula, Sanders, & Mumba, 2012; Nordine, Krajcik, & Fortus, 2011).

In section 1.6.1, we describe the concepts and propositions in relation to this topic that were selected. Subsequently, in section 1.6.2, a set of selected contexts is presented that is suitable to embed these concepts in relationship to each other. Both of these selections are dependent on the educational level of the students to which this topic is taught. We decided to choose tenth grade students in senior general secondary education as the subjects under investigation. This choice was made for two reasons. First, we considered it to be a challenge to find suitable social practices to teach and learn this topic. Students in senior general secondary education are more oriented toward the practical use of biological knowledge in real life practices or—for them—recognisable professional practices, compared to students at the pre-university level (Hamer, 2010). However, the topic of energy and matter transformation in cellular processes is often associated with contexts of a scientific nature, such as fundamental plant research. Such a scientific context is less suitable for these students because its problems and questions are more theoretically oriented. Moreover, it is expected that most of these students will not become scientists. Second, compared to students at the pre-university level, most students in senior general secondary education prefer to learn by an alternation of practical (hands-on) activities and small pieces of theory (Hamer, 2010). Because they are orientated toward the practical use of biological knowledge, the purpose of learning new theory should be clear to them at all times. This requires a well thought-out lesson sequence in which concepts and context are offered in relation to each other.

1.6.1 Selected concepts presented in a reference concept map

The objective of this research project is to design a context-based lesson sequence about energy and matter transformation in cellular processes for tenth grade biology students in senior general secondary education (havo-4). To design such a lesson sequence, we first needed to define the learning goals in terms of the propositions these students are expected to establish. Therefore, concepts to be learned related to this topic were selected from two biology textbooks for upper secondary education and the national Dutch exam standards (College voor Examens, 2009). This selection was based on the following question: Which concepts in relation to this topic are important to teach to tenth grade biology students in senior general secondary education (havo-4)? Next, a concept map was constructed that contained all the concepts and propositions to be learned. Because this concept map functioned as a point of reference to assess the students' ability to mention propositions, we call this a *reference concept map*. This reference concept map was used to analyse data from a variety of data collection strategies that elicited responses from students that included propositions. This reference concept map was also used to guide the design of (and structure LT activities in) context-based lessons. Discussions with researchers in the field of ecology and upper secondary biology teachers resulted in the following two guidelines for the construction of this reference concept map:

- The three metabolic processes, photosynthesis, cellular respiration and biosynthesis, must be related to each other at the cellular level of biological organisation.
- Each process should be related to the way in which matter (with a focus on substances that contain carbon) and forms of energy (light energy, chemical energy, heat and energy for cellular work) are transformed.

Based on those two guidelines, we defined four core concepts that formed the heart of the reference concept map: photosynthesis, cellular respiration, biosynthesis and energy. Energy was specified in the following forms: heat, energy from sunlight, energy for cellular activity and chemical energy. Although the concept of energy differs from the other three core concepts, which refer to metabolic processes, we regarded it as a core concept because it provides connections between the three metabolic processes (in correspondence with the first guideline). Figure 1.1 shows the final version of the reference concept map used in this research project. In Chapter two, three and four prior versions of this reference concept map are also presented.

1.6.2 Suitable contexts for the lesson sequence

For the design of the lesson sequence, suitable contexts had to be chosen. Therefore, the following criteria were used:

- Each context represents an authentic social practice that is recognisable (or can be made recognisable) to tenth grade students in general secondary education (havo-4).
- Each context is suitable to integrate promising LT activities (like those presented in section 1.5.2) that stimulate students to deal with concepts and establish propositions from the reference concept map.
- All of the contexts together cover all concepts and propositions from the reference concept map.

This resulted in the following four contexts:

1. Family context

In this context, students see themselves as family members that argue about vegetarianism in relation to the consumption of meat, plant substitutes and environmental consequences. This context may engage students in (their own) protein consumption. Because this context is expected to be recognisable in students' own lives, this context should be the first within the lesson sequence to be designed.

2. Context of environmental advisor

Students compare carbon dioxide emissions during the production of various protein-rich food products from the perspective of an environmental advisor. Although most students might not be familiar with this social practice, they may recognise that the unanswered questions of the family context could be addressed by the environmental advisor. Therefore, this context should be positioned in the lesson sequence after the family context.

3. Context of agricultural researcher

Students examine how the three metabolic processes from the reference concept map are involved in the growth of plants that produce protein-rich beans as an alternative

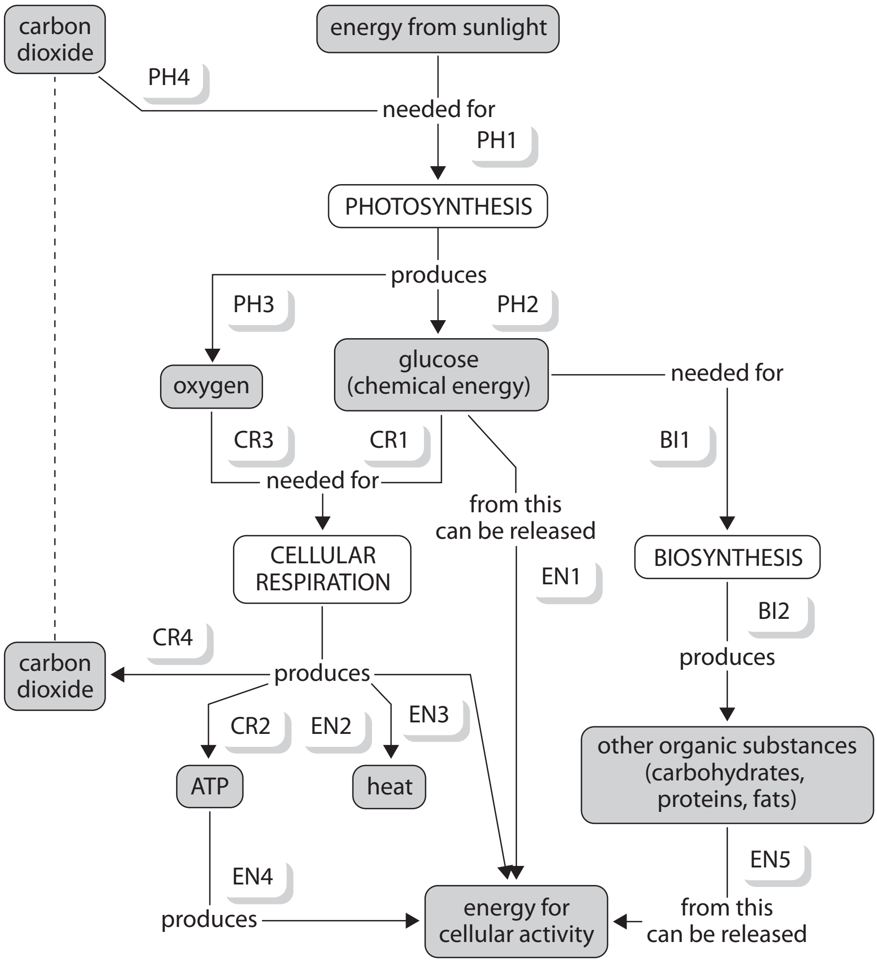


Figure 1.1 Reference concept map (also attached as an extension to the back cover of this thesis).

The relationships between the three metabolic processes (white boxes) with an emphasis on the transformation of forms of energy and matter (grey boxes) are indicated with proposition codes. Four groups of propositions are distinguished that are related to the core concepts of photosynthesis (code: PH1-4), cellular respiration (code: CR1-4), biosynthesis (code: BI1-2) and energy (code: EN1-5).

to the production of animal proteins in meat from the perspective of an agricultural researcher. This social practice is expected to be fairly recognisable to students.

4. Context of restaurant owner

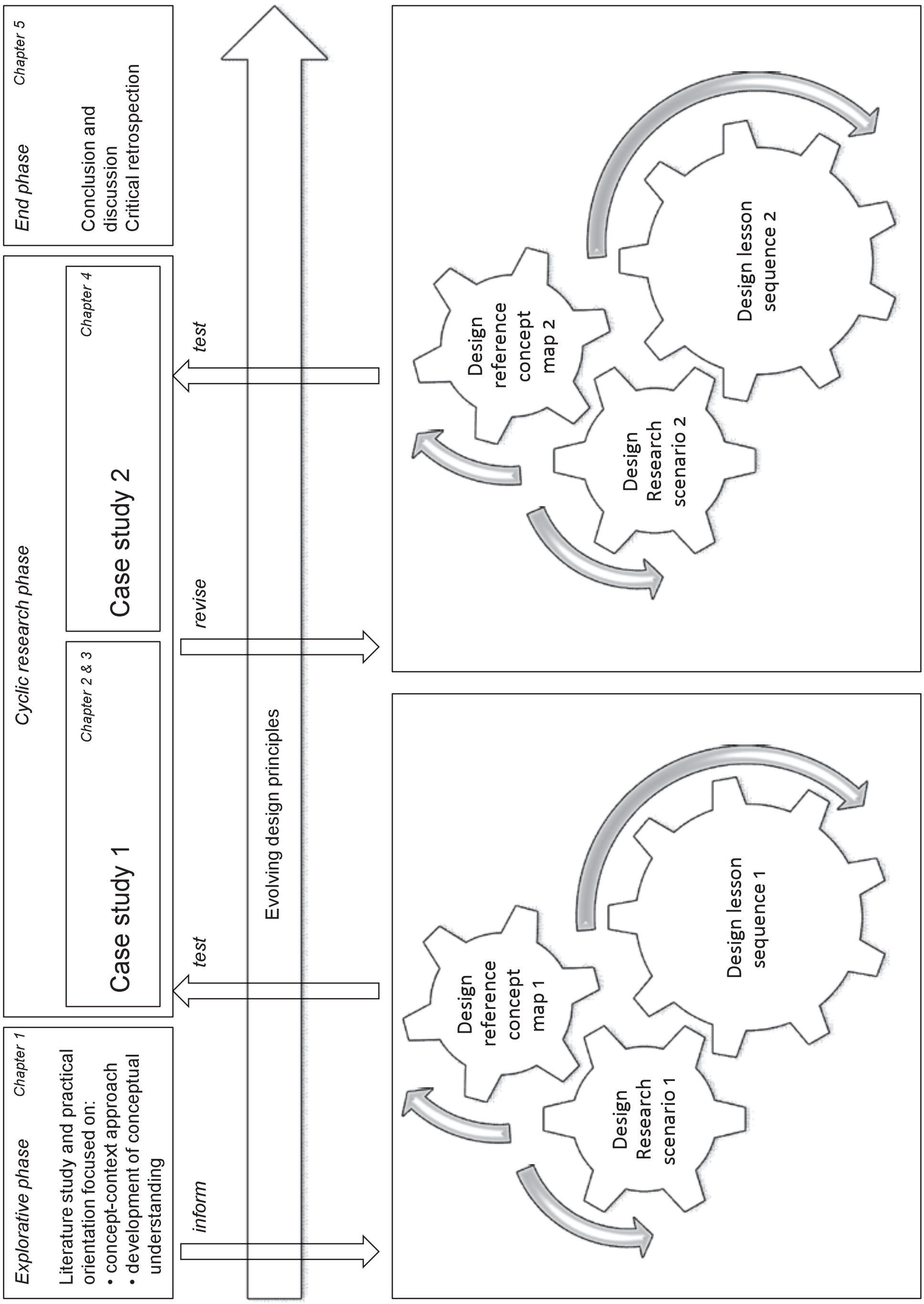
Students explain why consuming insects is better for the environment than consuming farm animals from the perspective of a restaurant owner who wants to promote sustainable food. This context may be fairly recognisable to students. Because this context does not relate closely to the previous ones, it should be positioned at the end of the lesson sequence. During the course of this research project, we decided to leave this context out of the design of the lesson sequence.

In Chapters three and four, we will indicate how the design principles were elaborated in each of these contexts.

1.7 Overview of the research project

The following three phases have been distinguished in our research project: the explorative phase, the cyclic research phase and the end phase (see Figure 2).

The explorative phase started with a theoretical orientation through a literature study that focused on learning and teaching concepts in context-based biology (and science) education in general and on learning and teaching the domain-specific topic of energy and matter transformation in metabolic cell processes in particular. This was followed by a practical orientation in which a concept-context based lesson sequence was observed. This was a lesson sequence about genetics that was developed at one of the developmental (BOS) schools. In cooperation with the developing teachers, we provided ideas for LT activities that could be integrated in the lesson sequence. The observation focused on the interplay between contexts and concepts and on the performance of these LT activities. We noticed that students were engaged in the given contexts and that classroom conversations, concept mapping and writing activities were promising LT activities because students were stimulated to mention concepts and relationships between concepts. Moreover, we observed that the teacher had a dominant role in the way the concept-context approach was conducted in practice. The consecutive steps of a lesson were often not conducted as intended by the teacher. This resulted in the conviction that an instrument was needed to compare the intentions of a lesson to what actually happened in the classroom. For this purpose, we developed *a research scenario* (Lijnse & Klaassen, 2004), as described in section 1.5. Furthermore, we determined whether the concept maps constructed by students individually during the lessons are representative of their conceptual understanding and whether they can be used to detect changes in their conceptual coherence. We interviewed students and asked them to reflect on their


Explorative phase
Chapter 1
Literature study and practical orientation focused on:
• concept-context approach
• development of conceptual understanding
Cyclic research phase
Chapter 2 & 3
Case study 1
Chapter 4
Case study 2
End phase
Chapter 5
Conclusion and discussion
Critical retrospection
inform
test
revise
test
Evolving design principles
Design reference concept map 1
Design Research scenario 1
Design lesson sequence 1
Design reference concept map 2
Design Research scenario 2
Design lesson sequence 2

1

Figure 1.2 Schematic overview of the research design.

Three consecutive phases are presented: the explorative phase, the cyclic research phase and the end phase. The explorative phase resulted in a first version of the design that consisted of three elements: a reference concept map, a research scenario and a lesson sequence. These elements were developed simultaneously and in close interaction with each other. After testing the first version of the design in the first case study, we revised and tested it in the second case study. During this process of design, testing and revision, the design principles were constantly adjusted. In the end phase, we reflected on the findings of the first and second case studies and on the design principles.

concept maps. It appeared that when students started to reason, they were able to articulate more and different correct relations between concepts than those that they had previously shown in their concept maps. Therefore, we decided not to rely on concept maps solely as an assessment instrument. Instead, we developed an assessment instrument in which data from various sources, collected in both a test setting and a naturalistic setting, could be combined. Eventually, a reference concept map (as presented in Figure 1.1) was developed in which every student's individual proposition, mentioned at a certain moment during the lesson sequence, could be placed. The explorative phase resulted in a set of initial design principles to promote the development of conceptual coherence within contexts. The design principles were used for the design of a context- based lesson about the chosen domain-specific topic: energy and matter transformation in cellular processes (see section 1.6).

In the cyclic research phase, the designed concept-context based lesson sequence, together with a designed research scenario and reference concept map, were tested in two case studies. In the first case study, the reference concept map was used to assess the development of students' conceptual coherence. Therefore, the sub-question (SQ) is:

SQ1: To what extent do tenth grade students in senior general secondary biology education (havo-4) develop conceptual coherence in a lesson sequence based on the concept-context approach that aims to stimulate students to connect concepts?

In the first case study, the collected data were also used to evaluate the lesson sequence on its practicability. The research scenario was used as an instrument to compare the actual conducted lesson sequence with its intentions. Therefore, the following sub-question was addressed:

SQ2: How should a concept-context-based lesson sequence, aimed at promoting conceptual coherence, be designed and evaluated regarding its practicability?

In the first case study, the lesson sequence was conducted in two classes. One class was considered to be the "practice class" and the other as the "test class." The researchers and the teacher reflected extensively on each lesson in the practice class. This resulted in recommendations to optimise the lessons that were conducted in the test class. Eventually, only data collected in the test class were analysed for the purpose of the first case study. Then, the lesson sequence was revised and tested in a second case study. This revised lesson sequence was conducted and evaluated on its effectiveness. This resulted in the following two sub-questions:

SQ3: How does students' conceptual coherence develop during a context-based lesson sequence?
SQ4: How do context-embedded learning-teaching activities influence the development of conceptual coherence?

The second case study was conducted one year later by the same teacher in the same school. There were three reasons for this choice. First, by choosing the same teacher and instructing this "experienced" teacher in minute detail, we expected to minimise the influence of the teacher and his specific teaching style on students' learning outcomes. This allowed us to use the research scenario as a point of reference and to relate the characteristics of the design, the actual teacher and student activities in the classroom and the learning outcomes of students. Second, students at this biology developmental school were accustomed to context-based biology education and to educational units in which they did not use their textbook. This prevented confusion and disturbance in their learning processes. In the second case study, the lesson sequence was conducted in only one class. This allowed us to prepare the lessons in close cooperation with the teacher, with greater precision and with sufficient time for the data collection activities such as student interviews, between the lessons. Third, the conditions in the school were very suitable for the administration of the lesson sequence and the collection of data. The teacher, colleagues, technical assistants, schedule assistants and the management of the school were very cooperative. Furthermore, all facilities (such as ICT support) were available. Appendices 1 and 2 present an outline of the first and second lesson sequences. In the end phase, the main findings of both case studies were integrated with reference to the literature.

We indicate how the design principles may guide the design of future context-based biology lessons and lesson sequences with an emphasis on promoting the development of conceptual coherence. Furthermore, in critical retrospection, the limitations of the methodological approach that might restrict the extent to which these findings can be generalised are discussed.

1.8 Thesis outline

The findings of two consecutive in-depth case studies, which have been published (or submitted) in three papers, form the heart of this thesis. For the first case study, a lesson sequence based on the concept-context approach was developed. The purpose of the first case study was to provide insight into the way students' conceptual coherence developed with respect to the domain-specific topic. This is reported in the first paper, which is presented in Chapter two.

The first case study was also used to provide insight into the ways design principles can be elaborated in the learning-teaching activities of a lesson sequence and to determine the extent to which these activities were performed as intended. This is reported in the second paper, which is presented in Chapter three.

After evaluation, the initial lesson sequence was revised for the second case study. The purpose of the second case study was to find out how the design and the administration of the lesson sequence influenced students' development of conceptual coherence. Specific attention was paid to the LT activities that were embedded in the contexts. This is reported in the third paper, which is presented in Chapter four.

In Chapter five, we formulate the main conclusions from the research project. We use the empirical findings from the case studies to discuss students' development of conceptual coherence with respect to the domain-specific topic. Then, we discuss how LT activities within contexts can contribute to the promotion of conceptual coherence. Subsequently, we reflect on the underlying design principles and consider points of interest when elaborating them in a context-based lesson sequence. Furthermore, the research project is discussed in critical retrospect, with specific attention on the developed assessment instruments: a reference concept map and a research scenario. Finally, implications for secondary biology education and teacher education are considered and directions for future research are suggested. Table 1.3 summarises the titles of the papers and presents the corresponding sub-questions and purposes.

Table 1.3 Outline of thesis

Chapter	Title	Main research question	
1	Introduction	How can the development of students' conceptual coherence be promoted within biology education based on the concept-context approach?	
		Sub-questions (SQ's)	**Purposes**
2	The development of conceptual coherence within biology education based on the concept-context approach.	SQ-1: To what extent do tenth grade students in senior general secondary biology education (havo-4) develop conceptual coherence in a lesson sequence based on the concept-context approach that aims to stimulate students to connect concepts?	1. Insight in the development of conceptual coherence in relation to the domain-specific topic. 2. Construction of a measuring instrument for conceptual coherence.
3	Designing and evaluating a context-based lesson sequence that promotes conceptual coherence in biology.	SQ-2: How should a concept-context-based lesson sequence aimed at promoting conceptual coherence be designed and evaluated regarding its practicability?	1. Insight in the elaboration of design principles in a lesson sequence to promote conceptual coherence in contexts. 2. Construction of an evaluation instrument to determine the extent to which the designed lesson sequence was conducted as intended.
4	Promoting conceptual coherence within context-based biology education.	SQ-3: How does students' conceptual coherence develop during a context-based lesson sequence? SQ-4: How do context-embedded LT activities influence the development of conceptual coherence?	Identifying factors that promote and hinder the development of conceptual coherence during eight LT activities within a lesson sequence based on the concept-context approach.
5	Conclusion and discussion		

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2

The development of conceptual coherence within education based on the concept-context approach*

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Abstract

In secondary education, it is problematic for many students to develop coherence between domain-specific concepts. The aim of this research project is to gain insight into the development of conceptual coherence and the ways that it can be enhanced. In this chapter, we describe a case study in which a context-based biology lesson sequence on energy transformation in relation to photosynthesis, cellular respiration and biosynthesis has been developed and conducted for tenth grade students in upper general secondary education. This lesson sequence has been designed according to the concept-context approach and contains learning-teaching activities that are intended to promote the establishment of connections between concepts by students. To measure coherence, using a reference concept map, we observed which and how many connections between concepts (propositions) were mentioned correctly by 21 students at six moments during the administration of the lesson sequence. The results indicate a significant increase between pre- and post-test in the total numbers of students that mentioned propositions correctly. Propositions including the core concepts of energy and biosynthesis were mentioned correctly less often. The instrument used to assess students' conceptual coherence is discussed. Our conclusion is that scoring propositions has the potential to measure students' development of conceptual coherence within educational practices.

2.1 Introduction

Educational research on the learning of the natural sciences shows that after the completion of this education, the conceptual knowledge of students is often fragmented in various ways (e.g., DiSessa, Gillespie, & Esterly, 2004; Donovan & Bransford, 2005; Pearsall, Skipper, & Mintzes, 1997). The degree to which knowledge is organised coherently determines the ability of a student to transfer this knowledge to a new situation. This is illustrated by the way in which experts, compared to novices, recognise, represent and solve problems. Expert knowledge does not consist of a simple list of domain-specific facts, but is organised around core concepts that guide their expert's thinking (Bransford, Brown, & Cocking, 2000; Chi, Feltovitch, & Glaser, 1981). For this reason, one of the challenges in science education is to design an educational environment that stimulates students to develop a cognitive structure in which domain-specific knowledge is organised coherently. A number of studies that aim to contribute to a solution of this problem suggest that education in which concepts and contexts are related to each other can promote conceptual coherence (Bennett, Lubben, & Hogarth, 2007).

In Dutch biology education, a specific form of context-based education is used: the concept-context approach (Boersma et al., 2007). According to this approach, a context is represented as a social practice that is transformed in order to be used in education. In such a context, students perform activities from the perspective of a participant in a social practice. During these activities, students deal with biological concepts that are connected in a certain way. The way in which these concepts are connected coherently in one specific context can be different from the way in which they are connected in other contexts. However, until now, it has been unclear how education based on the concept-context approach should be designed in order to promote students' conceptual coherence. There are indications that students, after receiving education based on the concept-context approach, are able to connect concepts within the context in which they are learned and to transfer these concepts to a new context. However, they often experience difficulties in connecting these concepts with abstract core concepts (Boersma, Kamp, Van den Oever, & Schalk, 2010). For this reason, it seems necessary to integrate learning-teaching (LT) activities that explicitly stimulate students to connect concepts into context-based education. In this respect, promising LT activities are concept mapping (Nesbit & Adesope, 2006), realistic writing assignments (Keselman, Kaufman, Kramer, & Patel, 2007) and classroom conversations in which the teacher asks questions that stimulate students to express connections between concepts (Chin, 2007).

The aim of this paper is to contribute to the optimisation of education based on the concept-context approach with an emphasis on improving conceptual coherence. Therefore, we conducted a case study as part of a design research project (Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). In this research project, a lesson sequence based on the concept-context approach for senior general secondary biology education (havo-4) has been designed and conducted. This lesson sequence contains LT activities that are aimed at stimulating students to connect concepts. We seek to address the following research question: *To what extent do tenth grade students in senior general secondary biology education (havo-4) develop conceptual coherence in a lesson sequence based on the concept-context approach that aims to stimulate students to connect concepts?* The lesson sequence addresses a topic that appears problematic for many students: energy transformation in photosynthesis and related metabolic cell processes (cellular respiration and biosynthesis) (e.g., Cañal, 1999; Lin & Hu, 2003). An aspect that is innovative in this research project is that, parallel to the design of the lesson sequence, a reference concept map was constructed in order to measure conceptual coherence. This reference concept map contains all of the connections between concepts (propositions) that students should learn. We will show how these propositions were used as a reference to provide insight into the development of conceptual coherence. In order to find possible explanations when students do not mention propositions correctly, we also try to identify remarks made by students that indicate an invalid conceptual understanding.

This paper is structured as follows: In the theoretical framework, we describe how we define coherent conceptual knowledge (2.2.1) and how such knowledge can be depicted in a concept map (2.2.2). The methods section presents how we designed the lesson sequence (2.3.1) and the reference concept map (2.3.2). Then, we describe how the lesson sequence was conducted (2.3.3), the data that were collected during measuring moments (2.3.4) and how these data were analysed (2.3.5). The results section describes, for each measuring moment, the numbers of students that mentioned the intended propositions correctly (2.4.1). Next, we show the average proposition scores for the entire class compared to the maximum number of the intended propositions. Moreover, we present the average learning gain by comparing the propositions that were mentioned correctly in the pre-test and the post-test (2.4.2). In addition to the average proposition scores, we also show the scores of students' remarks that indicate an incorrect understanding, with a focus on four core concepts from the reference concept map. In the final section, we discuss the usefulness and limitations of the way in which the development of conceptual coherence was measured (2.5.1) and how these findings might provide insight into the learning-teaching mechanism that explains how this development has occurred (2.5.2).

2.2 Theoretical framework

2.2.1 Coherent conceptual knowledge

This research project is in line with the learning theory of Ausubel (1968), which is based on the assumption that establishing relationships between concepts is essential for human cognition and that concepts are the fundamental units of cognitive structures. This theory distinguishes "meaningful learning" and "rote learning." Meaningful learning is regarded as a process in which students develop a cognitive structure by connecting new concepts with concepts that are already available to them. Vygotsky (1987) adds to this learning theory by introducing the process of *internalisation*, which implies that a learner does not copy a complete coherent conceptual structure, but reconstructs new concepts by integrating them into their own conceptual structure. Students who learn by rote establish no or few connections between new and available concepts. This results in the cognitive storage of concepts as isolated units (Mintzes, Wandersee, & Novak, 2005). In line with this, Scott, Mortimer, and Ametller (2011) emphasise that knowledge of one single concept is hardly usable. Instead, they state that concepts must be used in interconnection with each other and that these interconnections are dynamic. They argue that, in order to develop a deeper conceptual understanding of a scientific phenomenon, it is required that students recognise the concepts that are involved and how they should be connected. To provide insight into the degree to which students develop coherent conceptual knowledge, it is crucial to measure which connections between concepts that students are able to establish.

2.2.2 Depicting conceptual knowledge

Since the late sixties, concept maps have been used to depict and assess a learner's cognitive structure. A concept map consists of a network of concepts that are connected by arrows. The arrows are provided with labels that indicate the relationship between two concepts. Two interrelated concepts are called a proposition. A proposition can be regarded as the smallest unit of coherent conceptual knowledge (Mintzes et al., 2005; Novak & Wandersee, 1991).There are different ways to use concept mapping in the assessment of learning processes or learning outcomes. Ruiz-Primo and Shavelson (1996) distinguish three aspects that should be considered when using concept mapping as an assessment instrument: the *task* that elicits the propositions that students mention, the *type of responses by students* and the *scoring system*. Concerning the *task*, it is essential to know whether students have been exposed in advance to the concepts they have to connect. With regard to the *type of responses by students,* it matters whether it is the student who constructs the concept map (individually or in cooperation with others) or whether the researcher constructs the concept map based on the student's written text or on a protocol of a discussion between students in which concepts and propositions are mentioned. The *scoring system* may focus on the form (complexity, hierarchy) or the content (the number and quality of the propositions) of a concept map. In the methods section, we will explain the methodological choices that have been made in this research project.

2.3 Methods

In this section, we describe how the lesson sequence and the reference concept map have been designed. Further, we indicate the point in the lesson sequence at which we expected students to understand and mention certain propositions. Thereafter, a description of how the lesson sequence was conducted and the type of data that were collected is provided. Finally, we provide a step-by-step description of the data analysis procedure.

2.3.1 Design of domain-specific lesson sequence

Based on a literature review and explorative research, we formulated design principles (focused on the promotion of the development of conceptual coherence within contexts). These design principles were used to guide the design of a lesson sequence for tenth grade students in senior general secondary education (4-havo) on the subject of energy transformation during the three metabolic cell processes of photosynthesis, cellular respiration and biosynthesis. The lesson sequence contains four contexts that represent authentic social practices and some LT activities that are aimed at promoting conceptual coherence: classroom conversations, concept mapping and a writing assignment. During the design process, we developed three aspects in a complementary way: the choice of contexts (as representations of social practices), the order and the way concepts were offered to students within consecutive contexts, and the order and structure of learning-teaching activities within contexts. We obtained information from experts about the chosen social practices. In addition, we had critical discussions with three experienced biology teachers and with the teacher who conducted the lesson sequence. In addition to a student manual and a teacher manual, we also developed an accompanying research scenario (Lijnse & Klaassen, 2004). In this research scenario, we described all of the intended activities of the teacher and the students, along with the didactical function of each step in the learning-teaching process. The purpose of this research scenario is to evaluate the degree to which the lesson sequence was conducted as intended. In addition, it provides the possibility of finding explanations for unexpected learning outcomes.

2.3.2 Design of reference concept map

The concepts and propositions that we expected students to understand and—when asked— to be able to mention at the end of the lesson sequence, were presented in a concept map. Because all of the individual propositions in this concept map can be regarded as learning goals, the concept map functioned as a frame of reference that could be compared with the remarks made by students. For this reason, we call it the reference concept map. We expected to be able to place the propositions that were mentioned by students accurately in this reference concept map and that, by doing this at consecutive moments, students' conceptual coherence would be identified. The concepts were selected from different editions of biology textbooks for tenth grade students in senior general secondary education and from exam requirements (College voor Examens, 2009) based on the question which of the concepts are essential when learning photosynthesis and related metabolic processes. Subsequently, a literature study regarding the learning and teaching of photosynthesis and the other two metabolic processes (cellular respiration and biosynthesis), and discussions with scientific researchers in the field of ecology as well as biology teachers have led to a further selection of concepts. This has resulted in the formulation of two basic assumptions for the learning and teaching of this topic: (1) there should be a focus on the transformation of forms of energy (energy from sunlight, chemical energy, heat and energy for cellular activity); and (2) the relationships between photosynthesis, cellular respiration and biosynthesis must be addressed at the cellular level of biological organisation. Based on these basic assumptions, we defined the relations between the concepts of the energy transformation during the metabolic processes. This resulted in four groups of propositions related to the core concepts of photosynthesis, cellular respiration, biosynthesis and energy (Figure 2.1). The following codes were used, respectively: PH-propositions that describe how energy from sunlight is stored in glucose as a chemical form; CR-propositions that present how this chemical energy in glucose is prepared for use in the cell by conversion to the ATP-molecule; BI-propositions that show how the chemical energy in glucose is stored temporarily in other organic substances; and EN-propositions that describe how chemical energy is made available for cellular activity and the generation of heat.

2.3.3 Administration of lesson sequence

The lesson sequence was conducted by one teacher in two tenth grade classes of senior general secondary education (4-havo) in a small school in the Netherlands. This school was a biology developmental school (BOS), a pilot school of the Committee for the Innovation of Biology Education (CVBO), in which teachers developed and conducted learning-teaching materials based on the concept-context approach. Each lesson was prepared together with the teacher and discussed afterwards. In these discussions, there was attention to the way in which the concepts and propositions from the reference concept map were dealt with in the previous lesson or needed to be dealt with in the next lesson according to the research scenario. To structure classroom conversations, the teacher was asked to write the concepts and propositions that had to be discussed on the white board in front of the class. It appeared that the teacher conducted the lesson sequence with a high degree of correspondence with and as intended by the research scenario. In this paper, we present the data collected from the class in which the teacher

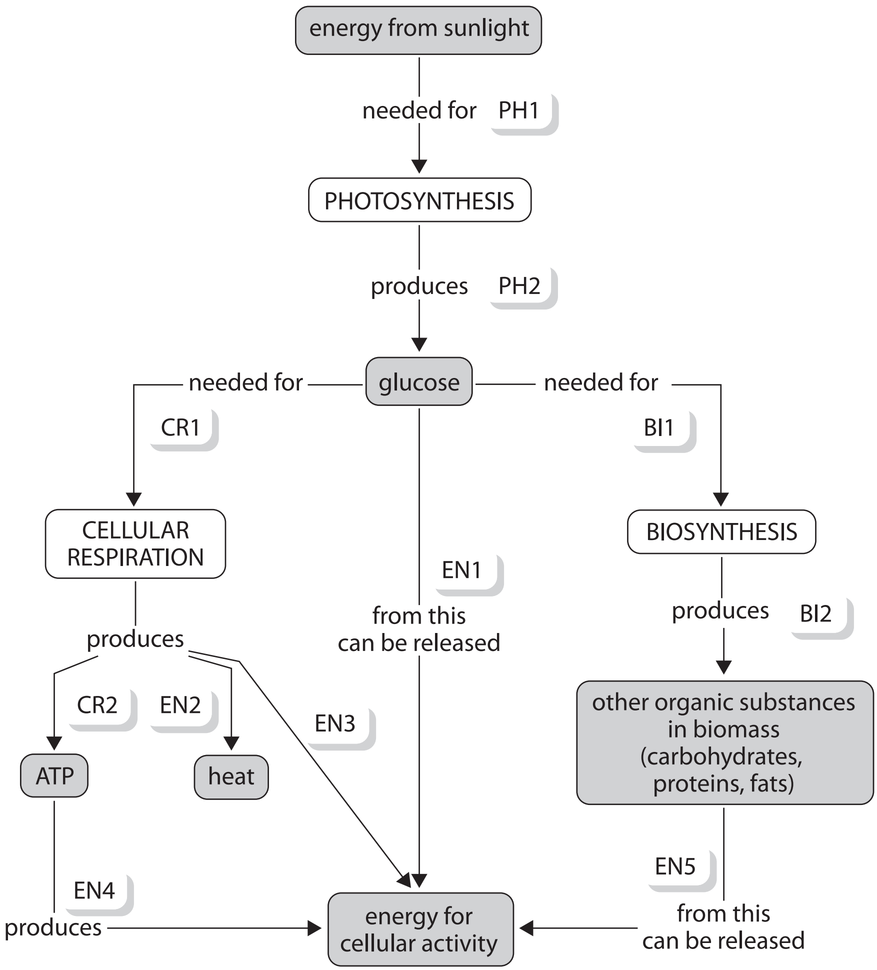

Figure 2.1 Reference concept map.

The connections between the three metabolic processes, with a focus on transformation of forms of energy, are indicated by proposition codes. The propositions are categorised in four groups related to the core concepts: photosynthesis (code: PH), cellular respiration (code: CR), biosynthesis (code: BI) and energy (code: EN).

Table 2.1 Overview of lesson sequence.

Lesson	Description of contexts and learning-teaching activities	Propositions from the reference concept map that students must deal with in the context.
1 & 2	*Context 1 (family context)* Role play about a family discussion taking place at the dinner table. Five students participate and see themselves as family members arguing about vegetarianism. The central question is: Are we still allowed to consume meat? Informative movies are shown and individual students are asked to explain their points of view in classroom conversations. There is an emphasis on the importance of proteins in food (for the human body). Proteins are related to energy for cellular activity.	EN5
3, 4 & 5	*Context 2 (context of environmental advisor)* Students must give advice about the balance between plant and animal protein-rich food consumption from the perspective of an environmental advisor. They make calculations in which they compare the areas of agricultural land needed for the production of an amount of plant and animal proteins and the amount of greenhouse gases emitted during the production of both plant and animal proteins. To explain the results of their calculations (i.e., for the production of animal proteins, a larger area of agricultural land is essential and more greenhouse gases are emitted) the teacher helps students to use biological knowledge: the chemical equations of metabolic processes (photosynthesis, cellular respiration and biosynthesis). These equations are written on the white board.	PH1, PH2, CR1, CR2, EN2, EN3, EN4, BI1, BI2
6, 7 & 8	*Context 3 (context of agricultural researcher)* Students (in small groups) conduct experiments with bean plants from the perspective of an agricultural researcher. The aim is to find out the conditions under which these plants grow optimally and produce protein-rich beans. They need to relate these conditions to photosynthesis and biosynthesis. During classroom conversations, the results are discussed and the teacher helps students to mention propositions related to photosynthesis and biosynthesis in their explanations.	PH1, PH2, BI1, BI2
9 & 10	*Conceptualisation phase* Students construct a concept map in groups of three. The focus question is: How do plants store and transform the energy they need to grow? The concepts are provided and the teacher gives feedback on request. There is a final classroom discussion that enables students to adjust incorrect propositions in their concept maps.	PH1, PH2, CR1, CR2, BI1, BI2, EN1, EN2, EN4, EN5

2

Table 2.1 Continued.

Lesson	Description of contexts and learning-teaching activities	Propositions from the reference concept map that students must deal with in the context.
11	*Context 4 (context of a restaurant owner)* Students perform a writing assignment from the perspective of the owner of a restaurant. The text to be written is destined for a website and should make clear why consuming (and producing) insects is more sustainable and more efficient (and thus better for the environment) than consuming farm animals. The concepts to be used are given.	PH1, PH2, CR1, CR2, BI1, BI2, EN1, EN2, EN4
After 4 weeks	Contexts 5 and 6 *(contexts of a grower of algae and a grower of crops)* In the final test, students answer questions from the perspectives of a grower of algae and a grower of crops.	PH1, PH2, BI1, BI2

conducted the lesson sequence for the second time. This class consisted of 21 students. In addition to the subject of biology, 14 of them also pursued the subjects of chemistry and physics for their graduation, while the other seven students pursued social subjects instead. The students were accustomed to education based on the concept-context approach. They had engaged in two similar context-based lesson sequences prior to the administration of the lesson sequence that was investigated in this study. The students were also accustomed to concept mapping, which was practiced prior to the administration of the lesson sequence. To prevent the possibility that the amount of time spent on the lesson sequence would vary too much between students, we decided to leave the student manual at the school during the administration of the lesson sequence. This enabled the researchers to collect students' products from their manuals after each lesson.

2.3.4 Data collection

We collected data at the following six measuring moments: a pre-test (T1), a defining test (T2), a concept mapping assignment (T3), a writing assignment (T4), a post-test (T5) and a final test (T6). We only analysed those data that referred to the propositions from the reference concept map. To avoid the occurrence of a "testing-effect," we collected data at three moments (T3, T4 and T6) in a *naturalistic setting*. This means that these measuring moments coincide with the intended LT activities (T3 and T4) or with an exam (T6). For the same reason, the other measuring moments that were not part of the lesson sequence (T1, T2 and T5) were of a short duration. These measuring moments are described in Table 2.2.

Table 2.2 Description of measuring moments.

Measuring moment	Description
T1 Pre-test	Prior to the lesson sequence, students must answer two open questions: How do plants get energy to grow? and How do animals get energy to grow? No concepts are offered.
T2 Defining test	After the introduction of the third context, students are given the assignment to interrelate the concept of biomass with the concepts of energy, biosynthesis and energy from sunlight.
T3 Concept mapping	After the third context, students receive (in groups of three) a set of cards, each containing a concept from the reference concept map. During two lessons, each group of students constructs a concept map with the focus question: How is energy from sunlight stored and transformed?
T4 Writing assignment	In the fourth context, students write a text from the perspective of a restaurant owner for the duration of one lesson. In this text, students must explain how it is possible that consuming (and producing) insects is more sustainable and more efficient (and thus better for the environment) than consuming farm animals. The first part of the text is provided as an introduction. Some of the concepts that must be used are provided.
T5 Post-test	Immediately after finishing the lesson sequence there is a post-test that is identical to the pre-test.
T6 Final test	Students are given a final test four weeks after finishing the lesson sequence. There are two context-related questions aimed at photosynthesis and biosynthesis; one from the perspective of a grower of algae and one from the perspective of a grower of crops. Some concepts are provided.

2.3.5 Data analysis

In order to provide insight into the development of students' conceptual coherence, we analysed the number of propositions from the reference concept map that students mentioned correctly at each of the measuring moments. Because the tasks (and the triggers to mention propositions) varied during each measuring moment, we determined, by using the reference concept map and the research scenario, which propositions students were intended to mention in an optimal response. These propositions are presented in Table 2.3. Because of the variety between the tasks, it was not intended that students would mention all propositions from the reference concept map at each measuring moment.

All of the students' written products were analysed with Atlas-ti software (www.atlasti.com). This software program was used to code all phrases that were similar to the propositions from the reference concept map. Students' concept maps were coded in the same manner. A second rater followed the same procedure to determine the degree to which the coding procedure was unambiguous. The degree of agreement between both raters appeared to be high (Cohens kappa = 0.92). In addition, students' remarks that indicated an invalid understanding of the four core concepts from the reference concept map were scored. Descriptions and examples of these remarks are given in Table 2.4. In this case, the degree of agreement between the first and second raters appeared to be less high (Cohen's kappa = 0.53). This can be explained because it was not possible to list all of the remarks that indicate an invalid understanding in the code book. These remarks are rather unpredictable and could not be derived directly from the reference concept map. In addition, the second rater was not an expert in biology content. Because of the small number of students, we conducted two non-parametric tests. Spearman's rank correlation test was used to determine whether there is a correlation between the students' proposition scores at the measuring moments. The Wilcoxon signed-rank test was used to determine whether there was an increase in the propositions that were mentioned correctly between the identical pre-test (T1) and post-test (T5).

2.4 Results

In order to make the development of coherent conceptual knowledge visible, we present the number of students that mentioned each proposition from the reference concept map for each measuring moment (2.4.1). Then, we show the average proposition scores for each measuring moment in a histogramme as a percentage of the total number of intended propositions to be mentioned (2.4.2). Finally, for each measuring moment, we scored the remarks that indicate an invalid understanding of one of the four core concepts (2.4.3).

Table 2.3 Intended propositions for each of the measuring moments.

Proposition group	Photo-synthesis		Cellular respiration		Biosynthesis		Energy					Maximum number of propositions to be mentioned
Proposition code	**PH1**	**PH2**	**CR1**	**CR2**	**BI1**	**BI2**	**EN1**	**EN2**	**EN3**	**EN4**	**EN5**	
T1 Pre-test	x	x	x	x			(x)		(x)	x		5
T2 Defining test	x	x			x	x						4
T3 Conceptmapping	x	x	x	x	x	x	x	x		x	x	10
T4 Writing assignment	x	x	x	x	x	x	x	x	x	x		10
T5 Post-test	x	x	x	x			(x)		(x)	x		5
T6 Final test	x	x	x						x			4

Note. It is indicated (with an x) which of the 11 propositions from the reference concept map students should mention in an optimal response. Regarding T1 and T5, it is possible that, as an alternative for propositions CR2 and EN4, the propositions EN1 or EN3 are also mentioned. This is indicated with an (x). The maximum number of propositions to be mentioned is less at T5 and T6 (compared to T3 and T4) because students are not triggered to mention many propositions.

2

Table 2.4 Descriptions of students' remarks that indicate an incorrect understanding of each of the four core concepts.

Core concept	Photosynthesis	Cellular respiration	Biosynthesis	Energy
Description of incorrect understanding	It is not clear to students that for this process, energy from sunlight is needed or that glucose is produced.	It is not clear to students that glucose is needed for this process and/or that ATP is produced and/or that it takes place in both plants and animals.	It is not clear to students that plants and animals need glucose for this process and/or that this process generates other organic substances. The biomass does not increase by this process.	It is not clear to students that energy can exist in a chemical form and/or can become available for cellular activity or be transformed to heat.
Examples of remarks	"Photosynthesis requires water and carbon dioxide" (sunlight is not mentioned).	"Cellular respiration only takes place in animals, not in plants." "Energy is needed for cellular respiration."	"Biosynthesis results in an increase of biomass."	"Carbon dioxide is a form of chemical energy." "ATP is heat." "The energy from sunlight is needed for photosynthesis and then it is gone."

Table 2.5 Numbers of students ($19 \leq n \leq 21$) who mentioned an intended proposition at least once correctly.

Proposition group	Photosynthesis		Cellular respiration		Biosynthesis		Energy				
Proposition code	**PH1**	**PH2**	**CR1**	**CR2**	**BI1**	**BI2**	**EN1**	**EN2**	**EN3**	**EN4**	**EN5**
T1 Pre-test (n=20)	2	3	1	0*			(2)		(4)	0	1
T2 Defining test (n=19)	12	4	1		7	8	1			1	
T3 Conceptmapping (n=21)	18	18	18	18	12	15	6	3		3	3
T4 Writing assignment (n= 20)	13	12	11	9	10	11	0	11	0	1	
T5 Post-test (n=20)	7	8	8	2	3	4	(5)		(4)	2	4
T6 Final test (n=19)	17	13	9	3	5	2		2	9	2	

Note. The white cells indicate the propositions that were intended. The dark grey cells indicate propositions that were not intended, but were nevertheless sometimes mentioned. The numbers between brackets indicate alternative possibilities (see note, Table 2.3).
* In the original publication, this cell was marked grey because we wanted to indicate that it was not expected that a student would mention this proposition ("cellular respiration produces ATP") at the pre-test. However, for the sake of consistency, we prefer to mark this cell white because in an optimal response (on both the identical pre-test and post-test), it is intended that students mention this proposition.

2.4.1 Propositions mentioned correctly

As presented in Table 2.3, we determined in advance which propositions students would mention in an optimal response. Each of the propositions was scored according to how many students mentioned it at least once. These numbers are presented in Table 2.5. The titles of the columns correspond with the proposition codes from the reference concept map (Figure 2.1). Each row indicates how many students mentioned this proposition correctly at a measuring moment at least once. By comparing scores between the measuring moments, we illustrate how students' conceptual coherence seems to develop. The nature of the instruction and how this elicits propositions is taken into account.

The score 2 in row T1/column PH1 illustrates that only two out of 20 students mentioned the intended proposition: "Energy from sunlight is needed for photosynthesis." The expectation that many students would mention this proposition did not occur. The same applies for other propositions in row T1. Only a few students appeared (to be) able to mention relevant propositions at measuring moment T1, although the teacher stated that these propositions were mentioned in some way in one of the biology lessons during the prior year. When comparing row T1 with row T5, it appears that more students mentioned propositions PH1, PH2 and CR1 at T5. This hardly applies to proposition CR2 and energy-propositions EN1, EN3 and EN4. Obviously, the learning process with respect to these propositions is not yet ideal.

A comparison between measuring moments T2, T4 and T6, in which students are expected to write sentences with the given concepts, shows in column PH1, with the numbers 12, 13 and 17, that there was an increase in the number of students who mentioned these propositions. Also, in column PH2, the numbers 4, 12 and 13 show that more and more students were able to mention the proposition: "Photosynthesis produces glucose." The increase from 4 at measuring moment T2 to 12 at measuring moment T4 is striking. Between T2 and T4, students performed the concept mapping assignment.

The number 18 in row T3/columns PH1 and PH2 shows that almost all students were able to formulate these propositions in the concept map or demonstrates that these propositions were established in the concept map by one of the group members. The numbers 18 in row T3/columns CR1 and CR2 show that this also applies to the numbers of students that mentioned these propositions correctly in relation to cellular respiration. The numbers 12 and 15 in row T3/columns BI1 and BI2 indicate that fewer students understood biosynthesis compared to the other two processes. The remaining numbers 6, 3, 3 and 3 in row T3/columns EN1, EN2, EN4 and EN5 show that only a few students were able to mention the propositions related to the concept of energy (EN-propositions) correctly.

2.4.2 Average proposition scores

For each measuring moment separately, we counted how many of the total number of intended propositions were actually mentioned correctly. Because the concept maps were constructed in groups of three students, we awarded each of the propositions that was mentioned in the concept map to each group member. In Figure 2.2, the average scores of the whole class for each measuring moment are presented. The relative numbers of propositions that were mentioned correctly are indicated in percentages.

Because the conditions of the measuring moments were different and other propositions from the reference concept map were elicited in students' responses, it is impossible to compare all of the percentages with each other. However, this is possible for the pre- and post-tests (T1 and T5) because they were identical. We used the Wilcoxon signed-rank test to determine if an increase in the propositions that were mentioned correctly occurred between the pre- and post-tests. This increase appeared to be significant ($W^+ = 96$; $z = 2.79$; $p = 0.005$), which indicates an overall improvement in students' conceptual coherence during the course of the lesson sequence. It is remarkable, however, that in the post-test, students were able to mention many concepts from the reference concept map, but they often were not able to relate these concepts in a correct way. For example, a student's

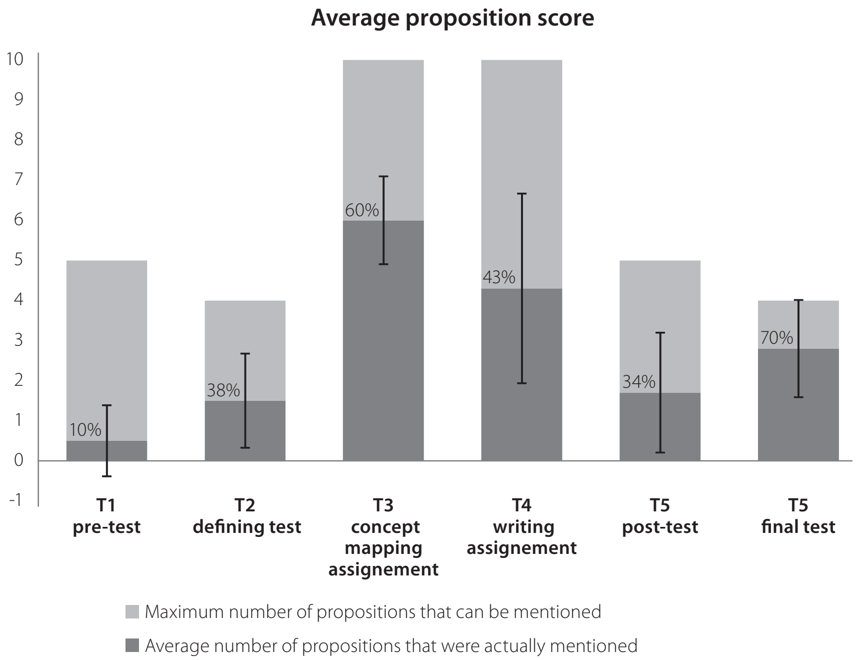

Figure 2.2 Numbers of intended propositions that were actually mentioned.

The percentages indicate, for each measuring moment, which parts of the maximum number of intended propositions were actually mentioned (correctly). The error bars represent the standard deviations from the numbers of propositions that were mentioned.

response: "This can be explained by the processes of photosynthesis, cellular respiration and biosynthesis" was not scored as a correct proposition, although it contained three concepts.

The results of Spearman's rank correlation test (Table 2.6) point out that the average proposition scores at T2 correlate in a relatively high degree with T4 ($r = 0.46$; $p = .053$) and T6 ($r = 0.45$; $p = .068$). This means that the students who mentioned many propositions at T2 also scored relatively high at T4 and T6. These relatively high correlations appeared not to be statistically significant, probably due to the low number of students involved in this analysis. Because the concept maps were constructed by cooperating groups of three students (which is another unit of analysis), we did not involve the results of measuring moment T3 in this analysis.

Table 2.6 Spearman's rank correlation coefficient of the scores on five measuring moments in which students mentioned propositions individually ($17 \leq n \leq 20$).

	T1	T2	T4	T5
T2	-.08			
T4	.09	.46		
T5	.26	-.07	.05	
T6	-.17	.45	.23	.30

2.4.3 Invalid understanding of core concepts

It was determined which remarks of students indicated an invalid understanding of each of the four core concepts (see Table 2.4). The data were analysed by counting, for each measuring moment, the number of students that showed an invalid understanding of one of the core concepts. This is shown in Table 2.7.

We discuss Table 2.7 by comparing the invalid remarks between the core concepts. This provides insight into the course of the students' learning process and possible interferences in it. In line with the results presented in Table 2.5 concerning the number of students that mentioned each proposition correctly, here it also appears that students experienced more difficulties with the core concepts of biosynthesis and energy than with photosynthesis and cellular respiration. We will illustrate two remarkable scores from Table 2.7: the high numbers of remarks that indicated an invalid understanding at row T2/column Biosynthesis and row T3/column Energy.

The number 11 at T2/Biosynthesis means that slightly more than half of the students showed that they did not understand (aspects of) biosynthesis at the defining test. It is

Table 2.7 Numbers of students ($19 \leq n \leq 21$) who made a remark that indicated an invalid understanding of one of the core concepts.

	Core concepts			
	Photosynthesis	**Cellular respiration**	**Biosynthesis**	**Energy**
T1 Pre-test (n=20)	2	2	0	2
T2 Defining test (n=19)	1	1	11	4
T3 Conceptmapping (n=21)	0	0	6	18
T4 Writing assignment (n=20)	1	3	4	6
T5 Post-test (n=20)	2	0	2	1
T6 Final test (n=19)	1	3	1	2
Total	7	9	24	33

worth noticing that this does not indicate that the other students do understand biosynthesis. Apparently, the concept of biosynthesis is still difficult for students at the moment of the defining test, despite the time spent on it during the three previous lessons. An analysis of these 11 remarks indicating an invalid understanding of biosynthesis shows that most students wrote: "biosynthesis results in an increase of biomass." These students do not understand that the biomass does not increase when glucose (as an organic substance) is transformed into organic substances (carbohydrates, proteins or fats) during biosynthesis. Possibly, these students do not know what organic substances are.

The number 18 at T3/Energy means that almost all (groups of) students showed, in their concept maps, some invalid connections with the energy concepts. When analysing the concept maps, it is remarkable that heat is often connected to ATP ("ATP is heat") and energy, in a chemical form, to carbon dioxide ("Carbon dioxide is a form of chemical energy"). It seems that students understand that, for photosynthesis, energy from sunlight is needed; however, subsequently, they do not understand that this energy can be stored in a chemical form in a molecule from which it can become available.

2.5 Discussion

The central research question in this paper was: *To what extent do tenth grade students in senior general secondary biology education (havo-4) develop conceptual coherence in a lesson sequence based on the concept-context approach that aims to stimulate students to connect* *concepts?* According to this study, it appeared that a reference concept map can be used to categorise the propositions that students mention. Because some measuring moments occurred in a naturalistic setting, we found empirical evidence that the LT activities of concept mapping and writing indeed stimulate students to formulate correct propositions from the reference concept map. This also indicated which propositions are still difficult for students. In the reported case study, it appears that these propositions are related to the concepts of biosynthesis and energy. A problematic understanding of energy is also found in the literature (e.g., Lin & Hu, 2003). These difficulties were also observed when the remarks that showed an invalid understanding of core concepts were put into the right perspective. The lesson sequence that was investigated was still not fully developed and these findings inform the revision. After discussing the measuring method used (2.5.1), we point out how measuring conceptual coherence can contribute to the optimisation of lesson sequences based on the concept-context approach (2.5.2).

2.5.1 Usefulness, limitations and adaptations of the measuring instrument

The reference concept map has proven to be a valid instrument to operationalise the development of conceptual coherence. A basic assumption is that, when a student mentions propositions, this indicates how his or her conceptual coherence has developed. From the high degree of correspondence between the first and second raters, it can be concluded that the measurement of individual propositions can occur in an unambiguous way. This applies, to a lesser extent, to the correspondence between the first and second raters with respect to the recognition of remarks that show an invalid understanding of concepts. Therefore, these findings must be interpreted with sufficient caution. When measuring individual propositions as a measure of conceptual coherence, we should comment that this only provides information about the degree to which students are able to interconnect two concepts. By also analysing the degree to which students are able to mention a combination of propositions, conceptual coherence at a higher level could be determined.

By determining in advance which propositions from the reference concept map were intended and, subsequently, by collecting the propositions that were actually mentioned, we could—with some caution— compare measuring moments with each other. In that manner, we showed how students developed conceptual coherence. However, the results of the Spearman's rank correlation test did not point out correlations between the scores at the measuring moments that are significantly different. We only showed that the correlation between the scores at the measuring moments at which concepts were offered and students were required to write a text was higher than at the measuring moments in which no concepts were offered. Apparently, the way in which propositions are triggered influences the outcomes of the measurement. Also, Ruiz-Primo and Shavelson (1996) point out that measuring moments having a comparable task and type of response by students are necessary to determine the development of conceptual coherence.

The only findings that indicate a significant increase in conceptual coherence are based on a comparison between the identical pre- and post-tests. However, due to the lack of a standard, it is still difficult to value the percentage of 34% propositions that were mentioned correctly at the post-test. To establish a standard, an identical set of propositions should be elicited, with a comparable task, from large groups of students after different types of education. The students within a group should have comparable backgrounds and comparable capacities.

2.5.2 Optimising lesson sequences based on the concept-context approach

One of the purposes of education based on the concept-context approach is that students acquire more conceptual coherence. This case study was aimed at promoting the development of coherence between core concepts in biology. There was a focus on the way this coherence could be measured. We expect that the method we used to measure conceptual coherence will also to be very useful for other subjects in which knowledge is organised around concepts, such as the other natural sciences, history, geography, economics and social studies. After identifying remarkable (that is to say, propositions not mentioned as expected) learning outcomes, it could be checked in the research scenario how the particular propositions were integrated into the lessons. Indications could be sought that provide evidence about the ways that contexts and embedded LT activities can or cannot contribute to an increase in conceptual coherence. When a measuring moment coincides with an LT activity (like concept mapping or a writing assignment), such evidence could be provided. In such a case, reliable data are needed regarding the question of whether students relate concepts explicitly during concept mapping or writing. In this case, video- and audio recordings are necessary. In addition to these recordings, interviews in which students are allowed to explicate how they relate concepts or how they related concepts during preceding LT activities seem to be important. During these interviews, richer and more valid information about students' coherence in conceptual knowledge could be collected as a supplement to the often poor phrases that are used in written products. A study in which an interview strategy was used that confronted students with scientific phenomena in a variety of contexts also showed that interviews provide in depth information (Gomez, Benarroch, & Marin, 2006). The identification of the propositions from the reference concept map that one individual student mentions during the course of the lesson sequence could provide additional information about the factors that promote conceptual coherence.

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3

Designing and evaluating a context-based lesson sequence promoting conceptual coherence in biology*

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Abstract

Context-based education, in which students deal with biological concepts in a meaningful way, is showing promise in promoting the development of students' conceptual coherence. However, literature gives little guidance about how this kind of education should be designed. Therefore, our study aims at designing and evaluating the practicability of a context-based biology lesson sequence. Four design principles for conceptual coherence were defined: build upon familiar concepts; focus on core concepts; stimulate establishing connections between concepts; and reflect on these connections. These design principles have been elaborated into a lesson sequence about concepts related to cellular metabolism and the relevant connections between the concepts have been visualised in a reference concept map. The activities of teacher and students that were expected to contribute in establishing these connections were described in a research scenario. The lesson sequence was administered in a 10^{th} grade class of 21 students, aged 15-16, in senior general secondary education. Data were collected from video-recordings in the classroom. The observed activities of the teacher and students were compared with the intended activities. The findings show that a research scenario is a powerful tool to systematically evaluate the design and to provide information for improving it.

3.1 Introduction

Students experience difficulties in biology education because many concepts are counter-intuitive and abstract. This is one of the reasons why students of all ages and educational levels, despite the best efforts of teachers, fail to understand the conceptual foundation of key content areas of biology (e.g. Pearsall, Skipper, & Mintzes, 1997; Wandersee, Mintzes, & Novak, 1994). These students seem to be unable to connect biological concepts in a meaningful way, for instance when explaining natural phenomena (e.g. Donovan & Bransford, 2005; Songer & Mintzes, 1994). Apparently concepts are not coherently organised in their cognitive networks. In this study we refer to the term *conceptual coherence* as the condition of a person's cognitive network, which enables him or her to establish meaningful connections between concepts. The type and quality of these connections are dynamic: the situation determines which concepts are required and which connections between these concepts, named *propositions*, are more relevant than others (Scott, Mortimer, & Ametller, 2011).

To promote students' conceptual coherence context-based education is promising. Although in literature there is no conformity about the absolute meaning of context-based, these approaches generally aim to improve students' engagement by situating their learning of science in meaningful contexts (King & Ritchie, 2012). It has been shown that starting from a context helps students to give meaning to scientific knowledge, resulting in an improved attitude towards science (Bennett, Lubben, & Hogarth, 2007). Education in which concepts and contexts are offered in relation to each other, moreover, seems to help students to develop a cognitive network with more elaborate connections between concepts (Gilbert, 2006). Here we refer to a specific kind of context-based biology education that is currently receiving broad attention in Dutch educational reform: the concept-context approach (Boersma et al., 2007). This approach is rooted in the cultural historical activity theory (Vygotsky, 1987). According to this approach, contexts are representations of social practices; that is to say scientific, professional or life practices. Students perform goal-oriented activities to solve specific problems and deal with biological concepts from the perspective of participants of these social practices. This requires the transformation of appropriate social practices into contexts in such a way that the use of biological concepts, and especially establishing connections between these concepts, makes sense.

Current literature does not provide guidance about how a concept-context lesson sequence that aims to promote conceptual coherence should be designed. Our research project aims at providing guidelines for such a design and its evaluation. Therefore, we have adopted an educational design research approach (McKenney & Reeves, 2012). This article describes the first cycle of the iterative process and seeks to address the research question: *How should a concept-context-based lesson sequence aimed at promoting conceptual coherence be designed and evaluated regarding its practicability?* The construction of a research scenario (Lijnse & Klaassen, 2004) during the design process is innovative. This research scenario consists of a detailed prediction and theoretical justification of the hypothesised learning-teaching process. It shows systematically how and where design principles have been elaborated. The use of a research scenario makes it possible to evaluate the practicability of the design of the lesson sequence in detail and to reflect on each elaboration of each of the design principles. Although literature often poorly describes what actually happened in the classroom and what the role of the teacher was (Leach & Scott, 2002), we believe that this information is essential to understand how and why learning-teaching theories work in practice. Evaluating the effectiveness of the design in terms of students' learning outcomes is a further step, however, beyond the scope of this article.

The structure of this article is as follows. Information is given on three (simultaneous) steps of the design procedure: defining design principles, defining learning objectives in terms of propositions in a reference concept map, and selecting contexts. The way in which these three steps led to the design is then illustrated in a part of the lesson sequence. The methodology section describes how a research scenario was used to evaluate how this lesson sequence was carried out. Each activity of the teacher and students was scored with regard to how well it was performed compared with the intended performance. The interpretation of these scores was used to evaluate the practicability of the design and subsequently to improve the design. Finally, we discuss the role of the research scenario in future research.

3.2 Design procedure

3.2.1 Defining design principles

Design principles are used to guide the design of an intervention. Here, the intervention is a biology lesson sequence based on the concept-context approach that aims to improve students' conceptual coherence. Based on literature and an explorative case study, the following four design principles were formulated.

1. *Build upon familiar concepts*. There is general agreement that attention for previously acquired conceptual knowledge is a prerequisite for conceptual development (Bransford, Brown, & Cocking, 2000; Novak, Mintzes, & Wandersee, 2005). Therefore, when a context is introduced in the classroom the initial focus should be on concepts with which students are expected to be familiar from prior education or personal life. If students are allowed to address their notions about these concepts, limited or incorrect ideas can be made visible and even be changed. Subsequently, these familiar concepts could function as "stepping stones" to connect to core concepts that are more inclusive and essential to understand a wide range of natural phenomena.

2. *Focus on core concepts*. Many concepts may be involved in the social practice represented in the context; for instance specific concepts that participants use to communicate with each other. Students might be confused by an overload of concepts. Therefore, it is essential that the design of the context contains only those concepts that are really necessary to understand what happens in the authentic social practice. The context should be designed in such a way that students' learning is guided in the direction of underlying core concepts that belong to the conceptual structures intended by the curriculum. A problem posing approach (Klaassen, 1995) could be useful to introduce these core concepts step by step in a logical, interrelated order.

3. *Stimulate interconnecting concepts*. Students should be stimulated to interconnect concepts actively and frequently. This calls for learning-teaching (LT) activities that trigger students to formulate propositions, such as concept mapping (Nesbit & Adesope, 2006), writing assignments (Keselman, Kaufman, Kramer, & Patel, 2007) and teacher questioning (Chin, 2007). One way to structure these LT activities within a context is by aligning them with "authentic" activities that participants perform in social practice. An important element of such LT activity is that students' conceptual thinking is made visible. This facilitates productive interactions about the quality of established connections. During these interactions the teacher scaffolds the learning process, for instance by giving adequate feedback on the way in which connections have been established.

4. *Reflect on meaningful connections between concepts*. When students learn concepts within one context, they might not be able to transfer these concepts to other contexts (Bransford et al., 2000; Wierdsma, 2012). Therefore, students need support to be able to reflect upon how concepts have been connected within one context or to compare these connections between two or more contexts. This metacognitive approach can promote the flexibility of students' cognitive networks.

3.2.2 Defining learning objectives

A lesson sequence was designed specified to the following three domain-specific core concepts: photosynthesis, cellular respiration and biosynthesis. Knowledge of these processes plays a crucial role in a meaningful appreciation of life. The ability to trace matter (carbon) and energy through these three processes prepares students to participate in evidence-based discussions about socio-ecological systems (Mohan, Chen, & Anderson, 2009). Even though education has given extensive attention to these processes (e.g. Ross, Tronson, & Ritchie, 2006), only few students reach the ability to trace matter and energy through hierarchically organised systems at the end of secondary school (Mohan et al., 2009). This is supported by the conceptual difficulties that have been reported in literature, indicating that this topic is one of the most difficult conceptual areas in biology. Three main difficulties are:

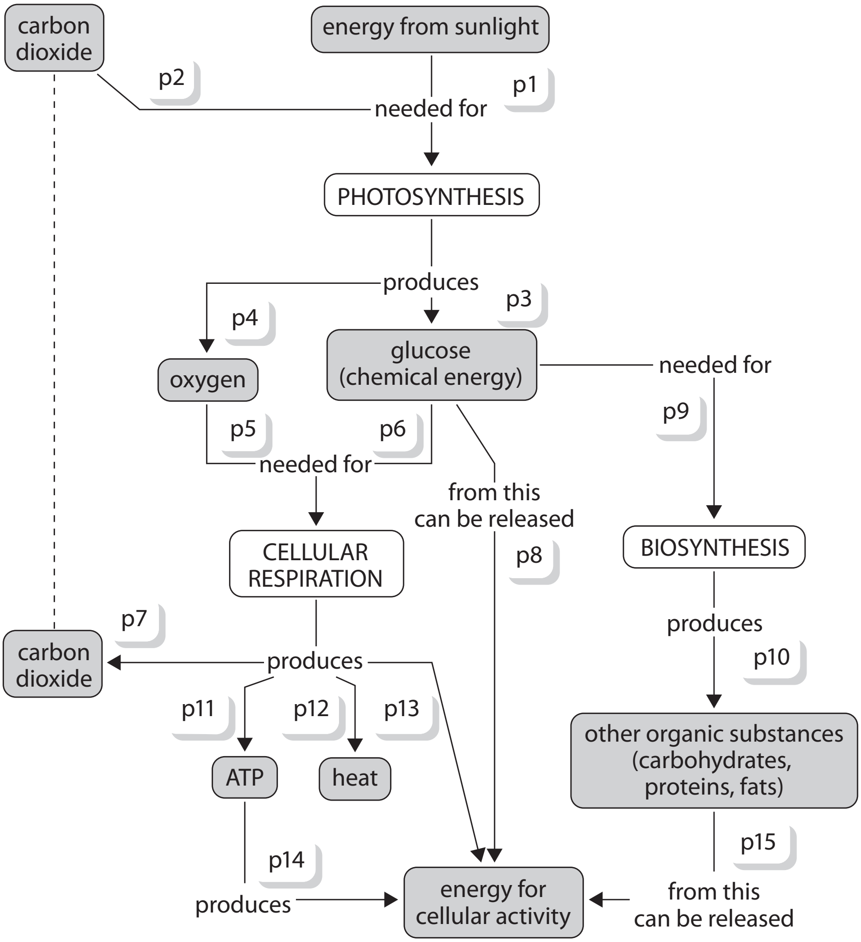
- Students do not understand cellular processes: they consider photosynthesis and cellular respiration as exactly opposite processes or solely as “gas exchanging” processes (Cañal, 1999).
- Students are not used to seeking explanations at the cellular or sub-cellular level of organisation when they explain biological phenomena (Songer & Mintzes, 1994).
- Students are not able to link the living world to the non-living world. They often do not grasp the idea that energy can be captured, transferred or released and chemical elements (like carbon) can be transformed in a cyclic way from one molecule to the other (Lin & Hu, 2003).

Based on these problems, learning objectives were defined in terms of propositions that have been visualised in a concept map (see Figure 3.1). Because each single proposition was regarded as a learning objective, the concept map functioned as a point of reference and was called the reference concept map. The focus in this reference concept map is on the relations between the three processes, especially on the transformation of matter (carbon and oxygen) and energy. To specify how energy is captured, transformed and released and how oxygen and carbon are transformed, eight additional basic concepts were selected. Basic concepts are more descriptive and less inclusive than core concepts. These basic concepts are: energy from sunlight; heat energy; energy for cellular work; ATP; glucose; carbon dioxide; oxygen; and other organic substances (referring to proteins, carbohydrates and fats). Less relevant basic concepts for this specification such as water, minerals, and biomass, were omitted.

3.2.3 Selecting contexts

We selected four contexts that are representations of authentic social practices, according to the following characteristics: their recognisability for students; their potential to integrate LT activities that promote conceptual coherence; and their possibilities for embedding concepts and propositions from the reference concept map. In each of the next contexts, the perspective of an “authentic person” was chosen. Students were instructed to perform activities which dealt with concepts and propositions from the reference concept map (see Figure 3.1).

- In the first “family” context, students have to reflect on a role play in which family members take different perspectives and argue about the consumption of meat and plant substitutes. This is expected to be a recognisable context from everyday life that engages students in environmental consequences of (their own) protein consumption.
- In the second context, students have to calculate and compare carbon dioxide emissions during the production of various protein-rich food products from the perspective of an environmental advisor. Although most students might not be familiar with this profession, they may recognise that these activities contribute to



3

Figure 3.1 Reference concept map.

The relations between three core concepts (white boxes) and eight basic concepts (grey boxes) with an emphasis on matter and energy transformation are presented by proposition codes p1 to p15.

solving the main problem from the previous context. Moreover, the core concepts can be embedded in this context and there are possibilities to focus on explanations at the cellular level of organisation.

- In the third context, students have to examine how the three metabolic processes are involved in the growth of plants that produce protein-rich lupine beans, as an alternative to the production of animal proteins in meat, from the perspective of a plant (or agricultural) researcher. It is expected that this scientific practice will be recognisable and that experiments with plants are challenging.
- In the fourth context, students have to explain why consuming insects is better for the environment than consuming farm animals, from the perspective of a restaurant owner who promotes sustainable food. This context is expected to be fairly recognisable and suitable to connect the core concepts again in a (guided) writing assignment.

3.2.4 Design illustration

We now illustrate how the four design principles were elaborated in part of the lesson sequence. These elaborations concern the first and second context; elaborations of design principles in the third and fourth contexts are not reported here due to limited space. At the beginning of the lesson sequence a role play is conducted by five students in which a family discusses arguments pro and contra the consumption of meat. In a final classroom discussion it should be concluded that consuming meat has an impact on the environment. This should be presented as a problem, resulting in the guiding question: *Are we still allowed to consume meat?* There should be a focus on concepts with which students are expected to be familiar: carbon dioxide (in relation to greenhouse gas) and proteins (as an essential nutrient for humans). Students' notions about these concepts have to be shared and corrected if erroneous. Explicating these familiar concepts in order to build on them when introducing new concepts, is an elaboration of *design principle 1*. Then the role of the environmental advisor is introduced. This person examines the problem, taking the consequences of protein-rich food production for the greenhouse effect into account. The teacher helps students to link the concept of the greenhouse effect to carbon dioxide emission and subsequently to the core concepts of photosynthesis and cellular respiration. These relations refer to the propositions p2 and p7 as indicated in the reference concept map. Focusing the context on underlying core concepts is an elaboration of *design principle 2*. Next, an LT activity should be introduced in which students are stimulated to formulate propositions. This is an elaboration of *design principle 3*. Students have to write down the chemical equations of photosynthesis, cellular respiration, and biosynthesis while they cooperate in small groups and use information from the manual. In this LT activity, propositions p1 to p7 and p9 to p11 are relevant. The teacher should ask questions and give feedback on request. Finally, each group's outcome is shared in a whole-class discussion. Next, students should perform activities from the perspective of an environmental advisor: they have to calculate for different protein-rich products how much carbon dioxide is emitted to produce a certain quantity of these products. The results should show that more carbon dioxide is emitted for the production of animal proteins (meat) than for the production of the same amount of plant proteins. In a final whole-class discussion these results should be explained by mentioning propositions of the reference concept map. The production of proteins in both plant cells and animal cells has to be linked to glucose by mentioning biosynthesis, referring to the propositions p9 and p10. The production of glucose has to be linked to the use of carbon dioxide by photosynthesis in plant cells, referring to the propositions p2 and p4. The production of carbon dioxide has to be linked to the use of glucose by cellular respiration in both plant and animal cells, referring to the proposition p6 and p7. This reflection on the use of these propositions within the context is an elaboration of *design principle 4*. Before proceeding to the next context (a plant researcher) there should be discussion of how the activity from the perspective of the environmental advisor contributes to answering the guiding question.

3.3 Methodology

3.3.1 Sample

The lesson sequence, containing 11 lessons, was administered in two 10th grade biology classes (class A and class B) in senior general secondary education. This type of education prepares students for studies at a university of applied science. The school is located in a semi-rural area in the east of the Netherlands. The teacher, who is specialised in teaching students in general secondary education, has about 15 years of teaching experience and can be qualified as a competent biology teacher. Each lesson conducted in class A was discussed with the teacher by the first author in order to clarify the intended teaching approach and to prepare him for conducting the same lesson in class B. Data from class B, composed of 21 students, aged 15-16, are presented here. To indicate the abilities of these students we compared their average biology grades over one year with those of students from a parallel biology class. The class that was the subject of this study scored on a scale of 1 to 10, an average grade of 6.19 (SD = 0.75), while the parallel class scored an average grade of 6.22 (SD = 0.90). This is not significantly different at a 95 % confidence interval: $t(42) = 0.11$; $p = .915$. All students were familiar with education according to the concept-context approach. Before the lesson sequence, many students were able to reproduce the chemical equation of photosynthesis which was taught in grade 9. However, when these students were asked to explain *how plants generate energy for life processes* almost none of the students were able to mention photosynthesis and related propositions in their response.

3.3.2 Research scenario and data analysis

The research scenario was developed simultaneously with the design of the lesson sequence. This research scenario described in detail the function of each episode and the intended activities of teacher and students (see Table 3.1). Data from video-recordings in the classroom were transcribed verbatim and analysed by evaluating to what degree the activities of teacher and students were performed as intended according to the research scenario. In this article, data from two consecutive lessons are presented. For each activity, one of the following scores was assigned: positive (+), if the intended activity was recognised in the transcripts; negative (-), if the intended activity was not recognised; and intermediate (±) if the intended activity was partially recognised. A second researcher followed the same procedure to determine if these scores were unambiguous. The agreement between the two researchers could be characterised as moderate to substantial (Cohen's kappa = .58). Because the researchers disagreed when assigning scores to four consecutive activities (one researcher assigned a positive score, the other an intermediate score), the Cohen's kappa could have been higher if the conditions to assign the intermediate scores had been defined more precisely. Alongside the scoring procedure, qualitative information from the transcripts was added in order to provide an interpretation of the scores.

3.4 Results

Table 3.1 shows the scores that indicate how teacher and student activities were evaluated: the degree to which the activities were performed according to the intention in this part of the research scenario.

3.4.1 Interpretation of scores

Explanations of the scores will be given with illustrations from the transcripts. The intended goal of episode 1 was to link the first context to concepts with which students were expected to be familiar and to focus on these concepts, namely carbon dioxide and proteins. The activities of fragment 1.1, in which it was intended that the teacher would focus on a specific problem, were scored positively. This is illustrated by the transcript, in which the teacher asked the question: "How could you tackle the problem concerning the greenhouse effect and reduce the amount of greenhouse gas?" Students responded: "by consuming less meat" (student 7); "by eating other animals than cows and pigs" (student 18). This is an indication that students reason at a macroscopic scale. They do not yet attempt to trace matter, such as carbon dioxide as a greenhouse gas, through metabolic processes at the cellular level of organisation. In fragment 1.2 it was intended that the teacher would focus on biological concepts that sound familiar to students and that can be related to the core concepts. This activity was scored positively. This is illustrated by the teacher's remarks in the transcript: "The problem is that organisms produce carbon dioxide" and “Proteins in meat are an important source in the food of humans”. Next, in fragment 1.3 it was intended that the teacher would stimulate students to share their initial notions about the concepts carbon dioxide and proteins. These activities received intermediate scores. The transcript showed that these activities were performed but not at the intended moment. Only after episode 3 did the teacher ask: “what is the function of proteins?’ and “what does it mean, a kilogram carbon dioxide as a gas?” These questions led students to mention some of their notions, as indicated by the positive scores. However, students’ responses did not show that they were triggered to link these familiar concepts to metabolic processes in cells. It is likely that more questions with a clear focus are required to prompt students to consider the notion that carbon dioxide and proteins are produced in cells.

In the second episode, it was intended that the teacher would explain why environmental advisors calculate carbon dioxide emissions in order to solve the aforementioned problem. The activities of fragment 2.1 were scored positively. The transcripts showed that the teacher mentioned the relations between carbon dioxide emissions and the production of protein-rich food products. Thereafter, in fragment 2.2, it was intended that the teacher would emphasise the need for environmental advisors to possess biological knowledge. This activity received one intermediate score. The teacher commented: “so it is clear that environmental advisors need biological knowledge, otherwise they can’t give advice”. It is doubtful if this remark legitimises why the environmental advisor needs to possess biological knowledge and creates a motive for learning. Then, it was intended that the teacher would give a short overview of the metabolic processes of cellular respiration and photosynthesis. This was scored positively. Negative scores were attributed to the last fragment of episode 2.2, in which it was intended that the teacher would connect carbon dioxide to both these metabolic processes by focusing on these propositions. The transcript showed that the teacher did not connect carbon dioxide to the core concepts of photosynthesis and cellular respiration.

The intended goal of the third episode was that students would interconnect concepts actively by reading a text, interacting in groups and writing down chemical equations. The positive scores for both teacher and student activities in fragment 3.1 indicated that the students understood the instructions of the teacher. However, the task appeared to be difficult: translating a text with many chemical terms into a schematic notation was problematic. One student mentioned: “so if plants can produce carbon dioxide, then photosynthesis must produce carbon dioxide” (student 16). During the final whole-class discussion it was intended that the teacher would stimulate students to mention the correct propositions. All activities in fragment 3.2 were scored positive/ intermediate. The transcripts showed that the teacher mentioned the first part of the proposition by asking a question—“what is needed for cellular respiration”—and one of the students responded by mentioning “glucose” (student 5), whereupon the teacher asked “and what else?”. Apparently, students were not stimulated to mention a complete proposition on their own.

Table 3.1 Part of research scenario including the evaluation of activities

Episodes Elaborated design principles	Fragment	Intended activities of teacher	Score	Intended activities of students	Score
Episode 1 Design principle 1: build upon familiar concepts. In a classroom discussion the teacher and the students reflect on the conducted role play about a family discussing arguments pro and contra the consumption of meat. The teacher concludes that there is a problem resulting in the guiding question: *Are we still allowed to consume meat?* (1.1) To answer this question from an environmental perspective, the teacher focuses on the involvement of biological concepts with which students are expected to be familiar: carbon dioxide and proteins (1.2). Students' prior knowledge regarding these concepts is shared (1.3). Estimated duration: 5 min.	1.1	Concludes that consuming meat has an impact on the environment. Poses this as a problem and formulates guiding question.	+ / + + / +	No relevant observable behaviour No relevant observable behaviour	
	1.2	Links the problem to biological concepts with which students are expected to be familiar: carbon dioxide and proteins.	+ / +	No relevant observable behaviour	
	1.3	Evokes notions about proteins. Evokes notions about carbon dioxide.	± / ± ± / ±	Respond and share initial notions. Respond and share initial notions.	+ / + + / +
Episode 2 Design principle 2: focus on core concepts The teacher introduces the environmental advisor and how this person seeks to solve the given problem (2.1). Moreover, the teacher explains why biological knowledge is essential for this person. Then he explains the relationship between carbon dioxide and both photosynthesis and cellular respiration (2.2). Estimated duration: 5 min.	2.1	Introduces work of environmental advisor. Explains how the advisor contributes to solving the problem by examining the impact of different protein-rich food products on the environment.	+ / + + / +	No relevant observable behaviour No relevant observable behaviour	
	2.2	Emphasises why an environmental advisor needs specific biological knowledge. Gives a short overview of relevant metabolic processes: photosynthesis and cellular respiration. Links carbon dioxide to these processes by mentioning p2 and p7.	+ / ± + / + - / - *	No relevant observable behaviour No relevant observable behaviour No relevant observable behaviour	

Episode 3 Design principle 3: stimulate to interconnect concepts. The students read background knowledge of an environmental advisor. They interact and translate this information to chemical equations (3.1). The final whole-class discussion focuses on mentioning correct propositions (3.2). Estimated duration: 20 min.	3.1	Instructs students to read text, to write down chemical equations and to discuss this in groups of three.	+/ +	Interact in group and mention propositions.	+ / +
	3.2	Stimulates students to mention propositions (p1-p7 and p9-p11) in a classroom discussion.	+ / ±	Mention propositions that describe: cellular respiration (p5-p7, p11) photosynthesis (p1-p4) biosynthesis (p9 and p10).	 + / ± + / ± + / ±
Episode 4 Design principle 4: reflect on the use of propositions. Students calculate how much carbon dioxide is emitted for the production of protein-rich food products. The results show that carbon dioxide emission is higher for the production of animal proteins (meat) than for plant proteins (4.1). In a final whole-class discussion they seek an explanation by referring to cellular metabolic processes and mentioning propositions. Proteins can be linked to glucose (biosynthesis) and glucose can be linked to carbon dioxide (photosynthesis and cellular respiration). Finally, the results of the calculations are used to answer the aforementioned guiding question (4.2). Estimated duration: 20 min.	4.1	Shows students a table with carbon dioxide emissions for different food products and gives instruction for the activity from perspective of environmental advisor.	+ / +	Perform activity in groups of three and calculate carbon dioxide emissions.	+ / +
	4.2	Makes an inventory of calculations and summarises findings. Triggers students to explain results of calculations by mentioning propositions. Asks how the results of the calculations contribute answering the guiding question (are we still allowed to consume meat?)	+ / + - / - ** + / +	Participate by checking their work. Mention some of the propositions: p9 and p10, p2 and p4, and p6 and p7. Mention that when humans consume plant proteins instead of animal proteins, less carbon dioxide is emitted.	+ / + - / - ** ± / ±

Note: The four design principles were elaborated in four subsequent episodes that are divided into fragments. The degree to which teacher and student activities in each fragment were performed as intended was scored. The scores of two researchers (divided by /) are presented as follows: a positive score (+) when an activity was observed as intended, a negative score (-) when an activity was not observed as intended, and an intermediate score (±) when an activity was partially observed as intended. Double negative scores (- / -) are explained in the footnote.

* The teacher simply did not mention the connection between carbon dioxide and the core concepts of photosynthesis and cellular respiration.

** The teacher tried to trigger students to explain the results of calculations and one of the students mentioned that carbon dioxide emission are lower when less meat is consumed. However, the teacher did not trigger students to shift their locus of explanation to the cellular level of organisation. As a consequence students did not mention propositions in relation to the core concepts of biosynthesis, cellular respiration and photosynthesis.

The fourth episode started with activities in which students had to calculate carbon dioxide emissions for the production of protein-rich products. The intended goal of this episode was that the results would be explained by mentioning propositions and, finally, to reflect on the functional use of these propositions. The positive scores of teacher and student activities in fragment 4.1 indicate that the task was clear for students. After this, the calculations were shared in classroom; these activities were also scored positively. The teacher asked students to explain the results of the calculations. However, the negative scores for the next activity of fragment 4.2 indicate that he did not trigger students to reason at the cellular level of biological organisation and to mention propositions which include the metabolic processes. The transcript showed that the teacher asked: "how could you explain that these food products produce so much carbon dioxide?" whereupon a student responded "because these food products are meat" (student 4). Remarkably, the teacher did not ask a follow-up question focusing on the propositions. The last teacher activity of fragment 4.2 was scored positively. The transcript showed that the teacher tried to link the results of the calculations to the guiding question. He asked: "to reduce the greenhouse effect, what would be the consequence for the choice of protein-rich food products?" The response of the students was scored intermediate. After the teacher repeated the question one of the students responded: "by eating less meat".

3.5 Discussion

The central research question in this article was: *How can a concept-context-based biology lesson sequence that aims to promote conceptual coherence be designed and evaluated regarding its practicability?* This research has shown that design principles are useful to structure contexts and align them with learning objectives for conceptual coherence. These learning objectives were made explicit by constructing a reference concept map containing propositions. This alignment was made visible in a research scenario that systematically and accurately describes how the teacher should act to generate student activities that are expected to promote their conceptual coherence. The research scenario proves to be an appropriate tool to score the degree of correspondence between actual and intended activities. It was shown that in seeking explanations of the scores, detailed information on the teaching-learning process and aspects that seem to promote or hinder the development of conceptual coherence is generated. Below, an example of how the design can be adapted is given for each episode.

3.5.1 Proposed adaptations of design

From the evaluation of the first episode it became clear that students were engaged in the context and reason at a macroscopic scale, but that they were not used or not able to reason from a biological perspective and use biological concepts at other biological levels of organisation. This corresponds with results from literature (e.g. Songer & Mintzes, 1994). Because this was more or less expected the familiar basic concepts (carbon dioxide and proteins) were introduced first in order to guide students to more abstract core concepts. Although attention was paid to these familiar concepts, the questions being asked did not prompt students to link the familiar basic concepts to processes at the cellular level and the related core concepts. This means that the teacher should be provided with a set of questions that help students to broaden their thinking to processes at the cellular level of organisation. A possible questioning strategy for the teacher to use here is *Socratic questioning*, in which the teacher provides scaffolding through asking guiding questions to advance students' thinking (Chin, 2007).

In the second episode, the teacher did not mention propositions in relation to the familiar basic concept of carbon dioxide. We propose that during the preparation of lessons the reference concept map functions as a road map, in which the concepts and propositions that need to get attention at a specific moment are marked. This supports the teacher in focusing on concepts and propositions that are relevant within a context. Moreover, because the teacher did not focus on carbon dioxide in the first episode, the need to discuss where this molecule is produced and how this relates to metabolic processes in cells did not occur in the second episode. Therefore, it is essential that the teacher does not deviate from the intended sequence in which concepts are introduced. Structuring the context according to a problem-solving approach (Klaassen, 1995), in which a problem has to be solved step by step is useful for focusing on the core concepts.

In the third episode students were successfully triggered to mention concepts and to discuss how to formulate correct propositions. Since translating text to chemical notations appeared to be difficult and the metabolic processes of photosynthesis and cellular respiration appeared to be confusing, which corresponds to the results from literature (e.g. Cañal, 1999), we propose that an incomplete schematic picture of a plant cell and an animal cell is more supportive for the task. It is essential that in both cells mitochondria, and in plant cells chloroplasts, are depicted. This can help students to discuss how to connect the processes of photosynthesis and cellular respiration to each other and the role of carbon dioxide in here. Moreover, when students complete such visualisation, the teacher can observe students' misconceptions effectively and provide immediate support if necessary. This also generates opportunities for the teacher to differentiate between groups or individual students, for instance by providing hints for "slower" students and challenging supplements to the assignment for "faster" students.

The fourth episode made clear that the context-related activity, in which students had to calculate carbon dioxide emissions, did not necessarily lead students to explain the results by using core concepts. This activity, which corresponds closely to authentic activities in the professional practice of an environmental advisor, appears inadequate to turn to metabolic processes and to reflect on the use of relevant propositions. This activity should be replaced. An activity in which students are challenged to establish propositions more easily, and in which they are triggered to reflect on these propositions, is recommended. This could be a writing task in which students have to write advice from the perspective of an environmental advisor.

3.5.2 Role of research scenario in future research

A research scenario is a powerful tool to evaluate the practicability of a design. For the next cycle of our research project, it is essential that we evaluate the effectiveness of the interventions and determine to what degree and how the design and the way in which it is administered in the classroom contributes to the learning outcomes. Therefore, it has to be indicated in the research scenario how each activity is aimed at the learning of specific concepts. Constructing the research scenario in this way can also be guiding for the selection and design of assessment tools. We expect that a structured interview (Southerland, Smith, & Cummins, 2005) is an appropriate assessment tool because it provides an opportunity to gain a well-grounded understanding of students' conceptual coherence. Because the research scenario relates the intended learning outcomes to classroom activities and underlying design principles, data from structured interviews will also provide valuable information about how learning-teaching theories work in practice.

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4

Promoting conceptual coherence within context-based biology education*

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Abstract

In secondary science education, the learning and teaching of coherent conceptual understanding are often problematic. Context-based education has been proposed as a partial solution to this problem. This study aims to gain insight into the development of conceptual coherence and how learning-teaching activities within a context-based lesson sequence can promote this. We describe a case study in which a lesson sequence consisting of three contexts about protein-rich food production was designed and conducted in a tenth-grade biology class. The conceptual framework consisted of the transformation of energy and matter in photosynthesis, cellular respiration and biosynthesis. All relevant concepts and their interconnections (propositions) were captured in a reference concept map. A research scenario was used to evaluate if the lesson sequence was conducted as intended. Learning outcomes were determined by analysing written products on the occurrence of propositions from the reference concept map. Additional interviews provided insight into the development of conceptual coherence in relation to eight context-embedded learning-teaching activities. The results indicated that students showed an improvement in mentioning propositions from the reference concept map. Propositions relating metabolic processes and including forms of energy were still difficult. Finally, design principles for promoting conceptual coherence within contexts are specified.

4.1 Introduction

Research on learning and teaching natural sciences has shown that students' conceptual knowledge at all educational levels is often incoherent (e.g. DiSessa, Gillespie, & Esterly, 2004; Wandersee, Mintzes, & Novak, 1994). This is reflected by students' inability and inconsistency to retrieve and connect concepts: for example to explain or predict natural phenomena and events. Moreover, students have difficulties transferring concepts to other situations than the one in which they were learned (Bransford, Brown, & Cocking, 2000b). Because traditional teaching and learning approaches are often inappropriate in terms of helping students to assimilate coherent frameworks of concepts, an international trend towards context-based education has developed in science education (e.g. Gilbert, 2006).

Context-based approaches generally aim to improve students' engagement by situating the learning of science in contexts that represent the real world (King & Ritchie, 2012). This helps students to appreciate the role science plays in their own lives and in society. Because various concepts come together within a context and reappear in other contexts, they are assumed to provide the basis for the development of coherent mental maps of the relationships between them (Gilbert, 2006). In this paper, we refer to the term *conceptual coherence* as the ability of a person's cognitive network to establish meaningful connections between concepts.

Up to now, there has been limited empirical evidence that proves that context-based education has a significant impact on the development of students' conceptual coherence (Bennett, Lubben, & Hogarth, 2007). Tsai (2000) found that a Science-Technology-Society (STS) instructional approach, similar to a context-based approach, improved the extent, richness and connectivity of students' cognitive structures compared with traditional teaching. Barker and Millar (2000) found in a longitudinal study on the Salters Advanced Chemistry course that a gradual introduction and revisiting of chemical ideas in different contexts appeared to have a significantly positive impact on the learning outcomes of a high proportion of students. Although these findings indicate that context-based courses can facilitate the development of students' conceptual coherence, the underlying mechanism that describes how this development proceeds still needs to be unravelled (Gilbert, Bulte, & Pilot, 2011; Pilot & Bulte, 2006). Therefore, identifying the principles underlying LT activities that foster the development of students' conceptual coherence is regarded as one of the major challenges in research on context-based science education. In response to this challenge we have adopted a design research approach (McKenney & Reeves, 2012; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). In this paper we describe a case study that focuses on the design and evaluation of a context-based lesson sequence. Specific attention is paid to a two-step evaluation procedure which provides profound insight into the teaching and learning processes. First, the lesson sequence is evaluated on its *practicability*. It is determined to what extent the lesson sequence is conducted as intended. The methodological approach is built on a previous study within our research project in which we described how a research scenario was used to compare the intentions of the design with the way in which it was enacted in the classroom (Ummels, Kamp, de Kroon, & Boersma, 2014). Second, the lesson sequence is evaluated on its *effectiveness*. It is determined to what extent students' conceptual coherence has developed. Therefore, it is built on another study within our research project in which it was shown that determining changes in mentioning concepts and propositions from a reference concept map during a lesson sequence gives information about their development of conceptual coherence (Ummels, Kamp, de Kroon, & Boersma, 2013).

The learning goals of the lesson sequence are aimed at a conceptual framework in the domain of biology that is complex and difficult to learn and teach: transformation of energy and carbon-substances in photosynthesis, cellular respiration and biosynthesis (Amir & Tamir, 1990; Brown & Schwartz, 2009; Cañal, 1999; Lin & Hu, 2003; Mohan, Chen, & Anderson, 2009). This conceptual framework is embedded in contexts that are related to the social and scientific debate on the impact of protein-rich food production on the environment (McMichael, Powles, Butler, & Uauy, 2007). It is important that a context is defined as a representation of "an authentic community of practice within society" wherein students, supported by the teacher, work collaboratively on relevant tasks in a problem-centred way for a sustained period (Gilbert et al., 2011). During these tasks they are expected to deal with biological concepts and to establish relationships between these concepts. Our aim is to explore how students' conceptual coherence develops in order to contribute to optimising context-based science lesson sequences in general. Such information will be valuable for educational researchers who examine how context-based lesson sequences work in practice, educational designers of similar context-based lesson sequences in similar settings, and teachers who conduct these lesson sequences. Consequently, we address the following two research questions:

1. *How does students' conceptual coherence develop during a context-based lesson sequence*?
2. *How do context-embedded learning-teaching activities influence the development of conceptual coherence?*

4.2 Theoretical framework

4.2.1 Conceptual learning

This research is built on the theory that concepts are fundamental units of knowledge and that learners do not store these concepts as isolated bits of information but form connections between concepts (Ausubel, 1968). Conceptual learning occurs when a new concept is assimilated actively and meaningfully in someone's cognitive structure. This is also one of the basic assumptions of constructivist approaches on learning (Ogborn, 1997). This implies that a new concept is connected to one or more relevant available concepts. This process proceeds when more elaborate connections are established between two or more concepts (Mintzes, Wandersee, & Novak, 2005). So, the more connections (or cognitive pathways) there are established between concepts, the greater the chance of retrieving these concepts. Studies on expert learning showed that an easy retrieval of concepts is supported by a systematic or hierarchical organisation of concepts in cognition because memory easily "travels down" these well-worn pathways (Fisher, 2001). Moreover, a more coherent organisation of conceptual knowledge enables experts to represent and solve new problems more successfully than novice learners (Bransford, Brown, & Cocking, 2000a). One characteristic of this coherent conceptual organisation is the presence of inclusive or core concepts that structure other, often more descriptive, concepts.

4.2.2 Context-based biology education

There are many variations in the definition of context-based approaches in science education (King & Ritchie, 2012). Here, we focus on a specific form of context-based education in the domain of biology that is currently focus of Dutch educational reform: the concept-context approach (Boersma et al., 2007). This approach is rooted in the cultural historical activity theory (Vygotsky, 1987). In this approach contexts are defined as representations of existing scientific, professional or real-life practices. To engage students in contexts it is necessary for suitable social practices to be transformed for classroom use in such a way that students experience them as relevant. This happens when students recognise the perspective of participants of such a social practice or imagine themselves as these participants. From this perspective they perform goal-oriented activities in which they enter into a *cognitive apprenticeship* with the teacher. The teacher demonstrates how a context and its activities might be interpreted, being aware of the *proximal development zone* of individual students. During this process it is assumed that conceptual learning takes place. Finally, relevant concepts are summarised and their meaning in the given context considered. The different, often subtle, meanings of a concept in two or more contexts can be compared. This facilitates the process of recontextualisation, which means that a concept is transferred from one context to another (Van Oers, 1998).

4.2.3 Design principles

Four design principles, specific to the concept-context approach, were used to steer the design of a lesson sequence. Following van den Akker et al. (2006) these design principles are defined and formulated as theoretically and empirically grounded constructs (substantive knowledge), linking strategies (procedural knowledge) with intended pedagogic effects. In the following formulations, where possible, we refer to findings of a previous case study within our research project (Ummels et al., 2014).

Building upon familiar concepts. In line with constructivist approaches to learning and teaching, attention to previously acquired (conceptual) knowledge is a prerequisite for learning new concepts (Novak, Mintzes, & Wandersee, 2005). This implies that when a context is introduced in the classroom the initial focus should be on concepts with which students are expected to be familiar from personal life or prior education. Our previous case study showed that a role play followed by a classroom discussion is a good LT activity for introducing such concepts and sharing notions about these concepts. Subsequently, these concepts can function as “stepping stones” to introduce new concepts. The questions asked by the teacher are important in scaffolding students to widen their thinking from the concepts they are familiar with to new concepts.

Focusing on core concepts. Studies on expert learning have shown that experts organise their knowledge around core concepts that guide their thinking (Novak & Cañas, 2008). Introducing core concepts in a drip-feed manner in different contexts and constantly reinforcing them in different ways seems to be a fruitful learning and teaching strategy (Barker & Millar, 2000). Our previous case study also provided indications that a problem-posing approach (Klaassen, 1995), in which a context-related problem is solved in a guided step-by-step fashion, could be a useful strategy for creating a motive to focus on core concepts within a context.

Stimulating students to interconnect concepts. When students are stimulated to interconnect concepts actively and frequently it is expected that their cognitive connections between these concepts will be reinforced (Fisher, 2001). This calls for LT activities that prompt students to formulate propositions in a social environment, such as concept-mapping in groups (Nesbit & Adesope, 2006), writing assignments about real-life topics (Keselman, Kaufman, Kramer, & Patel, 2007) and classroom conversations in which the teacher poses questions that engage with students’ thinking (Chin, 2007). One way to embed those LT activities within a context is to align them with activities that participants perform in an authentic social practice from which a context is derived. In the previous case study, it became clear that mainly the interactive moments during these LT activities stimulated students to mention propositions.

Reflecting on conceptual relationships within a context. Learning to recontextualise concepts from one context to another is assumed to enhance conceptual coherence (Van Oers, 1998). Recontextualisation requires that students are supported to reflect on the inter-relationships of concepts within a context (Wierdsma, 2012). The previous case study showed that if there was no need for students to reflect on propositions within a context this resulted in a teacher-guided non-interactive recapitulation of concepts and propositions. Therefore, it can be useful to start a reflective period by emphasising the perspective(s) of participants in an authentic social practice from which the context is derived. This could generate a need for students to reflect on the way in which they deal with concepts and propositions within a context. In addition, a problem-posing approach, (Klaassen, 1995) in which an overarching context-related problem has to be solved, could provides a reason to reflect on conceptual relationships. Interactive classroom conversations and writing assignments seem suitable LT activities for elaborating this design principle.

Although there is no prescribed order in which these design principles should be applied it seems natural that the first design principle is elaborated at least at the beginning of a context and the fourth design principle at least at the end of a context. For the purpose of this article we focus on LT activities of a context-based lesson sequence in which one of the four design principles is elaborated more prominently than the others.

4.3 Methods

4.3.1 Reference concept map

One way to represent the conceptual relationships within the cognitive structure of a learner is to make use of concept maps (Novak & Cañas, 2008). A concept map is a graph consisting of concepts connected by labelled lines. Two of these connected concepts within a concept map are known as a proposition. Therefore a proposition can be regarded as the smallest unit of coherent conceptual knowledge (Mintzes et al., 2005). The concepts and propositions students were expected to learn during the lesson sequence to be designed were presented in a concept map. Because each proposition that students mentioned could be pointed out in this concept map, we called it the *reference concept map*. This reference concept map was used to guide the design in the direction of the learning objectives and as a tool to assess an improvement in mentioning propositions correctly. The reference concept map presented here is an adapted version of that developed in our previous case study (Ummels et al., 2013).

The concepts to be learned were selected from two biology textbooks for upper secondary education and the national Dutch exam standards (CvE, 2009) and based on the question of which concepts in relation to the concept of photosynthesis it is important to teach to tenth-grade biology students in senior general secondary education. Next, an analysis of relevant literature about learning and teaching photosynthesis and other metabolic processes was conducted. The following three main problems were identified:

- Students do not understand cellular “processes.” They consider photosynthesis and cellular respiration as exactly opposite processes or purely as “gas exchanging” processes (Cañal, 1999; Kose, Usak, & Bahar, 2009).
- Students are not used to seek explanations at the cellular or sub-cellular level of biological organisation when they are asked to explain observable natural phenomena (Flores, Tovar, & Gallegos, 2003; Songer & Mintzes, 1994).
- Students are not able to link the living world to the non-living world. They often do not grasp the idea that in living things energy can be captured, transferred or released and chemical elements (like carbon) can be transformed in a cyclic way from one molecule to another (Amir & Tamir, 1990; Lin & Hu, 2003; Mohan et al., 2009).

This last problem is not surprising considering that textbooks do not convey the idea that the metabolic processes (photosynthesis, cellular respiration and biosynthesis) in living things are instances of matter and energy conservation and transformation (Roseman, Linn, & Koppal, 2008). A problematic understanding of the energy concept was also confirmed by a previous case study within our research project (Ummels et al., 2013). Students hardly showed improvement in mentioning propositions including the concept of energy during the course of a lesson sequence. After discussions with researchers in the field of ecology and upper-secondary biology teachers the following two guidelines for the construction of the reference concept map were devised:

- The three metabolic processes of photosynthesis, cellular respiration and biosynthesis need to be related to each other at the cellular level of biological organisation.
- Each process should present how matter (with a focus on carbon-containing substances) and forms of energy (light energy, chemical energy, heat energy and energy for cellular work) are converted.

On the basis of those two guidelines we defined the relationships between concepts, which resulted in four groups of propositions focused on the *core* concepts of photosynthesis, cellular respiration, biosynthesis and energy. The propositions related to energy refer to the release of heat energy or energy for cellular activity from chemical forms of energy. Figure 4.1 shows the reference concept map containing all these propositions.

4.3.2 Overview of the lesson sequence

To guide the selection of authentic social practices which can be transformed into contexts a socio-scientific topic was chosen: the environmental impact of producing meat and other protein-rich food products (Tytler, 2005). After making an inventory of social practices that related to this topic we focused on those that: (1) had the potential to provide a framework for the setting of "focal events: important or typical events that draw the attention of learners while remaining imbedded in its cultural setting" (Gilbert et al., 2011, p. 819); (2) could be transformed into contexts that covered as many concepts and propositions from the reference concept map as possible; and (3) could be interlinked by a storyline. Eventually three practices were chosen that could be interconnected by an overarching guiding question. In the next paragraph, it is explained how this guiding question provided a framework for a storyline throughout the lesson sequence. Appendix C shows the concepts and propositions from the reference concept map which are integrated in each of the three contexts. In the following paragraphs the three contexts of the lesson sequence are described in which eight LT activities are highlighted. We define an LT activity as a delimited unit of a lesson consisting of an introduction phase, action phase and reflection phase. For each LT activity it is indicated which of the design principles was elaborated more prominently than the others.

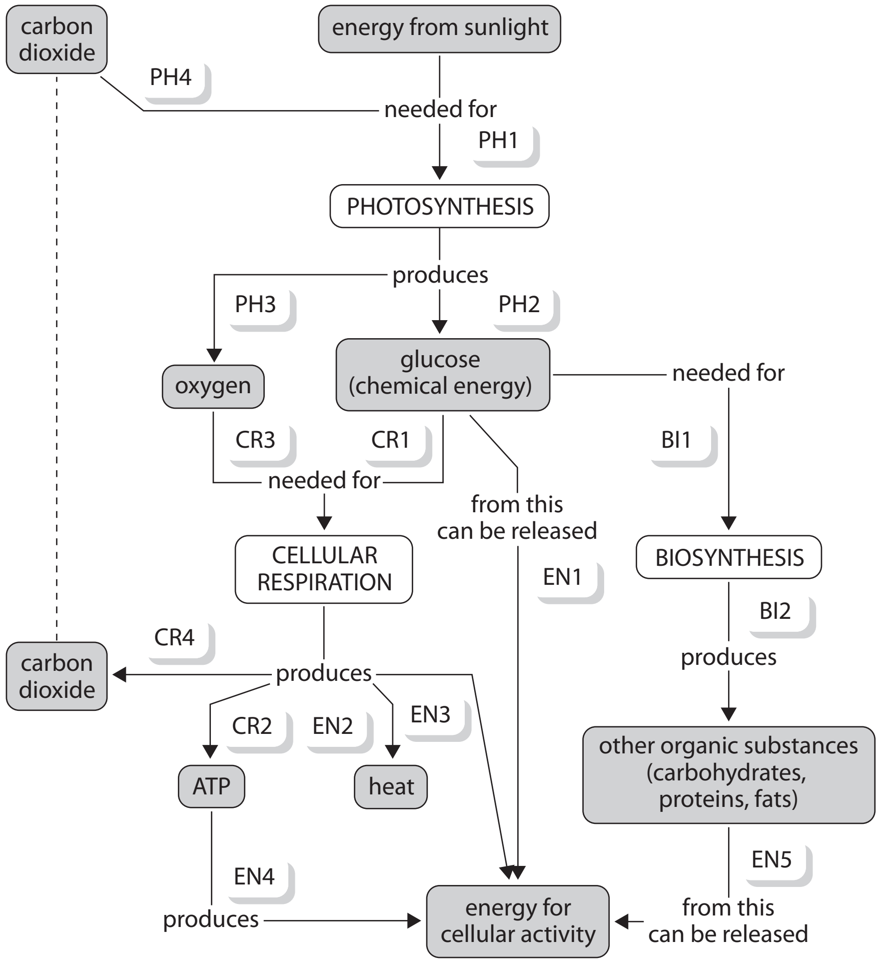

Figure 4.1 Reference concept map.

The relationships between the three metabolic processes (white boxes) with an emphasis on transformation of energy and matter (grey boxes) are indicated with proposition codes. Four groups of propositions are distinguished that are related to the core concepts of photosynthesis (code: PH1-4), cellular respiration (code: CR1-4), biosynthesis (code: BI1-2) and energy (code: EN1-5).

First context: family discussion about vegetarianism

The first context is representative of a real-life practice: a family discussing whether to become vegetarian or not. It is assumed that students recognise that such discussions could reflect their own situations. During the introduction phase of LT activity 1 five students are invited to participate in a role play about meat consumption. The script of this role play is given out. Other students try to find out which arguments they agree upon. In these arguments concepts students are expected to be familiar with from everyday language such as carbon dioxide, proteins and energy, are integrated. Thereafter, a classroom conversation considers the arguments that consumers may have to make for the consumption of meat or protein-rich vegetable substitutes. The discussion ends with the question: *Are we still allowed to consume meat?* In LT activity 2 this problem is illustrated by three short video fragments about the global environmental consequences of consuming meat. Students fill out concepts that have been discussed in both the role play and the video fragments in a pre-structured concept map (Figure 4.2). They discuss the relations between these concepts (e.g. proteins, carbon dioxide, livestock and greenhouse effect). During the reflection phase the teacher uses the concept map to give an overview of the consequences of the production of meat and other protein-rich products on carbon dioxide emissions causing the greenhouse effect. There is an emphasis on the concepts of carbon dioxide and proteins that are intended to function as "stepping stones" to the metabolic cell processes involved. In these two LT activities the first design principle (building upon familiar concepts) is elaborated prominently. At the end of context 1, the teacher uses the concept map to look ahead to the next context: the work of an environmental advisor.

Second context: environmental advisor

The second context is representative of the professional practice of an environmental advisor. Because students may not be familiar with this profession a chart is developed to visualise the context. This is used to introduce the relation between the greenhouse effect and food production, with a focus on carbon dioxide emissions during the production of various plants and animal protein-rich food products. Figure 4.3 shows the context visualisation in which the role of the environmental advisor (in front) in the protein-rich food production chain has been displayed. Protein-rich food is specified as meat for beef burgers and soya for vegetable burgers. Other participants involved are: a consumer, a cattle farmer, a crop (soya) farmer and an agricultural researcher. This visualisation also links the second context to the other two contexts: the consumer refers to the first context and the agricultural researcher refers to the third context. In the following two LT activities the second design principle (focusing on core concepts) is elaborated prominently. In LT activity 3 students use the context visualisation to indicate where in the production chain there is a release and an intake of carbon dioxide. Figure 4.4 shows the arrows students are expected to draw in the context visualisation during the action phase of this LT activity.

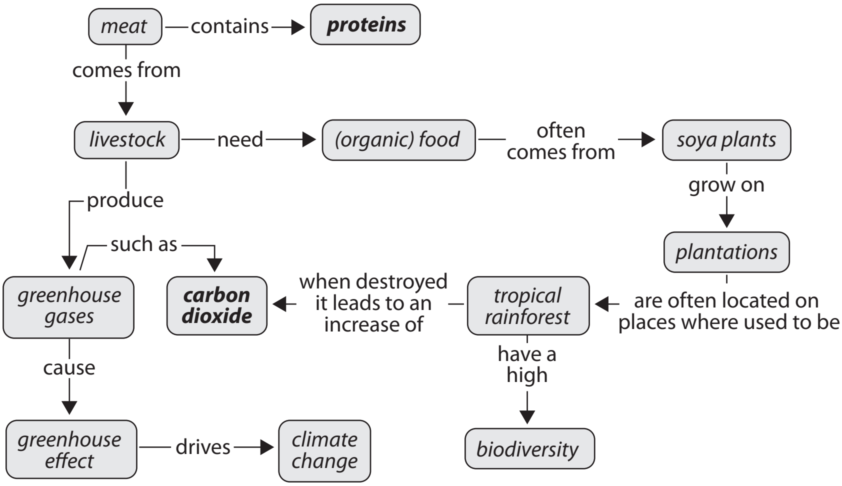

Figure 4.2 Pre-structured concept map, in which the relations are given and the concepts have to be filled out.

These concepts are discussed in the role play and three short video fragments and written here in *italics*. The concepts of proteins and carbon dioxide (in bold) are expected to be familiar to students. These two concepts are present in the reference concept map (see Figure 4.1).

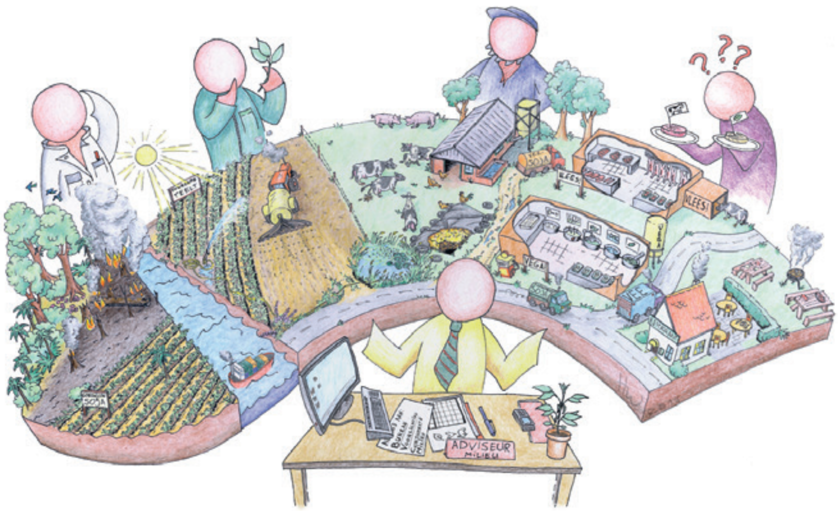

Figure 4.3 Context visualisation.

In front the environmental advisor who has to deal with the impact on the environment during the production chain of protein-rich food products. Other participants involved (anti-clockwise): a consumer, a cattle farmer, a crop farmer and an agricultural researcher.

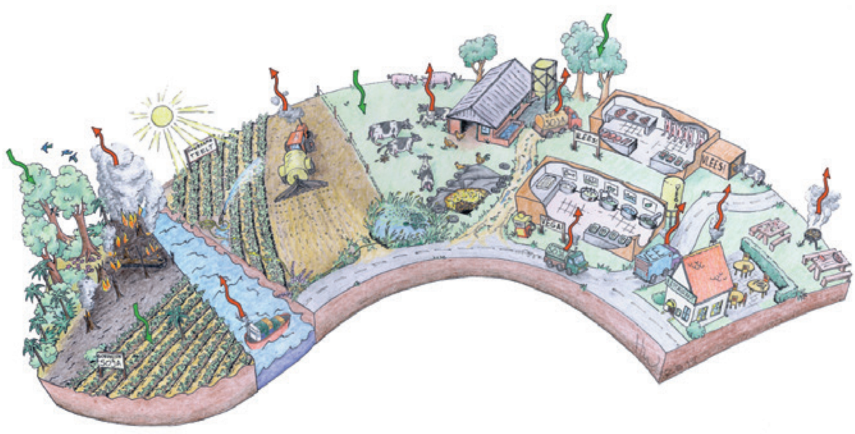

Figure 4.4 How the context visualisation is used to indicate where in the food-production chain there is an intake and a release of carbon dioxide.

In the reflection phase of LT activity 3 the teacher links carbon dioxide to two processes in cells: cellular respiration and photosynthesis. The question is asked: *how do animals and plants respire?* In LT activity 4 students examine the leaves of soya plants with this question in mind. During the action phase they observe stomata with a microscope and draw plant cells. In the reflection phase the role of stomata in carbon dioxide (and also oxygen) exchange in plant cells is discussed. The teacher uses visualisations of mitochondria (produce carbon dioxide, use oxygen) and chloroplasts (use carbon dioxide, produce oxygen) to make a distinction between plant cells and animal cells and to focus on the core concepts of cellular respiration and photosynthesis (Figure 4.5).

Next, there is an interactive lecture in which the teacher uses these and other visualisations of cells to explain how metabolic processes are involved in the production of proteins. Therefore, the core concept of biosynthesis is also introduced to link carbon dioxide via PH4, PH2, BI1 and BI2 (Figure 4.1) to the production of proteins. During this lecture students fill out a blank scheme linking the three processes. Particular attention is also paid to the transformation of energy.

At the end of the second context LT activity 5 is conducted in which students have to write advice destined for a public information association named “Consumer and Environment” from the perspective of the environmental advisor. The guiding question is: *will we still be allowed to consume meat in the future with regard to carbon dioxide emissions?* In the action phase students conduct a brainstorm in pairs before they write the first paragraph of this advice. They are directed to use conceptual information from certain pages

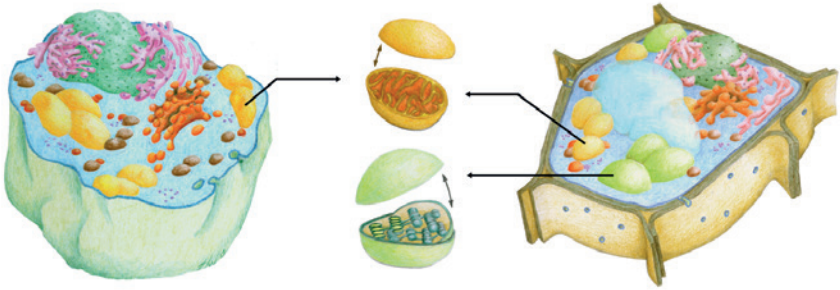

Figure 4.5 Visualisations of an animal cell (left) and a plant cell (right), mitochondrion (top, centre) and chloroplast (bottom centre) used by the teacher to focus on cellular respiration and photosynthesis.

in their manual. In this LT activity the fourth design principle (reflecting on conceptual relationships in a context) is elaborated more prominently than the others.

Third context: agricultural research

The third context is representative of the scientific practice of researchers in agriculture. Students examine in LT activity 6 what percentages of proteins are lost when proteins in plants are converted to proteins in animals. They weigh the total amount of soya beans collected from a plant. Subsequently, they calculate how much agricultural land is needed for the production of a quantity of proteins in soya beans in comparison with the same quantity of proteins in chicken meat. Students find out that a much larger surface of agricultural land is needed for the production of proteins in chicken. In the reflection phase of this LT activity the teacher helps students to give an explanation for calculated outcomes using biological concepts. Helping students to explicate the relevant propositions from the context is an elaboration of the fourth design principle (reflecting on conceptual relationships within a context).

Furthermore, in LT activity 7 students construct concept maps in groups of three about how the three metabolic processes are involved in protein production in both plant and animal cells. Students receive two copies of relevant concepts on stick-on cards. They first have to categorise which concepts belong to plant cells, animal cells or both. Then, they organise the cards to form the skeleton of a concept map. Finally, the cards are connected by labelled arrows. Each of these steps is checked by the teacher, who provides feedback. After completion of the concept maps the teacher challenges students to explain, using the maps, why plant cells produce proteins more efficiently than animal cells. In this LT activity, the third design principle (stimulating students to interconnect concepts) is elaborated more prominently than the others.

Finally, the lesson sequence returns to the perspective of the environmental advisor. In LT activity 8, students perform a second writing task in which they use their earlier written text and information from the manual to write a final version of the advice to the public information association "Consumer and Environment." Students are expected to give explanations using concepts and propositions from the reference concept map. The guiding question is now extended to: *will we still be allowed to consume meat in the future with regard to both carbon dioxide emissions and the use of agricultural land?* Students receive hints and are directed to use conceptual information from certain pages in their manual. It is intended that students will integrate concepts and propositions which they dealt with in the third context in their writing products. In this second writing activity, the third design principle (stimulating students to interconnect concepts) is elaborated more prominently than the other design principles.

4.3.3 Administration of the lesson sequence

The lesson sequence was administered in a tenth-grade biology class of 29 students, aged 15 to 16, in senior general secondary education. This type of education prepares students for studies at a University of Applied Science. To assess the abilities of these students we compared their average biology grades for one year with those of students from a parallel class. The former class on a scale of one to ten, scored an average grade of 6.17 (SD = 0.66) whereas the latter class scored an average grade of 6.35 (SD = 0.64). This is not significantly different at a 95 % confidence interval: $t(58) = -1.12$; $p = 0.269$. The school was located in a semi-rural area in the east of the Netherlands. The teacher, who is specialised in teaching students in senior general secondary education, had about 15 years of teaching experience and is a highly competent biology teacher. In advance of each lesson, the first author and the teacher discussed the intended LT approach. To support the teacher during the lessons there were digital presentations that provided him with information: for example, the questions he could ask in a classroom conversation. Instructing and preparing the teacher as accurately as possible means the influence of undesirable actions on students' learning processes is minimised. Because the school participated in a pilot project for the implementation of biology education based on the concept-context approach, students were familiar with this type of education. The lesson sequence was conducted in ten consecutive lessons within a period of three weeks. To limit the variation in students' time spent on the lesson sequence, students were not allowed to take their manual home during this three-weeks period. Only for the final test were they allowed to study the manual at home.

4.3.4 Research scenario and evaluation

A research scenario predicts and theoretically justifies in detail the learning-teaching process expected to take place and why it is expected to happen in a particular way (Lijnse & Klaassen, 2004). In this study, a research scenario was constructed that included a stepwise description of context-embedded LT activities that were expected to contribute to students' conceptual coherence. These expectations were based on a pedagogical analysis of the content to be taught (see section 4.3.1) and a previous case study on concept-context-based education (Ummels et al., 2014). In this case study we examined why LT activities were effective from the students' perspective. Table 4.1 demonstrates this research scenario. For the purpose of this article, eight selected LT activities are presented here.

Data from video-recordings in classroom were collected and transcribed verbatim to evaluate these LT activities on practicability. This evaluation focused on the degree of correspondence of the intended steps and what actually happened in classroom practice. An example of one of those steps is: students are prompted to articulate the relation between cellular respiration in livestock and the emission of greenhouse gases. One of the following scores was assigned to each step: positive (+) when the step was fully recognised in the transcripts; negative (-) when the step was not recognised in the transcripts; or intermediate (±) when the step was partially recognised in the transcripts. An example of the intermediate score is as follows: students mention livestock and greenhouse gases but do not connect this to cellular respiration. A second rater (second author) followed the same procedure. The level of agreement between the raters appeared to be high (Cohen's Kappa = 0.87). Observational remarks on intermediate and negative scores were noted. The scores were used to interpret how characteristics of the design might have contributed to students' learning processes. The assumption is that when essential steps are missing this interrupts the development of conceptual coherence. These interpretations will be considered when discussing the role of the eight LT activities in the development of students' conceptual coherence.

Because all steps in LT activity 1 and 2 were scored positively, it was expected that students could explain the impact of consuming meat on the greenhouse effect by using the concepts of carbon dioxide and proteins. After LT activity 3 students were expected to relate carbon dioxide to cellular respiration (mentioning proposition CR4; Figure 4.1) and photosynthesis (mentioning proposition PH4). The teacher made some incorrect formulations, however, about the concept of energy during the reflection phase when chemical equations were discussed (step 3.5). For example, the teacher said: "Here is glucose and during cellular respiration this matter is partly transformed into energy." After LT activity 4 students were expected to link the level of biological organisation they observed when studying the leaves of soya plants to the core concepts of photosynthesis and cellular respiration at sub-cellular level (mentioning PH4, PH3, CR3 and CR4 in relation to each other). The teacher did not prompt students to think about gas exchange in plants

Table 4.1 Research scenario for eight context-embedded LT activities of the lesson sequence.

In each LT activity one design principle has been elaborated more prominently than the others. Each step of an LT activity was scored with regard to how well it was performed compared with the intended performance. The scores of two researchers (divided by /) are presented as follows: a positive score (+) when a step was observed as intended; a negative score (-) when a step was not observed as intended, and an intermediate score (±) when a step was partially observed as intended. Observational remarks on intermediate and negative scores are presented in the last column. The LT activities (1-8) are listed in the order in which they occur in the lesson sequence. Therefore, the elaborations of design principle 4 are presented before the elaborations of design principle 3.

	The design principle most prominently elaborated in the LT activity *Specification of LT activity*	**Score**	**Observational remarks on intermediate and negative scores**
Design principle 1: building on familiar concepts			
LT activity 1: performing a role play (in context 1)			
1.1	Five students perform a role play about vegetarianism in a family while others listen.	+/+	
1.2	Teacher evokes a classroom discussion focusing on concepts students are expected to be familiar with.	+/+	
1.3	Students provide arguments pro and contra vegetarianism.	+/+	
1.4	Teacher focuses on environmental impact of meat consumption (referring to the familiar concept of carbon dioxide) and emphasises guiding question: Are we still allowed to consume meat?	+/+	
LT activity 2: filling out a pre-structured concept map of a context (in context 1)			
2.1	Three short movies are shown which provide students with information and illustrate the problem concerning the environmental impact of meat consumption.	+/+	
2.2	Teacher gives instruction to fill out pre-structured concept map picking concepts from a list.	+/+	
2.3	Students fill out concept map in pairs and argue about relations between concepts.	+/+	
2.4	In reflection phase, the teacher uses concept maps to indicate the problem and interact with students emphasising the relation between consumption of (animal) proteins and carbon dioxide emission.	+/+	
Design principle 2: focusing on core concepts			
LT activity 3: using context visualisations (in context 2)			
3.1	Teacher uses context visualisation to make clear that environmental advisor studies carbon dioxide emission in food production chain.	+/+	
3.2	Teacher gives instruction to draw arrows in context visualisation indicating carbon dioxide exchange.	+/+	
3.3	Students discuss in pairs and draw arrows in context visualisation.	+/+	
3.4	Students check correctness of arrows.	+/+	
3.5	In reflection phase, the teacher helps students to link carbon dioxide to cellular respiration and photosynthesis focusing on transformation of matter and energy in chemical equations of these processes.	+/±	The teacher did not formulate the concept of energy correctly.

LT activity 4: combining microscopic observations of leaves with visualisations of cells (in context 2)			
4.1	Teacher recapitulates task of environmental advisor and introduces soya plants in classroom.	**+/+**	
4.2	Teacher prompts students to find out how plants inhale and exhale carbon dioxide (and oxygen).	**+/±**	The teacher did not really prompt students and no questions were asked.
4.3	Students study leaves of soya plants with microscope and draw stomata.	**+/+**	
4.4	In reflection phase, the teacher helps students to relate structure of stomata to carbon dioxide (and oxygen) exchange and subsequently to cellular respiration and photosynthesis.	**+/+**	
4.5	Teacher now focuses on the location within cells where these processes take place using visualisations of mitochondria and chloroplasts.	**+/+**	
Design principle 4: reflecting on conceptual relationships within context			
LT activity 5: writing advice; draft version (in context 2)			
5.1	Teacher legitimises why an environmental advisor writes advice.	**+/+**	
5.2	Teacher indicates that the texts should make clear how carbon dioxide emission in the production of protein-rich products of a vegetable origin is lower than for those of animal origin.	**+/+**	
5.3	Teacher instructs on steps in writing process.	**+/+**	
5.4	Students brainstorm in pairs: they discuss the line of reasoning and go through their manual.	**±/±**	Many procedural questions from students indicated that they did not seem to understand the assignment.
5.5	Students individually write a draft version.	**±/±**	Teacher's support still needed.
5.6	In reflection phase, the teacher asks students to point out essential points in argumentation, with an emphasis on concepts and propositions to be used.	**±/±**	Reflection was limited to just a presentation of a slide.
5.7	Students read each other's written products and give feedback on established propositions.	**-/-**	Reacting to each other's products did not occur. Time was lacking.
LT activity 6: reflecting on hands-on activity with soya plants (in context 3)			
6.1	Students weigh all soya beans of one plant and calculate how many square meters of agricultural land are needed for one kilogram of animal proteins in comparison with one kilogram of plant proteins.	**+/+**	
6.2	The teacher recapitulates the main results of the hands-on activity and guides students through the (complex) calculations resulting in the conclusion that more agricultural land is needed for the production of animal proteins.	**+/+**	

Table 4.1 Continued

	The design principle most prominently elaborated in the LT activity *Specification of LT activity*	**Score**	**Observational remarks on intermediate and negative scores**
6.3	The teacher prompts students to look for a biological explanation for this conclusion.	±/±	The teacher "taught by telling."
6.4	The teacher gives hints to help students to reason at the cellular level of organisation using concepts and propositions from the reference concept map.	±/±	The teacher "taught by telling."
6.5	Finally, students are able to give explanations referring to the interrelationship between the three metabolic processes and transformation of energy.	-/-	This step was not recognised.
Design principle: 3: stimulating students to interconnect concepts			
LT activity 7: concept-mapping (in context 3)			
7.1	Teacher explains goal: shows in two concept maps how plant cells and animal cells produce proteins.	+/+	
7.2	Teacher instructs on steps in mapping process and gives each student in group a responsible role.	+/+	
7.3	Students construct maps and interact about connections between concepts to be made.	+/+	
7.4	Teacher gives each group feedback and asks students to explain connections they have made.	+/+	
7.5	Students check their own concept maps by looking at the work of other groups.	+/+	
7.6	In reflection phase, the teacher challenges students to use concept maps to explain why proteins are produced more efficiently in plant cells than in animal cells, referring to the transformation of energy.	±/±	There was limited time, the teacher recapitulates with limited interaction.
LT activity 8: writing advice; final version (return to context 2)			
8.1	Teacher indicates that the text of the final advice should make clear how it is possible that both carbon dioxide emissions and the use of agricultural land for the production of protein-rich products of a vegetable origin can be lower than those of animal origin.	±/±	Teacher recapitulates activities in prior lessons but does not mention the main focus of the final version.
8.2	Students individually write a final version and use their manual.	+/+	
8.3	In reflection phase, the teacher points out essential points in the argumentation with an emphasis on concepts and propositions to be used.	-/-	This step was not recognised. There was no time.

before they observed the leaves with the microscope, although this was intended (step 4.2). Concerning LT activity 5, students asked the teacher many questions during the brainstorm phase of the writing assignment (step 5.4) and when they were supposed to write individually (step 5.5). Obviously they experienced problems in applying conceptual knowledge when giving explanations. Moreover, interaction that prompted students to reflect on conceptual relationships did not really take place (steps 5.6 and 5.7). The first two steps of LT activity 6 (6.1 and 6.2) were performed as intended. Subsequently, the teacher “taught by telling” (steps 6.3 and 6.4) and did not prompt students to reflect on conceptual relationships when explaining differences in the use of agricultural land and comparing the production of plant and animal proteins (6.5). The first five steps of LT activity 7 were performed as intended. Students looked focused, worked cooperatively in groups when trying to establish propositions, followed the procedural steps to construct a concept map (steps 7.1-7.3) and to check with other groups (step 7.5). Moreover, the teacher interacted with each group and gave feedback (7.4). Only the last step (7.6), in which it was intended that the teacher would ask students to use the concept map when giving explanations, was not recognised. Here the teacher also taught by telling and did not interact with students. LT activity 8 started with an introduction (step 8.1) that missed the essential point which had to be explained in the advice: the impact of consuming meat on both carbon dioxide emissions and the use of agricultural land. Students wrote their texts individually and used the manual as intended (step 8.2). Final reflection (step 8.3) did not take place.

4.3.5 Data collection and analysis

Various data sources were collected by multiple means and at different points to shed light on how this lesson sequence improves the development of students’ conceptual coherence. These data sources consisted of video-recordings of all lessons, written responses on a pre-test, a post-test and a final test, semi-structured interviews with four students and the teacher and short written evaluations of all students after each lesson (post-lesson evaluations). Moreover, two data sources as “naturalistic” products of the lesson sequence itself were collected: concept maps as products of group work and the draft and final texts of the writing assignment. Each data source provides a different insight into students’ learning processes. Therefore, the triangulation of these data was used to describe how students’ conceptual understanding develops during the lesson sequence.

4.3.5.1 Pre-test, post-test and final test

An identical pre-test and post-test were performed, consisting of explanatory tasks and defining tasks. In the explanatory tasks students had to predict what would happen with a number of shrimps and green algae that were trapped for one year in a sealed ecosphere, containing water and with unrestricted sunlight. They also had to predict what would happen with a mouse and a green plant that were individually trapped in a sealed container with unrestricted water and sunlight. This task was derived from an empirical study on the understanding of cellular respiration and photosynthesis of college-level biology students (Songer & Mintzes, 1994). Our intention with these tasks was to confront students with inconsistencies in their thinking and persuade them to formulate plausible solutions to biological problems. In correct responses they should refer to photosynthesis as *a process to capture energy* and to cellular respiration as *a process to release energy*. Moreover, students had to explain the relationship between animals and plants in terms of oxygen and carbon dioxide release and intake. This task was inspired by the work of Tamir and Amir (1990) who showed that eleventh- to twelfth-grade students often think that cellular respiration only takes place in animals and that photosynthesis is the opposite process of cellular respiration. Most students do not know that the processes are complementary. In the defining tasks students were asked to formulate a definition of the concepts from the reference concept map: cellular respiration, biosynthesis, photosynthesis, organic substances and ATP. Moreover, they had to relate some given concepts from the reference concept map: photosynthesis, sunlight, carbon dioxide, heat, cellular respiration, ATP, glucose, water and oxygen. We assumed that the propositions mentioned in these defining tasks could be obtained from merely reproductive learning. The propositions mentioned in the explanatory tasks, in which no core concepts were given, are more likely to be the result of meaningful learning (Mintzes et al., 2005). The post-test was performed immediately after lesson 10. Students received back their responses on the prediction tasks given in the pre-test. They were asked to check these responses and to indicate adjustments. For the defining tasks students were also asked to adjust their definitions given in the pre-test and to add definitions they could not formulate in the pre-test.

In the final test the responses to ten questions were analysed: eight context-oriented open questions in which students had to give explanations, comparable with the explanatory tasks in the pre-test and post-test, and two multiple choice questions. These were selected because a correct choice required students to relate four propositions to each other. In one question the core concepts of photosynthesis and cellular respiration had to be related to each other and in the other question photosynthesis and biosynthesis had to be related to each other.

For all three tests we coded the propositions from the reference concept map that were expected in correct responses. For each proposition we quantified how many students were able to mention it at least once in each test exactly as described in the reference concept map. In line with previous work we assumed that mentioning propositions is an indicator of the degree to which conceptual coherence has developed (Ummels et al., 2013). A second rater followed the same procedure for five randomly selected students. In this procedure students' concept maps and written products were also included collected during the execution of the lesson sequence (see section 4.3.5.3). The level of agreement between the raters was high (Cohen's Kappa = 0.97). Apparently, the code-book that described which remarks had to be scored as a correct proposition was unambiguous. The results obtained from responses on the defining and explanatory tasks were compared between pre-test, post-test, and with the open context-oriented questions in the final test. Statistical analysis was conducted between the identical pre- and post-tests. Because of the relatively low numbers of students a non-parametric sign test was conducted to determine whether there was a significant increase between the two tests in the numbers of students who mentioned propositions correctly. The results of the two multiple choice questions were compared to provide additional information on students' abilities to establish combinations of propositions. These results should be treated with considerable caution, however, because the questions might not have been understood and students made the wrong choice even if they understood the required concepts and propositions.

4.3.5.2 Semi-structured interviews

Semi-structured interviews (Southerland, Smith, & Cummins, 2005) were conducted with four students individually after every two lessons and after the pre-test and the post-test. These students (two males, aged 16 and 17, and two females, aged 15 and 16) were selected by the teacher on the basis that they represented different learning styles and were cooperative. A Mann-Whitney *U* test was used to compare the average grades of these students (5.72; SD = 0.66) with the average grades of all students from the class (6.23; SD = 0.65). No significant difference was found ($U = 30.50$; $p = 0.189$). Each student was interviewed six times. An interview lasted about 30 minutes and had a similar structure. The research scenario was used to formulate appropriate probes and follow-up questions to gain a complete understanding of the interviewees' views. Video-recordings of these interviews were transcribed verbatim and analysed by close reading and highlighting passages that indicated how students' learning processes with respect to understanding and interconnecting core concepts from the reference concept map had occurred. There was a focus on remarks that included single propositions (e.g. photosynthesis produces glucose) and combinations of propositions connecting two or more core concepts (e.g. photosynthesis produces glucose which is needed for cellular respiration and biosynthesis). This was followed by axial coding which allowed clustering and summarising of the information. Students' ideas about the usefulness of the eight LT activities were also inventoried. Three semi-structured interviews were also conducted with the teacher. The transcripts of these interviews were analysed by looking for passages that indicated how the teacher perceived that the LT activities influenced students' development of conceptual coherence in both a positive and a negative way.

4.3.5.3 Concept maps and writing assignments

Two data sources were collected from a "naturalistic setting": the texts of the writing assignment (LT activity 5 and 8) and concept maps as products of group work (LT activity

6). The two texts of the writing assignment were analysed by coding the propositions from the reference concept map and counting the numbers of students who mentioned each of these propositions. In the first (draft) version students had to link the consumption of meat and other protein-rich food products to carbon dioxide emissions. In the second (final) version students had to explain how consuming meat is also related to the use of agricultural land. The concept maps were analysed by coding each proposition from the reference concept map, indicated by an arrow and a label connecting two concepts. For each proposition we counted how many times it was recognised in nine concept maps. This gave information about which and to what extent propositions were established during these LT activities.

4.4 Results

4.4.1 Changes in mentioning propositions before and after lesson sequence

Figure 4.6 shows the numbers of students who mentioned each proposition in defining and explaining tasks in the pre-test, post-test and final test. We discuss the results with respect to the propositions related to each of the four core concepts: photosynthesis, cellular respiration, biosynthesis and energy.

In the pre-test more students were able to mention propositions in relation to the core concept of photosynthesis than the other core concepts. This is not surprising because the chemical equation of photosynthesis was taught in an earlier module. In the defining tasks many students wrote down this chemical equation when asked to define photosynthesis. Fewer students mentioned propositions related to photosynthesis in the explanatory tasks. This might indicate that establishing propositions in new situations is more difficult than reproducing propositions. There were only two students (no. 5 and no. 16) who mentioned proposition PH2: "algae produce glucose (as a food source for shrimps) by photosynthesis." Although there were more students who stated: "algae produce food for shrimps" without mentioning glucose, this was not scored as a correct proposition. Ten students mentioned the propositions PH3 and PH4 in one sentence: "Algae use sunlight in photosynthesis to turn carbon dioxide into oxygen." This indicates that these students consider photosynthesis mainly as a gas exchanging process. This problem is also reported in the literature (Amir & Tamir, 1990; Cañal, 1999).

The interviews conducted after the pre-test with four students (no. 11, 13, 21 and 26) made clear that their prior knowledge contained the idea that photosynthesis is a "mysterious" process taking place in plants and that plants need sunlight, use carbon dioxide and produce oxygen. One of the students (no. 21) said: "Plants perform all kinds of tricks like photosynthesis." They often reasoned from the perspective of the organism: what a plant needs and produces. The process of cellular respiration seemed to be largely unknown to these students. Each of the four students mentioned that animals need

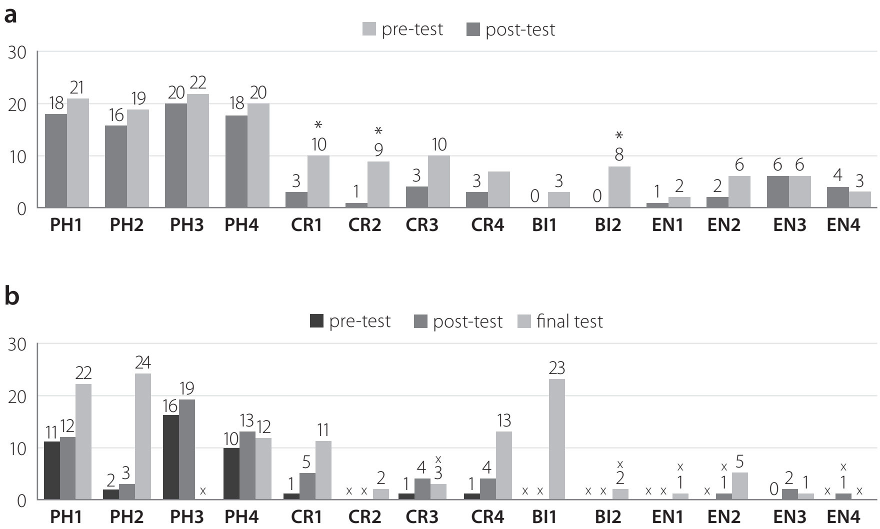

Figure 4.6 Numbers of students (n=29) who mentioned propositions related to the concepts of photosynthesis (PH1-4), cellular respiration (CR1-4) biosynthesis (BI1-2) and energy (EN1-4) in defining tasks at pre-test and post-test (a) and at the explanatory tasks at pre-test, post-test and final test (b).

The asterisks (*) in Figure 4.6a indicate significant differences between pre-test and post-test scores. The final test was not included in statistical analysis. The crosses (x) in Figure 4.6b indicate propositions that were not evoked and therefore not expected. EN5 was in none of the tasks evoked and is excluded from these figures. The codes refer to the propositions shown in the reference concept map as presented in Figure 4.1.

oxygen but could not explain this by referring to cellular respiration. Student no. 13 said: "I think oxygen is needed for blood circulation." Only student no. 26 said: "I think that plants also use a bit of oxygen but I'm not sure." All four students had problems shifting their locus of explanation from the organism level of organisation to the cellular or sub-cellular level. From the defining tasks it became clear that none of the students could describe biosynthesis. Furthermore, the students were not able to describe how energy can be transformed from one form to another: for instance, that light energy could be captured as a form of chemical energy (glucose) and that this chemical energy could be transformed into energy for cellular work. Student no. 13 said: "Energy from sunlight is turned into oxygen." None of the four students was able to describe any transformation of forms of matter or energy during one of the metabolic processes. This phenomenon was also recognised by Lin and Hu (2003).

Total test scores were computed for the total number of correctly mentioned propositions for both the pre-test and the post-test. The sign test showed a significant increase between pre-test and post-test regarding the differences in the total number of propositions that were mentioned correctly in both defining tasks (16 positive and three negative differences and 10 ties, $p = 0.004$) and explanatory tasks (10 positive differences and no negative differences and 19 ties, $p = 0.002$). For each proposition separately, only a significant increase between pre- and post-test was found for the propositions CR1 (seven positive differences and 22 ties, $p = 0.016$), CR2 (nine positive and one negative differences and 19 ties, $p = 0.021$) and BI2 (eight positive differences and 21 ties, $p = 0.008$) in the defining tasks. No significant differences between pre-test and post-test were found for the other propositions (for all: $p > 0.05$). Although students adjusted their responses, they often only mentioned concepts they had not mentioned before (mainly concepts in relation to cellular respiration) but they did not establish any new propositions. There were only three or four students who mentioned three propositions concerning cellular respiration: CR1 (four), CR3 (three) and CR4 (four) in the explanatory tasks, but they did not mention these propositions in the pre-test. For example, one of the students (no. 10) said in the pre-test: "The plant (in the sealed container) is going to die because it needs carbon dioxide to live. This carbon dioxide is transformed into oxygen and when it runs out of carbon dioxide it dies." The student corrected this response in the post-test into the following: "The plant needs carbon dioxide for photosynthesis, which also requires water and sunlight. This process produces oxygen and glucose which the plant needs for cellular respiration. From this process carbon dioxide, water and sunlight are released." Although this student related the process of photosynthesis to cellular respiration he seemed unfamiliar with the concept of chemical energy and the transformation of energy during these processes. This problematic understanding is supported by the small number of students who mentioned the relation between glucose and the production of energy for cellular work (EN3) correctly in the explanatory tasks: only two out of 28 students.

The interviews with the four students conducted immediately after the post-test revealed that students were able to mention correct propositions in relation to photosynthesis and cellular respiration in a conversation when appropriate cues were offered. In accordance with the results of all students as presented in Figure 4.6, the interviewed students had problems with the concepts of biosynthesis and energy. This is illustrated by the following quote. In the pre-test this student (no. 21) mentioned the propositions PH1, PH2, PH3 and PH4 in the defining tasks by writing down the chemical equation of photosynthesis. In addition to the four PH propositions, he also mentioned the propositions CR1, CR2, CR3 and CR4 and BI2 in the defining tasks in the post-test. This might indicate that this student knew the chemical equations of photosynthesis and cellular respiration and that proteins are produced by biosynthesis. Yet in the explanatory tasks in the post-test he only mentioned PH3 (photosynthesis produces oxygen).

Interviewer (I): *"So, the question with the shrimps and algae in the sealed container. You adjusted your previous answer by adding: algae perform photosynthesis producing oxygen for the shrimps."* (The student mentioned proposition PH3)

Student (S): *"Yes, I thought algae are green plants which performs photosynthesis producing oxygen needed for the shrimps to live. The first time* (referring to the pre-test) *I hadn't thought about that."*

I: *"Can you tell me what is needed for photosynthesis?"*

S: *"Water is needed, which is there anyway, and light energy, maybe from a light bulb, and carbon dioxide which must be added to the container or released from cellular respiration."* (The student mentioned proposition CR4 and the first part of propositions PH1 and PH4)

I: *"So what is produced by photosynthesis that allows the shrimps to live?"*

S: *"Oxygen and glucose."* (This refers to propositions PH2 and PH3)

I: *"And can you be more specific about this light energy, where is it going when it enters the container?"*

S: *"That is still difficult for me, because it has something to do with ATP. I think it is important for the biosynthesis which produces proteins* (he mentioned BI2). *But I'm quite sure the light energy is used somehow."*

From this fragment it becomes clear that this student learned to shift his locus of explanation to the cellular level of organisation because he was now reasoning, as shown by his mentioning cellular processes. This was not observed during the interview conducted after the pre-test. Although the relation between photosynthesis and cellular respiration seemed to be partly understood he did not understand the relation between photosynthesis and biosynthesis. This might be owed to misunderstanding of the conversion of energy from one form to the other. Moreover, he did not grasp the idea that molecules can contain energy. The low numbers of students who mentioned energy-related propositions (EN1-4) as shown in Figure 4.6 indicates that he was not alone.

The results of the explanatory questions in the final test showed high numbers of students who mentioned the following propositions correctly compared with the explanatory tasks in the post-test: PH1 (from 12 to 22), PH2 (from 2 to 24), CR1 (from 5 to 11) and CR4 (from 4 to 13). Although it is possible that the formulation of questions in the final test prompted students rather better to mention these propositions, many students appeared to make considerable progress compared with the results of the post-test. Furthermore, 23 students mentioned proposition BI1 whereas only three students mentioned this proposition in the defining tasks in the post-test. The responses showed that students learned to give biological explanations by switching to metabolic processes at the cellular level of biological organisation. For instance, in a context-oriented question with the grower of algae in a central role more than 20 students mentioned the concept of photosynthesis as a glucose-producing process that is dependent on the presence of light and referred to PH1 and PH2. The number of students who mentioned proposition EN2 (five) and EN3 (one) was still low, however. Although 11 students mentioned that glucose is needed for cellular respiration only one student mentioned that this process generates the energy for cellular activity (EN3). The results of the multiple choice questions in the final test were: two students gave a correct response to the first question which required the propositions PH4, PH2, BI1 and BI4 and 20 students gave a correct response to the second question in which the propositions PH4, PH2, CR1 and CR4 were required. Although 23 students mentioned the individual proposition "Glucose is needed for biosynthesis" (BI1; Figure 4.6b), apparently it was difficult for students to relate all four propositions to each other in the multiple choice question.

4.4.2 Role of eight context-embedded LT activities

For each of the context-embedded LT activities, we first refer to the scores attributed to the individual steps of the LT activities as presented in the research scenario (Table 4.1). Next, we show how data from the student interviews were used to describe students' learning processes in relation to the concepts from the reference concept map. If available, students' written products and concept maps collected during the lesson sequence were used to support this description. Finally, we show how data from the student interviews and–if available–from the post-lesson evaluations and teacher interviews were used to shed light on the influence of each LT activity on the development of conceptual coherence.

4.4.2.1 LT activity 1: performing a role play

Five students performed a role play, situated in a family setting, about meat consumption. Other students listened and tried to find out which of the arguments adduced they agreed with. The scores in the research scenario showed that all steps of this LT activity were performed as intended (Table 4.1). Students showed engagement and were eager to participate in the classroom discussion. The teacher guided this discussion in the direction of consequences of meat consumption for the environment. focusing on carbon dioxide.

In the interviews all four students mentioned that the setting of the role play was realistic and personally interesting. Two students (no. 11 and no. 26) even noticed that after the lesson they discussed this topic at home. When asked what the role play was about, all four students indicated the relation between food consumption and environment. Student no. 26 was specific: "Eating less meat means less carbon dioxide emission." The role play seems suitable for engaging students with a context, starting a discussion and raising guiding questions focused on biological concepts students are expected to be familiar with.

4.4.2.2 LT activity 2: filling out a pre-structured concept map of a context

Students filled out a pre-structured concept map and were challenged to argue about the concepts that were mentioned earlier in the role play, in classroom conversations and in the three short videos. During the reflection phase the teacher used this concept map (Figure 4.2) to focus on the role of concepts with which students were expected to familiar: carbon dioxide and proteins. All steps of this LT activity were performed as intended according to the research scenario (Table 4.1). Here the students also showed interest and were concentrated. In the interviews students were asked to explain the role of carbon dioxide and proteins when considering the impact of consuming meat on the greenhouse effect. All four students succeeded in this. As an example one student (no. 13) said: "The animals consume soya and soya grows somewhere rainforest used to be. Because more and more people consume meat more and more soya is needed. Those animals produce carbon dioxide just like the machines used to grow and transport the soya. And carbon dioxide is bad for the environment." Students cited many associations when asked about their ideas on carbon dioxide and proteins: "Carbon dioxide is a greenhouse gas" (no. 11), "Plants need carbon dioxide and humans, animals and machines produce it" (no. 13 and no. 21), and "Proteins are important building blocks for the human body" (no. 21 and no. 26).

In the post-lesson evaluations they were asked: "Which of the preceding LT activities was or were useful for your learning process?" and 22 out of 28 students mentioned that filling out the pre-structured concept map was useful to them. In the interviews one of the students (no. 13) said that this activity was too simple and therefore useless to her. Another student (no. 11) said in the interview: "Normally I find it hard to construct concept maps myself. Because the structure was already there and the concepts to fill out were given this activity really helped me to see the overall picture." Another student (no. 26) said that he liked to start with an activity with more concepts that were familiar and proceed to a more difficult activity with new biological concepts. Apparently, differences in prior knowledge and learning style determine how students valued this structured concept-mapping activity. The teacher remarked in an interview that filling out the concept map helped students to clarify the problem: "I think the students can now point out that the environmental problem of meat consumption is related to carbon dioxide as a green house gas and the use of agricultural land." The teacher also noticed that the concept map, when presented on the white board, helped him to ask questions and underline the main problem. Hence, filling out a pre-structured concept map followed by a teacher-guided reflection is suitable to support students in recognising the concepts that are relevant in a given context and to focus on the concepts with which students are familiar.

4.4.2.3 LT activity 3: using context visualisations

Context visualisations (Figures 4.3 and 4.4) were used to relate differences in the production chains of meat and organic protein-rich food products to carbon dioxide emission and uptake. Eventually, during the reflection phase the teacher presented chemical equations of cellular respiration and photosynthesis focusing on carbon dioxide, glucose and forms of energy. The evaluation of steps according to the research scenario (Table 4.1) showed that the activities of teacher and students were performed as intended, except for the reflection phase. Here the teacher made some mistakes when explaining how energy was transformed during these processes.

During the interviews all four students (nos 11, 13, 21 and 26) were able to explain the difference between combustion (as a process in which a substance reacts with oxygen to give heat and light) and cellular respiration. They could relate the release of carbon dioxide to cellular respiration (proposition CR4) and the uptake of carbon dioxide to photosynthesis (proposition PH4). Moreover, three students (nos 11, 21 and 26) mentioned that during photosynthesis oxygen and glucose were produced (propositions PH3 and PH2) and three students (nos 11, 13 and 26) mentioned that cellular respiration also produces energy for movement (EN3). Surprisingly, they connected both processes only by mentioning carbon dioxide and oxygen and did not notice glucose. Only one student (no. 26) said: "Food is needed for cellular respiration." Possibly, the focus on carbon dioxide emission and uptake in LT activity 3 reinforced their ideas that the processes are mainly opposite gas exchanging processes and that cellular respiration only takes place in animals and humans. These misunderstandings seem to be associated with unfamiliarity with the concept of chemical energy and the involvement of cellular respiration in the transformation of energy. When asked where the energy (for movement) produced by cellular respiration came from, none of the students responded correctly. Moreover, the conservation of matter appeared totally unfamiliar to them. They thought that matter (C-atoms) could just disappear during metabolic processes. One of the students (no. 11) said: "Carbon dioxide is turned into oxygen." When the interviewer asked: "Can you explain what happens with the C of carbon dioxide?" the student responded: "I don't have a clue." A retrospective analysis of the video-recordings of this lesson revealed that when the teacher explained the chemical equations on the whiteboard he wrote carbon dioxide as a chemical notation (CO_2) and spelled glucose as a word without mentioning its chemical notation ($C_6H_{12}O_6$). This might have prevented students from tracing C-atoms. The teacher also did not explain the concept of chemical energy in relation to glucose. He said: "Glucose is turned partially into energy like movement and heat." This oversimplification could explain students' misunderstandings about the transformation of energy and matter, which persisted after the lesson sequence, as shown in section 4.4.1. Moreover, because the teacher described the forms of energy "movement and heat" as the result of cellular respiration, students intuitively tended to relate this process to (homoeothermic) animals at the organisational level of the organism. Consequently, it is not surprising that they did not link cellular respiration to plant cells. Because during the reflection phase there was no focus on the use of energy within an animal or plant cell, e.g. the movement of cellular particles during growth, so students' idea that cellular respiration only takes place in animals (and animal cells) was reinforced.

From the interviews it became clear that students perceived that the context visualisations were supportive of their learning processes. When we asked them to explain how an environmental advisor deals with carbon dioxide emissions during the production chains of meat and soya, all students mentioned that they thought immediately of the visualisation of the production chains (Figure 4.3). One student (no. 21) said: "By studying the context visualisation I got an overview and by drawing the arrows it was clear to me where carbon dioxide was used and produced." This was also recognised by the teacher in an interview. He said: "By showing the visualisation of the context I could explain in a concrete manner which activities an environmental advisor performs. Students collaborated constructively when drawing the arrows to indicate carbon dioxide uptake and release." He continued: "From carbon dioxide I could easily switch my explanation to the chemical equations of photosynthesis and cellular respiration. However, because I focused on transformation of carbon-substances and energy and did not mention other substances like water and oxygen student students got confused."

4.4.2.4 LT activity 4: combining microscopic observations of leaves with visualisations of cells

Students studied leaves of soya plants and made drawings of stomata. In the reflection phase, the teacher helped students to relate the opening and closing of these stomata to exchanges of gases for cellular respiration and photosynthesis. Visualisations of mitochondria and chloroplasts (Figure 4.5) were used to indicate the location within the cell where these processes take place. It was expected that students would mention that carbon dioxide is needed for photosynthesis (PH4), that photosynthesis produces oxygen (PH3) which can be released from the plant or used for cellular respiration (CR3) and that cellular respiration produces carbon dioxide (CR4) which in turn can be used for photosynthesis or released from the plant. The steps of this LT activity were performed as intended, with the exception that the teacher did not prompt students to think about the reasons for gas exchange in plants before they started to look at stomata with the microscope (see Table 4.1).

In the interviews all students were able to mention the expected propositions. They understood that cellular respiration takes place in both plant and animal cells and they switched between the organisational level of the organism (plant) and the (sub-)cellular level. Linking cellular respiration and photosynthesis remained difficult, however. One student (no. 11) said: "A plant needs carbon dioxide which is directed to the chloroplasts. There photosynthesis takes place and the part of carbon dioxide that is not used in this process is the carbon dioxide that is emitted by the plant." It seems that by only paying attention to the use and production of oxygen and carbon dioxide students do not consider the processes to be complementary. Moreover, because less attention was paid the chemical notation of glucose ($C_6H_{12}O_6$) until LT activity 4 was conducted, they did not think about transformation of matter. For example, none of the four students seemed to understand that the carbon (C) atom of carbon dioxide is fixed in glucose. One student (no. 11) even remarked: "Carbon dioxide is converted into oxygen."

All four students were positive about the hands-on activity with the microscope. One student (no. 13) remarked: "I always prefer doing things instead of listening and reading." It appeared that knowing how a plant exchanges gases helped them to learn about these processes. One student (no. 11) said: "The moment I saw these stomata I thought: so this is the way a plant releases carbon dioxide." When asked if they had any idea why an environmental advisor needs to know how plants and animals exchange gases they could do so. Student no. 11 said: "I think an environmental advisor needs to know how gases are released by plants and animals. This might give him an overall view." Furthermore, all students confirmed that the visualisations of chloroplasts and mitochondria were very useful for locating where in a cell photosynthesis and cellular respiration take place and seeing the differences between plant and animal cells.

4.4.2.5 LT activities 5 and 8: writing advice from the perspective of the environmental advisor

Students had to write a draft version (LT activity 5) and a final version (LT activity 8) of advice from the perspective of the environmental advisor. It was expected that students would mention propositions from the reference concept map. From the evaluation of the steps in the research scenario (Table 4.1) it was evident that during LT activity 5 students asked the teacher many questions during the brainstorm phase. They seemed to experience difficulties when starting to write. Moreover, the reflection phases of LT activities 5 and 8 were not conducted as intended. Although design principle 4 (reflecting on conceptual relationships within a context) was elaborated prominently in LT activity 5, reflection was limited to a short presentation by the teacher without interaction. In LT activity 8, the reflection phase was not observed at all.

Figure 4.7 shows the numbers of students who mentioned propositions from the reference concept map. It appears that not many propositions were mentioned except for proposition PH4 (carbon dioxide is needed for photosynthesis) and CR4 (cellular respiration produces carbon dioxide). The propositions CR2, CR4 and EN3 were mentioned even less frequently in the final version of the written product. This was surprising because in the final version it was expected that students would mention more propositions from the reference concept map when giving explanations. Furthermore, it was remarkable that some students wrote a text in which they explained the differences in carbon dioxide emissions between the production chains of animal and plant protein-rich food products without referring to cellular processes.

From the interviews conducted after LT activity 5 it was clear that students were able to explain the aim of writing environmental advice. For example, one student (no. 21) said: "To show how the production of proteins in both plants and animals leads to carbon dioxide emissions." The interviews conducted after LT activity 8 showed that the four students were able to mention most of the individual propositions but found it hard to apply these propositions in the advice. Student 21 said: "I don't know how these cellular processes are involved in the growth of animals." Moreover, interrelating cellular respiration and biosynthesis was difficult. Students seemed to regard the conversion of glucose into either carbon dioxide or proteins as unidirectional processes. One student (no. 21) said: "As soon as you have the proteins, they can't be used for cellular respiration and turned into carbon dioxide anymore." Another student (11) said: "If a chicken eats proteins, it grows

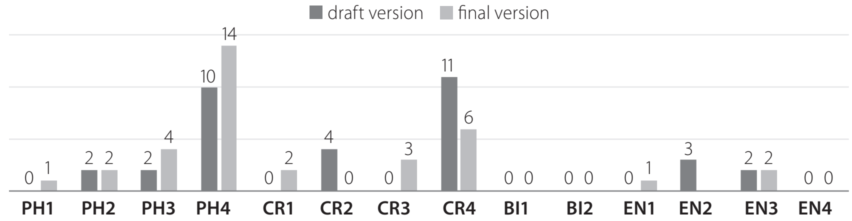

Figure 4.7 Numbers of students (n=27 in draft version, n=24 in final version) who mentioned propositions in products of writing assignment.

The codes refer to the propositions shown in the reference concept map as presented in Figure 4.1.

because proteins are building blocks." It appears that ignorance of digestion processes, chemical structures of molecules and other chemical breakdown processes (than cellular respiration) hinders students in establishing a clear line of reasoning.

Although students understood the aim of the advice, they all said they needed more support at the beginning of the writing process. This mainly concerned LT activity 5. During LT activity 8 they could build on their drafts from LT activity 5. One student (11) said: "After the teacher explained which cellular processes had to be used in the advice it became clear to me. I found it hard to find the appropriate information from the manual myself." Apparently, more guidance was needed to switch from the context to the (underlying) concepts. When asked how they valued both writing activities the four students considered them as useful. Student no. 26 said: "The writing activities forced me to think about everything, so I learned from it. The written text was a kind of summary of the lesson sequence." The post-lesson evaluations revealed, however, that the students had divergent opinions about the usefulness of the writing assignments. Ten students mentioned that the assignments were too difficult for them. This was also confirmed by the teacher. He said: "The step from constructing chemical equations during my explanation to integrating these equations in a text is too big for many of these students. They had to explain differences in energy loss and carbon dioxide release during protein production by connecting these complex chemical processes. During the brainstorm phase I noticed this was very difficult for them and, although they really tried, most of them did not know how to start writing a text. I think the time spent on this topic in advance of the writing activity was too short."

4.4.2.6 LT activity 6: reflecting on a hands-on activity with soya plants

In LT activity 6 the students weighed the soya beans of one plant and calculated the number of proteins produced by this plant. This was followed by a teacher-guided reflection in which propositions were explicated in order to give a biological explanation.

It was intended that the teacher would ask questions to help students explain why more agricultural land is needed to produce animal proteins compared with plant proteins. The evaluation of the steps described in the research scenario (Table 4.1) showed that the teacher "taught by telling" and did not really support students in active thinking. From the interview with the teacher it became clear that there was less time for conversation and that he thought that relating the three processes to the context was probably too complex and too abstract for these students. This forced the teacher to give an explanation himself because "interactions take time."

In the student interviews we asked them to explain why much more agricultural land is needed for the production of a quantity of animal proteins compared with the same quantity of plant proteins. Students gave reasonable explanations such as: "For the production of animal proteins one extra step in the food production chain is required." None of them, however, referred to the metabolic processes. Apparently, more scaffolds are required to help students connect the concepts to the context when reasoning. Only two students (nos 13 and 26) referred to proposition EN5 (energy for cellular activity can be released from proteins). Student (no. 13) said: "Part of the proteins that animals consume is converted into energy and waste and therefore the production of animal proteins requires more agricultural land."

All four students were positive about the hands-on activity with the soya plants and the subsequent calculations. One student (no. 11) remarked: "The focus on protein production meant the relation with the previous lessons became clear to me." Another student (no. 13) said: "By weighing the soya beans of one plant and calculating how many soya beans a chicken consumes during its life you know how much agricultural land is needed for one chicken."

4.4.2.7 LT activity 7: concept mapping

In this LT activity nine groups of students constructed two concept maps during two lessons. The focus questions of these concept maps were: *how do plant cells produce proteins?* and *how do animal cells produce proteins?* This LT activity was structured in several steps during the mapping process. In the reflection phase it was intended that the students would be prompted to explain the differences between the processes in plant cells and animal cells. Only this last step was not recognised as intended (Table 4.1).

Figure 4.8 presents the groups of students who showed propositions in their concept maps. It was mainly the energy propositions (EN1, EN2 and EN4) which were incorrect or lacking. This was also recognised by the teacher. He said in an interview: "I noticed that many students had problems with the term chemical energy and even more with ATP." It also appeared that the concept maps helped the teacher to point out exactly which propositions were problematic for students.

In student interviews they were asked to explain how the three metabolic processes are involved in protein production in plant and animal cells. All four students explained

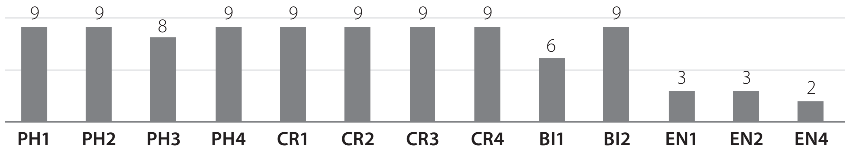

Figure 4.8 Numbers of groups (n=9) consisting of 2, 3 or 4 students who mentioned propositions related to the concepts of photosynthesis (PH1-4), cellular respiration (CR1-4), biosynthesis (B1 and B2) and energy (EN1, EN2 and EN4) in products of a concept-mapping activity.

The codes refer to the propositions shown in the reference concept map as presented in Figure 4.1.

the relation between photosynthesis and cellular respiration. They seemed to feel confident when talking about these processes but they all had problems when linking photosynthesis to biosynthesis. The role of glucose as a "building block" to produce proteins was not clear to them. Student no. 26 said: "I think the proteins in animal cells are there because animals consume protein-rich food." He also remarked that biosynthesis was still a rather vague concept. Student no. 21 thought that only ATP and minerals are needed for biosynthesis to produce proteins. When asked to explain why photosynthesis is the basis for protein production only student no. 11 was able to connect this to the production of glucose needed for biosynthesis.

Students rated the concept-mapping activity as very useful. This was also confirmed by almost all students in the post-lesson evaluations. Interacting in groups and comparing and discussing their own concept maps with those constructed by other groups were mentioned as positive aspects of this LT activity. Moreover, during the mapping activity the teacher prompted students to explain the relations between concepts and gave feedback.

4.5 Discussion

The two central research questions addressed in this study were: *how does students' conceptual coherence develop during a context-based lesson sequence?* and *how do context-embedded LT activities influence the development of conceptual coherence?* Following a design-based research approach we described how a context-based lesson sequence in biology was designed, conducted, and evaluated on its practicability and effectiveness. First, we discuss reported changes in mentioning propositions (as presented in section 4.4.1) and give explanations for unexpected findings. Then, we use findings from the eight examined LT activities (as presented in section 4.4.2) to reflect on the design principles and to adjust or specify these design principles. These design principles can be used to optimise both the design and execution of future context-based lesson sequences. Finally, we reflect upon the usefulness and limitations of the research scenario and the reference concept map with a view to future research on context-based science education.

4.5.1 Development of conceptual coherence

The significant gains in test scores for mentioning propositions from the reference concept map indicated that students' conceptual coherence developed during the lesson sequence. More specifically, students were better able to mention propositions related to just one of the core concepts than propositions between core concepts. Mentioning propositions that included the core concept of energy appeared extremely difficult, even at the end of the lesson sequence. Other consistent findings in our data were students' attempts to mention more concepts and propositions in their explanations. This indicates that switching their reasoning to the cellular level of biological organisation improved.

Nevertheless, the results indicated that the gains in mentioning propositions were limited. This is slightly surprising because much efforts was made during the design process to support students in overcoming the reported learning problems on this topic. Possibly learning the conceptual framework as presented in the reference concept map might be too difficult for many of these students at this level of education, especially given in the short time span of ten lessons. In respect of the same type of explanatory tasks, Songer and Mintzes (1994) showed that even between novice and experienced university biology students, there were hardly any significant increases between their ideas on photosynthesis and cellular respiration. Difficulties in both teaching and learning this topic were also recognised by Mohan et al. (2009) who reported that even at the end of high school no more than half of the students were attempting to use, more or less consistently, chemical processes to explain macroscopic and large-scale events. Only 10 percent of the students distinguished matter from energy during metabolic processes. The other 90 percent of the students were not able to describe chemical changes based on scientific principles such as the conservation of matter and energy. This is also in line with our findings. We found that alternative (incorrect) understandings concerning the energy concept did not disappear. Students still had problems interrelating two (or more) metabolic processes and they did not understand the conservation and transformation of matter and energy in the metabolic processes. Lin and Hu (2003), who showed that 13-year-old students failed to interrelate biological concepts concerning energy flow and matter cycling, pointed out that a lack of chemical and physical interpretations when teaching biology is one of the causes of this failure. Moreover, it seemed that at the beginning of the lesson sequence there was a lack of basic understanding of the concepts of energy and matter. Therefore, we recommend that lessons in chemistry, physics and biology pay more attention to providing a common base for these concepts. For instance, in ninth-grade science lessons the focus could be on conversations of forms of energy and matter in meaningful contexts. In addition, we recommend that the conceptual network (or parts of it) needs frequent revision during the course of the curriculum. There are opportunities to relate the conceptual network to a variety of context-areas like health, sport and environment.

We now try to give explanations for the limited gains in mentioning propositions based on our research approach which emphasises the relation between design, its conduction and the learning outcomes. Moreover, we propose some adjustments to the lesson sequence. First, the findings showed that in the teacher's explanations there was a lack of specific attention to the chemical notation of glucose ($C_6H_{12}O_6$) and the idea that the C-bindings contain energy in a chemical form. Therefore, students found it hard to trace matter (C-atoms) and energy in all three metabolic processes. Second, giving too much attention to the concepts of carbon dioxide and oxygen supported students' intuitive ideas. They persisted in thinking that photosynthesis and cellular respiration are solely opposite gas-exchanging processes (Cañal, 1999), without regarding them as energy-transforming processes. This is another reason to focus sooner, more intensively and more frequently on glucose as a connecting concept between the metabolic processes. We expect that a focus on the chemical structure of glucose will support students' understanding of the concept of chemical energy and transformation of energy and matter in relation to the three metabolic processes. Therefore, we propose an LT activity in which students build a chemical model of glucose with attention to the energetic bindings between the C-atoms. Third, the introduction of the concepts of biosynthesis and chemical energy lasted until the end of the second context. Therefore, relatively less time was available to master these concepts compared with photosynthesis and cellular respiration. This suggests that the number of concepts that are introduced in a lesson sequence should be balanced with the number of lessons. According to the theoretical basis of the concept-context approach, however, it is preferable that there is a logical reason to introduce a new concept (Boersma et al., 2007). This dilemma is bound up inextricably with the design and study of a single context-based lesson sequence as presented in this paper. A sequence of contexts in a spiral curriculum would solve this problem. Then each concept could be drip-fed into the lesson and revisited in-depth and in more than one context.

4.5.2 Influence of context-embedded LT activities on the development of conceptual coherence

The first design principle (*focusing on familiar concepts*) was elaborated in the LT activities 1 (performing a role play) and 2 (filling out a pre-structured concept map). The findings showed that the simulation of interactions in a social practice during the role play was very suitable for engaging students in the context. Filling out the pre-structured concept map helped students to see which concepts were involved in the given context and how they were interconnected. Moreover, because both LT activities offered an excellent opportunity for a class discussion in which the teacher could connect to students' prior conceptual knowledge and subsequently help students to focus on the conceptual framework underlying the context.

The second design principle *(focusing on core concepts)* was elaborated in the LT activities 3 and 4. These two LT activities were characterised by hands-on activities using visualisations (Figures 4.3, 4.4 and 4.5) in which students, in interaction with each other, had to draw arrows and connecting lines, respectively. Both LT activities resulted in classroom discussions in which the teacher helped students to focus on core concepts. The evaluation showed convincingly that the visualisations helped students to structure their thoughts and to link the context to concepts and vice versa.

The third design principle *(stimulating students to interconnect concepts)* was elaborated prominently in LT activities 4.7 and 4.8 (concept-mapping and second writing activity). The results showed that many more propositions were established during the concept-mapping activity (Figure 4.8) than during the writing assignment (Figure 4.7). This is not surprising because students constructed the concept map while discussing in a group and all concepts were already given. Moreover, expressing conceptual thinking allowed the teacher to judge which concepts and propositions were problematic and to start an interaction, e.g. by asking questions that triggered students to formulate propositions. This is in line with previous research showing that concept-mapping is a very supportive LT activity which promotes active thinking and construction of new propositions (Nesbit & Adesope, 2006). Establishing propositions when reasoning during the individual writing process, proved to be difficult for many students. It seemed that students who lacked a certain level of conceptual understanding experienced problems when reasoning. Moreover, much variation between students was observed in their abilities to write a text. This could be associated with metacognitive abilities required to structure their writing. Therefore, it is recommended that the writing assignment is adjusted at some points. Differentiation and more scaffolding are needed, for instance by providing sample sentences to individual students on demand. A remarkable difference that was observed between the concept-mapping activity and the writing assignment was the role of the teacher. During the concept-mapping activity the teacher was able to provide much more support, for instance by asking critical questions and giving feedback. When students are allowed to demonstrate their conceptual thinking, productive interactions are evoked between teacher and students and between students. Therefore, we suggest the following specification of the third design principle: make conceptual thinking visible when interconnecting concepts.

The fourth design principle (*reflecting on conceptual relationships within a context*) was elaborated prominently in LT activities 5 and 6 (first writing activity and reflection on hands-on activity). From the evaluated research scenario it became clear that the reflection phases of these LT activities were not conducted as intended. This also applied to other reflection moments in the lesson sequence. More guidance on structuring these reflection moments is apparently needed. A well-thought questioning strategy could be helpful here. Such a strategy should elicit what students think, encourage them to elaborate on their previous answers and ideas and help them to construct conceptual knowledge. The teacher should be prepared in terms of which questions to ask and the sort of responses from students which can be expected to them. We suggest that parts of the reference concept map underlying the contexts (see Appendix C) function as a “roadmap” to structure such a question strategy and help teachers to adapt questions to students’ answers. The “question-based discourse” analytic framework developed by Chin (2006) would be useful to stimulate productive thinking during reflective moments. Therefore, as a specification for the fourth design principle we advise: use a questioning strategy when reflecting on conceptual relationships in a context.

4.5.3 Reflection on use of the reference concept map and the research scenario

Studying the influence of a context-based learning environment on the learning of concepts is a challenge which is also recognised in other context-based projects (e.g. Pilot & Bulte, 2006). We showed that a design-based research approach can shed light on the mechanism involved in teaching strategies and learning processes. This section reflects on the usefulness and limitations of two innovative elements in our design-based research approach: the reference concept map (Figure 4.1) and the research scenario (Table 4.1).

4.5.3.1 Reference concept map

The reference concept map was used in two ways: to guide the design process and to assess students’ learning outcomes. Because the reference concept map was the result of a systematic analysis of school books, literature and discussions with experts, it functioned as a theoretically and empirically underpinned framework from which learning objectives could be derived. During the design process decisions could be legitimised by pointing out which concepts and propositions from the reference concept map were involved. Therefore, implicit decisions about the selection of social practices, the transformation of these social practices into contexts suitable for integration into the lesson sequence and the structuring of promising LT activities could be explicated.

With respect to the evaluation of students’ learning outcomes this study showed that using the reference concept map as an assessment tool gave a clear focus for analysis. Multiple types of data sources, including those which were derived from a naturalistic setting, were analysed on the occurrence of (intended) propositions systematically and with high validity, as indicated by the high Cohen’s Kappa values (see section 4.3.4). Analysing these multiple data sources in a unified way allowed triangulation. Although analysing changes in concept maps of individual students could be a useful—and often logical—methodological approach to measuring conceptual coherence (Novak, 2005;

Pearsall, Skipper, & Mintzes, 1997), this would not have been suitable for the purposes of the case study presented here. Testing the effects of concept-mapping activities would have clouded the learning effects of the intervention, all the more because the reported intervention covered a relatively short period of only ten lessons.

There were two limitations in the way we used the reference concept map to assess students' conceptual understanding, however. First, different types of data sources cannot be compared one-to-one with high validity if they are not identical. For instance, the extreme rise of PH2 in the final test compared with the explanatory tasks in the post-test (from 3 to 24, Figure 4.6b) could suggest that the cues that prompted students to mention this proposition were different. In the post-test this proposition was probably elicited more easily. Second, scoring only correct propositions from the reference concept map seems to give only a rough indication of students' conceptual coherence. A subtle improvement in students' understanding such as the observation that students gradually shifted their locus of explanation from the organism to the (sub-)cellular level of biological organisation, could not be detected. We observed that students often used common language instead of biological terms ("Animals need food to burn and to get energy"). On the other hand, when students mentioned the biological terms as presented in the reference concept map they often did not formulate the exact proposition ("Sunlight is needed to produce glucose"). These indications of a certain development of conceptual coherence were not detected with our assessment method using the reference concept map. This might also explain the relatively low number of students who showed improvement in the post-test and—to a lesser extent—in the final test.

For future research an even more discriminating assessment tool could be developed in which each proposition is subdivided into progressive levels of understanding. Students' responses could be categorised into these levels. For instance, when a student remarks: "A plant needs sunlight to produce food" this is correct but does not prove an understanding of the involvement of metabolic processes at the cellular level of biological organisation. Therefore, this remark could be seen as an intermediate level of understanding of the propositions PH1 (energy from sunlight is needed for photosynthesis) and PH2 (photosynthesis produces glucose). This would require test items to be developed carefully in order to evoke responses in which different levels of propositional understanding could be recognised. Moreover, these different test items that trigger students to mention the same proposition should be validated. Furthermore, analysing the degree to which students mention combinations of propositions in one response would indicate their conceptual coherence at a higher level. We should, however, be aware that a single assessment tool always gives a limited interpretation of student's understanding (Mintzes et al., 2005). We have shown in this paper that it is the accumulation of multiple data sources obtained through multiple means of data collection that results in a coherent description of the learning and teaching processes.

4.5.3.2 Research scenario

The aim of the research scenario was two-fold. First, because it was constructed in parallel with the design of the lesson sequence the designers were forced to consider each step of the lesson sequence carefully. Second, it was used to evaluate the design on its practicability (Ummels et al., 2014). This evaluation (section 4.4.3.4 and Table 4.1) provided insight into the quality of each of the LT activities within the lesson sequence. If steps were conducted as intended by the teacher but did not result in the intended learning outcomes this gave input useful for adapting the written design. If steps were not conducted as intended by teacher or students the learning outcomes had to be considered carefully. This analysis made it clear that the specific actions of the teacher are extremely important in terms of students' conceptual learning. For instance, the language and phrasing used by the teacher when explaining complex concepts like the energy concept need to be balanced: on the one hand, simplifications of a complex topic can all too easily confirm students' misconceptions; on the other hand, students become lost when the teacher gives too much content-specific information. In conclusion, for future design-based research on learning concepts within context-based education we recommend both the use of a reference concept map and a research scenario to keep a focus on the research aims and to gain an in-depth understanding of teaching strategies and learning processes.

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5

Conclusion and discussion

5.1 Introduction

The objective of this research project is to provide insight into the mechanisms involved in the development of students' conceptual coherence within biology education based on the concept-context approach. Therefore, the main research question is:

"How can the development of students' conceptual coherence be promoted within biology education based on the concept-context approach?"

To address this question we adopted a design research approach. Based on a theoretical framework and explorative empirical research, we formulated four initial design principles for the promotion of conceptual coherence within contexts. These initial design principles evolved during the course of this research project. We elaborated them for a concrete setting: the design of a lesson sequence about a specific topic in the domain of biology. We chose a topic that is difficult to learn and teach: energy and matter transformation in the metabolic cell processes of photosynthesis, cellular respiration and biosynthesis. Further, promising learning-teaching (LT) activities to promote conceptual coherence were selected, and integrated in the lesson sequence. The lesson sequence was administered in two iterative case studies and evaluated on its practicability and effectiveness. For the evaluation of practicability, a research scenario was used to determine to what degree the activities of the teacher and students were actually performed as intended. For the evaluation of effectiveness, a reference concept map was constructed and used to assess the development of students' conceptual coherence. Using a combination of the research scenario and the reference concept map provided an insight into the learning-teaching mechanism involved in the development of conceptual coherence during the concept-context-based lesson sequence.

In section 5.2, we return to the four sub-questions (Table 1.3) and summarise the general conclusions from the previous three chapters. Next, we answer the main research question in three parts. First, in section 5.3, we focus on the development of conceptual coherence with respect to the domain-specific topic. We consider propositions from the reference concept map that were mentioned by the students. In particular, we discuss the propositions that fell short of expectations, which suggest an interrupted learning process. This results in four recommendations for the adaptation of the lesson sequence. Second, in section 5.4, we discuss three LT activities and focus on the way in which they can be structured in a context in order to promote the development of conceptual coherence. Third, in section 5.5, we reflect systematically on each of the design principles and provide points of interest when elaborating these design principles. In addition, we describe measures that were taken in our research design to ensure that these design principles can be generalised for use in other settings outside this research project. Then, in section 5.6, we critically reflect on the research project with specific attention to the usefulness and limitations of the two instruments that were used for the design of the lesson sequence and evaluation of the learning-teaching process: the research scenario and the reference concept map. Finally, in section 5.7, we consider implications for secondary biology education and teacher education and propose directions for future research.

5.2 General conclusions

In this section, we summarise the general conclusions from the three previous chapters. Therefore, we return to the four sub-questions (SQ) that structured this research project (Table 1.3).

In Chapter two, we explore to what extent tenth grade students in senior general secondary education develop conceptual coherence during a concept-context-based lesson sequence (SQ-1). We demonstrate the value of a reference concept map as an instrument to provide insight in the abilities of students to mention propositions at several moments during the course of a concept-context-based lesson sequence. We show that the total number of propositions that students mention correctly increased during the course of the lesson sequence. However, some propositions fell short of expectations. This concerns in particular the propositions related to biosynthesis and energy.

In Chapter three, we answer the question how a concept-context-based lesson sequence, aimed at promoting conceptual coherence, should be designed and evaluated regarding its practicability (SQ-2).

We demonstrate that the four design principles are useful to structure the contexts and align them with learning goals for conceptual coherence, as depicted in the reference concept map. Furthermore, this alignment is made visible in a research scenario that systematically and accurately describes how the teacher should act to generate student activities that are expected to promote conceptual coherence. We point out that the research scenario is a valid instrument to score the degree of correspondence between intended and actual activities and to seek explanations of the scores. We show how the research scenario provided us with detailed information on the learning-teaching process and how this allowed us to identify aspects of the lesson sequence that had to be adapted. For example, this applies to the activities in which students reflected on the use of propositions in the context. These were not performed as intended.

In Chapter four, we deal with the questions how students' conceptual coherence develops during the revised concept-context-based lesson sequence (SQ-3) and how context-embedded LT activities influence this development (SQ-4). We demonstrate how we combined the research scenario and reference concept map to elaborate the design principles systematically in the revised version of the lesson sequence. Moreover, we show how these two instruments, complemented with semi-structured interviews, were used to evaluate this lesson sequence on practicability and effectiveness. This generated in-depth information on students' development of conceptual coherence with respect to the domain-specific topic and allowed us to identify impediments to this development. Next, we demonstrate how eight context-embedded LT activities, that are elaborations of the four design principles, appear to influence the development of conceptual coherence. Based on these empirical findings, we conclude that the use of the four design principles for the structuring of LT activities in contexts has a high potential to create a powerful context-based learning environment for the promotion of conceptual coherence. In the next three sections, we will discuss the empirical findings from the case studies in more detail.

5.3 The development of conceptual coherence with respect to the domain-specific topic

In this research project we define conceptual coherence as: "the ability of a person to establish scientifically accepted meaningful connections between concepts" (section 1.1). Based on the literature (section 1.1), it is expected that contexts can facilitate the development of conceptual coherence. We define contexts as "representations of existing scientific, professional or real-life communities of practice in which participants perform goal-oriented activities" (section 1.2). As a measure for conceptual coherence, we analysed which connections between concepts (called propositions) students were able to mention during the course of a lesson sequence. We focused on a limited set of propositions that was depicted in a reference concept map (Figures 1.1, 2.1, 3.1 and 4.1). A variety of data collection strategies was used to elicit responses from students that were expected to include these propositions. The data were generated from (pre-, post- and final) tests, written products and concept maps and were analysed with non-parametric tests in a quantitative way. The degree in which certain propositions were or were not mentioned at a certain moment, compared to the propositions that were intended to be mentioned, provided information about the development of conceptual coherence. Furthermore, data from written responses, video-recordings in the classroom and semi-structured interviews were analysed qualitatively, to obtain more specific information about the learning-teaching process.

The findings of both case studies illustrate that the total number of propositions from the reference concept map that students mentioned at the pre- and post-test increased significantly (sections 2.4.2 and 4.4.1). This indicates that students' conceptual coherence improved during the course of the context-based lesson sequence. This is supported by data from the semi-structured interviews, in which students articulated more and more concepts and propositions from the reference concept map. In addition, when students were asked to give explanations for biological phenomena, they improved their articulation of concepts and propositions from the reference concept map during the course of the lesson sequence. This suggests that the students showed improvement in switching their thinking from the (observable) organism level of biological organisation to metabolic processes at the cellular level. When we compare individual propositions that were mentioned at the pre- and post-test, the improvement is less convincing.

Both case studies show that some individual propositions fell short of expectations. This applies especially to propositions related to the core concepts of energy and biosynthesis. Based on the results of the first case study, we paid more attention to these core concepts (and related propositions) in the design of the lesson sequence for the second case study. For instance, during the interactive lecture (see Appendix B) there was more focus on the concepts of energy and biosynthesis and during the concept mapping activity the teacher was instructed to ask questions that evoked responses in which students were intended to mention sentences that included these propositions. It was expected that this allowed the teacher to give adequate feedback. However, the interviews that were conducted in the second case study revealed that the context-based lesson sequence was still not completely adequate to help students attain the intended learning goals, i.e., to articulate the propositions related to the core concepts of energy and biosynthesis in conjunction with the reference concept map. In the qualitative analysis we focused on these two core concepts. Findings from both case studies point out that the required knowledge foundation in physics and chemistry that students need to understand and apply these core concepts, was often lacking. For instance, students had difficulty linking the growth of organisms to the synthesis and break-down of molecules in cells. In short, it remained difficult to understand for many students: (1) how organic molecules can contain (chemical) energy; (2) that changes in the molecular structure are accompanied by changes in chemical energy; and (3) that energy can be transformed from one form to another. This hindered students' understanding of the cycle of atoms and energy in ecosystems and their recognition that the chemical and physical principles of transformation and conservation of matter and energy can be applied to all organisms. Although these problems are well-known in the literature (e.g., Barak, Gorodetsky, & Chipman, 1997; Chabalengula, Sanders, & Mumba, 2012; Jin & Anderson, 2012; Lin & Hu, 2003), we underestimated the limited relevant knowledge in physics and chemistry that the students in our research possessed at the start of the lesson sequence. Moreover, the design of the lesson sequence proved not sufficiently adequate to "repair" this lack of knowledge. We assume that students experienced difficulty in connecting the concepts that were offered in the lesson sequence to their prior conceptual knowledge because of their limited foundation of knowledge in physics and chemistry.

As a result, we now present four recommendations for the adaptation of the lesson sequence. The first recommendation is to accept that the learning-teaching process *requires more time to allow students to master all the concepts and propositions from the reference concept map*. Our research shows that a lesson sequence that has a time span which is too short, i.e., only ten or eleven lessons over a period of three weeks, does not provide students with an adequate foundation of knowledge in physics and chemistry to help them develop the core concepts from the reference concept map. Because we decided not to allow students to study at home during this three-week period (to limit the variation in time that students spent on the lesson sequence), students' "time-on-task" was even more limited. Based on the experiences of curriculum developers on this topic, Roseman, Linn and Koppal (2008) estimated that it would take 8-16 weeks to teach students how atoms form molecules, how atoms are arranged in molecules and how molecules can be rearranged. Teaching students the mechanism of energy transformation in chemical reactions would take even more time. There are also curriculum developers who believe that it is not realistic to teach students the link between molecular structures and chemical energy during high school (Roseman et al., 2008). An attempt to do so may overburden students when they are already struggling to understand the mechanism of matter transformation. However, we do not agree with this assumption, because we expect that the potential benefits for students of understanding the link between (transformation of) matter and energy will justify the extra (instructional) time. Therefore, we advise to focus the learning-teaching process on a relevant domain in which knowledge of the link between matter and energy is functional for students, e.g., energy conversion in relation to food production and consumption (McMichael, Powles, Butler, & Uauy, 2007) or the cycling of carbon in relation to climate change and global warming (Mohan, Chen, & Anderson, 2009).

The second recommendation is that the learning-teaching process focuses on *the underlying chemical and physical principles that are needed for students to understand the biological concepts and propositions from the reference concept map*. Therefore, the curricula of the science subjects need to be aligned. Our research provides indications how such alignment can be realised in practice. We propose that, prior to the administration of the lesson sequence in the biology curriculum, certain topics should already have been administered in the physics and chemistry curriculum, i.e., different forms of energy (and transformation of energy from one form the another) in the physics curriculum and matter transformation during chemical reactions in the chemistry curriculum. Intensive interaction between the teachers of these science subjects is essential. This was also confirmed by a Dutch project in which teachers of the three disciplines cooperated intensively and collectively prepared lessons about the concept of energy (Lichtenegger, Genseberger, Mooldijk, & van der Kooij, 2004). As a result of this cooperation, teachers felt more confident and better able to adjust their instruction to students' prior knowledge. It is worth noticing that the concept of energy has also been recognised as the most prominent concept that cuts across the curricula of the science subjects (Boersma, Bulte, Krüger, Pieters, & Seller, 2010).

Our research indicates that, in the cooperation between science teachers, focus on a common and accurate use of vocabulary about matter and energy across the disciplines is important. This refers to both the written and spoken language. For example, with respect to the written language, video-observations revealed that the teacher wrote the concept of glucose in the chemical reactions of cellular respiration and photosynthesis on the white board (section 4.4.2.3). If he had used the chemical notation of glucose ($C_6H_{12}O_6$) consistently during the lesson sequence, this would have enabled students to trace atoms and forms of energy in these metabolic processes. Helping students to follow carbon atoms during cellular respiration in a consistent way also appeared successful in the design research of Wierdsma (2012). As for spoken language, we found that the teacher (who was very experienced) easily made mistakes during instruction with respect to the principles of matter and energy conservation. For instance, the teacher said: "Here is glucose and during cellular respiration this matter is partly transformed into energy" (section 4.3.4). As a consequence, students might conclude that the first law of thermodynamics (energy can be transformed from one form to another, but cannot be created or destroyed) does not apply to the domain of biology. This is also recognised in the literature. Students often have difficulty applying principles of the "non-living world" to the "living world", i.e., to use these principles to explain natural phenomena in relation to living systems (Barak et al., 1997).

A third recommendation is that the learning-teaching process focuses on *the essential concepts that have the potential to help students master other concepts and propositions from the reference concept map*. In this research, this refers to the concept of glucose, which can be considered as the "linking pin" between the three metabolic processes. The findings of the second case study indicate that focussing on the chemical structure of glucose and the chemical energy that this molecule stores helps students to understand transformation of matter and energy (section 4.5.1). This is in line with the ideas of Jin and Anderson (2012), who state that "associating chemical energy with specific configurations of atoms in organic molecules and tracing energy separately from matter are essential for analysing biochemical systems" (p.1177). Furthermore, we expect that most students are familiar with the term "glucose" from real life, e.g., as a nutrient or as an energy supplier in food. Therefore, we assume that glucose can form a bridge between students' intuitive notions of the concept of energy and scientific notions of the concept of energy.

A fourth recommendation is that the learning-teaching process focuses on *overcoming knowledge gaps as a requirement for uninterrupted conceptual development*. The findings of both case studies point out that the learning process of students who missed one or more lessons and students who seemed to have a weak foundation of knowledge in physics and chemistry was interrupted. These students could not keep up with the pace in which new concepts were introduced in the lessons. As a consequence, they did not succeed in integrating these concepts into their cognitive networks. This applied predominantly to the students who did not follow the subjects chemistry and physics for their graduation (in both case studies, approximately 20 percent of the students). Although we did not focus on the learning process of these students in particular, it seems that these students learned mainly by memorising the propositions from the reference concept map.

Reasoning about energy and matter transformation and establishing propositions that were not part of the reference concept map, appeared difficult for them. For example, in one of the interviews in the second case study, one of the students said: "As soon as you have the proteins, they can't be used for cellular respiration and turned into carbon dioxide anymore" (4.4.2.5). Apparently, this student–who did not study chemistry and physics for graduation–was not aware of the chemical structure of proteins and the notion that biosynthesis transforms the chemical energy in glucose into chemical energy in proteins. Therefore, we assume that when the lesson sequence offers several opportunities to differentiate between individual students, this helps them to overcome their (initial) knowledge gap(s). In the next section, we will discuss how LT activities in relation to contexts might provide such opportunities.

5.4 The role of learning-teaching activities

In the General introduction, we described how three promising LT activities intend to promote the development of conceptual coherence: classroom conversations, concept mapping and writing activities (section 1.5.2). These three LT activities were adapted to the contexts in the design of the lesson sequence. We will discuss, inspired by empirical findings from the case studies, how these LT activities–in relation to contexts–can promote conceptual coherence.

5.4.1 Classroom conversations

In each of the contexts, the questions the teacher asked during classroom conversations appeared essential. These questions helped students link these contexts to their prior conceptual understanding, and subsequently, to integrate new concepts into their conceptual (cognitive) frameworks. As discussed in Chapter one, we distinguished two types of classroom conversations, i.e., dialogic and authoritative conversations. For an optimal learning process, in which students develop conceptual coherence, a balance between the two types of conversations is advised (Scott, 1998). In the case studies, we observed that mainly in the family context the teacher asked open questions that characterised a dialogic conversation. In response to a question, we noticed that many students were willing (and presumably able) to respond. However, a limited number of concepts was embedded in this context. As soon as the teacher focused on the core concepts and related propositions in the other contexts, we noticed that the teacher asked more questions that are associated with an authoritative conversation. This type of conversation was mainly observed in the context of the environmental advisor and the agricultural researcher. As a result, the number of students that participated in the conversation decreased. Probably, because the students did not understand the questions that were asked, they did not participate in classroom conversations. We assume that they did not connect their own conceptual knowledge with new concepts that were introduced by the teacher. As a consequence, the teacher posed closed questions, answered questions himself, or did not pose any questions at all; he just "taught by telling."

There were also moments in the lesson sequence in which the teacher succeeded in guiding a dialogic conversation and in which he paid attention to students' prior conceptual knowledge. We use empirical findings from these moments to show how contexts offer opportunities to structure a dialogic conversation. It appeared that, as soon as the teacher presented the context visualisation (Figures 4.3 and 4.4), the classroom conversations had a dialogic nature. The teacher used the context visualisation to pose an overarching guiding question that illustrated the objective of the conversation. After such a question, the teacher was better able to ask follow-up questions that were adjusted to students' prior conceptual knowledge. In this way, the visualisation of the context functions as a framework for questioning. Furthermore, context visualisations prove useful to structure questioning approaches (Table 1.2). For instance, *semantic tapestry* was used by starting at the level of the organism (depicted in the visualisation of the context). From there, the teacher asked questions that helped students to zoom in on metabolic cell processes at the sub-cellular level (and related concepts from the reference concept map). In addition, the context visualisations offer the teacher opportunities to formulate questions from the perspective of one of the participants (e.g., the environmental advisor). This opportunity was also recognised by the teacher (section 4.4.2.3).

However, there are even more opportunities to structure a classroom conversation in context-based education. By starting with a "problem" from the perspective of a participant of a context, the teacher can ask questions in the direction of a final solution. This corresponds with the problem-posing approach (Klaassen, 1995). For example, a problem could relate a drought climate which limits the growth of soya plants, resulting in a low amount of (protein-rich) soya beans for consumption. In line with this problem, a question from the perspective of the agricultural researcher could be: How can we improve the protein production of soya plants in dry areas? Such a question can be divided into sub-questions that contribute to a part of the solution. For example, one such sub-question is: What do soya plants need to grow? By making an inventory of students' responses, the teacher can identify students' levels of understanding. This offers opportunities to differentiate between students, for instance, by giving some of them additional instruction. Moreover, the teacher can discuss the responses, not necessarily by indicating which ones are right or wrong, but by indicating which elements of each response are useful for the participant in the context. This may motivate students for the next sub-question. Then, the teacher can pose a new sub-question from the perspective of the participant to focus the students' learning process on the concepts to be learned. For example, the teacher says: The agricultural researcher decided to focus on the influence of water. How much water do soya plants need? In this way a context can structure a classroom conversation in order to contribute to the development of conceptual coherence.

5.4.2 Concept mapping

Two types of concept mapping activities were integrated in the design of the lesson sequence: filling out a pre-structured concept map and constructing a concept map with given concepts. The assignment in which students had to fill out concepts in a pre-structured concept map (Figure 4.2) was added to the design of the lesson sequence for the second case study. The aim of this adjustment was to help students recognise the concepts from the reference concept map in a complex problem related to a context. Although students saw this assignment as relatively simple, most of them considered it useful to understand the given problem. Moreover, the teacher indicated that the pre-structured concept map appeared to be very suitable for a guided classroom discussion. For example, he summarised the relations between concepts in the context and focused on some of the (biological) concepts that were intended to be learned. In this way, the shared visualisation of the concept map provided a "reference point for discussion" (Kinchin, 2011, p. 186). Additionally, the pre-structured concept map is useful to help students identify the essential (biological) concepts that have to be learned. Furthermore, when pre-structured concept map assignments are embedded in several contexts, this offers opportunities for the teacher to compare the concept maps and focus on the ways in which similar concepts (meaning concepts with similar labels) are connected to other concepts in each of the concept maps. When students learn how concepts reappear in contexts, this helps them to recontextualise concepts and, therefore, promotes conceptual understanding. In section 5.7, we address further opportunities for recontextualisation in relation to the development of conceptual coherence.

In both case studies the lesson sequence contained a LT activity in which students, in groups of three, constructed concept maps with (biological) concepts that were embedded in the previous contexts. Essential for this LT activity was the introduction of the focus question, that helped students to construct propositions, which were functional within the context. In these concept maps, students mentioned many propositions from the reference concept map (Figures 2.2 and 4.8). We also observed many social interactions during this LT activity in which students discussed the definition of the propositions. Both the teacher and the students valued this activity. All these findings support the idea that concept mapping activities contribute to the development of conceptual coherence (Nesbit & Adesope, 2006).

Moreover, because students' thinking was made visible, the teacher was able to give adequate feedback adjusted to each group. There are also opportunities for differentiation. The teacher can give an extra set of concepts to groups of students that are faster than the others. Furthermore, groups of students that experience difficulty with establishing certain propositions in the concept map can get suggestions. In conclusion, we found that concept mapping activities are effective for focusing on relations between concepts within one context and between contexts, to stimulate students to establish new propositions, to generate productive student-student and student-teacher interactions, and to differentiate between groups of students. This agrees with the assumption that, in addition to the actual concept maps, the learning process is especially influenced by the mental processes that occur during the concept mapping activities (Kinchin, 2011).

5.4.3 Writing activities

During the writing process, students are forced to deal with interpretations of scientific concepts, which has been considered an effective way to connect new concepts with prior conceptual knowledge and to make meaning of these scientific concepts (Balgopal & Montplaisir, 2011). In this research, we expected that writing would force students to structure their conceptual knowledge and stimulated them to establish propositions. Because there is evidence that writing, in relation to authentic tasks, fosters knowledge integration (Keselman, Kaufman, Kramer, & Patel, 2007), we embedded writing assignments in contexts of the lesson sequence. In the first case study, the students had to write a text from the perspective of the owner of a restaurant at the end of the lesson sequence. In the second case study, there were two writing assignments from the perspective of an environmental advisor. Students had to write a draft version in the sixth lesson and a final version in the tenth lesson (see Appendices A and B). The findings indicated that students mentioned propositions from the concept map, but fewer than expected (Figures 2.2 and 4.7). These expectations were based on the propositions that students were able to articulate before the writing assignment, for instance during the interviews. A qualitative analysis of the written products revealed that most students had written their texts by reasoning from the perspective of a participant of the context and that they were engaged in the context. However, they often did not retrieve concepts, nor did they establish propositions.

Although this research provides empirical findings to indicate that writing assignments in contexts can be effective to promote the development of conceptual coherence, we assume that they can be even more effective in the following ways. First, it is essential that the writing activity and its purpose are concrete and strongly connected to, or functional in, a context. Announcing the writing activity during the preceding lessons and highlighting a particular line of argument can be helpful. Second, more scaffolding is needed. This requires moments within the lesson sequence in which students are triggered to demonstrate their thinking. Such moments allow the teacher to provide feedback, to ask critical questions and to provide sample sentences for students who need extra support. Third, the writing assignment can be spread out over a longer period in the lesson sequence and contain several steps. Butler (1991) proposed the following steps which seem useful: prewriting, precomposing, writing, sharing, revising, editing and evaluation. For the precomposing step, which intends to focus students' ideas, Butler suggests constructing a "semantic map" (Butler, 1991, p. 108) in groups. This may offer opportunities to combine the writing activity with the concept mapping activity in a context with a focus on the promotion of conceptual coherence.

5.5 Design principles

In the General introduction, we presented four design principles that were developed during the course of this research (section 1.5.1). These design principles are specific for the promotion of conceptual coherence in contexts. We used these design principles to give direction to the design of a domain-specific lesson sequence in biology. In this section, we reflect on the design principles and consider points of interest when elaborating each of the design principles in a lesson sequence (5.5.1). Moreover, we consider generalisation of these design principles (5.5.2).

5.5.1 Reflection on design principles

The first design principle was: *building on familiar concepts*. This design principle builds on the idea that students develop conceptual understanding when they recognise how new concepts can be connected to concepts with which they are already familiar. In the first context, we elaborated this design principle as follows. A complex situation in relation to food consumption and food production was "peeled off" and, eventually, the context focused on a few (familiar) concepts from the reference concept map: carbon dioxide, proteins and energy. These concepts re-occurred in the next context(s) and new concepts were linked to these concepts. Although we knew that students could recognise these concepts from prior education, we were not fully aware of the fact that a gap in students' basic knowledge in physics and chemistry (in relation to these familiar concepts) would hinder their conceptual development. Therefore, in retrospect, we conclude that it is necessary to better investigate the possible basic deficiencies in students' prior knowledge in relation to the familiar concepts, and to overcome these knowledge gaps with the design of the lesson sequence.

The second design principle was: *focusing on core concepts*. When a context is introduced, there are often many concepts involved that belong to different domains in biology. For the teacher, it is a challenge to lead the learning process in the direction of the biologic concepts that have to be learned, without losing too much time and effort to explain context-related issues (e.g., the role and activities of participants in contexts) which are beyond the scope of the learning goals. However, if students do not understand the context, they also cannot understand how biological concepts are functional within the context. During the administration of the lesson sequence in the first case study, it was difficult to consider the metabolic processes from the perspective of the environmental advisor, without losing too much time. To solve this, we developed a visualisation of the context (Figures 4.3 and 4.4) and other visualisations (e.g., Figure 4.5) in order to structure LT activities (e.g., classroom conversations) and to focus on the core concepts in a functional way. We conclude that such visualisations can be successful to elaborate this design principle. Therefore, we recommend incorporating visualisations of contexts in the design.

The third design principle was: *stimulating students to interconnect concepts.* This design principle aims to help students practise their articulation of propositions from the reference concept map. We identified three LT activities that were expected to be promising and had proven successful in other research. From the empirical findings, two points of interest emerged in relation to this design principle. First, if these promising LT activities are embedded in contexts, this offers opportunities for stimulating students to attempt to interconnect concepts in a meaningful way (as discussed in section 5.4). Second, paying explicit attention to making students' thinking visible generates more productive interactions between students and between students and teacher. During these productive interactions students articulate, or attempt to articulate, propositions.

The fourth design principle was: *reflecting on conceptual relationships within a context.* Reflecting on the propositions within contexts can reinforce the sometimes fragile understanding of relationships between concepts that students have established. Such reflection can help students to transfer and apply concepts in new contexts (Bransford, Brown, & Cocking, 2000). Our intention was that the reflection was functional within the context, for example by returning to the main (context-related) problem and formulating a solution to this problem, with an emphasis on the role of the propositions from the reference concept map. However, in both case studies, activities during reflection moments, mainly as a part of classroom conversations, were often not performed as intended. There was no time for reflection in classroom or the students were not able to respond to the teacher's questions during the moments of reflection. This often resulted in a recapitulation given by the teacher, without the intended interaction with students. Therefore, based on the empirical data, we cannot clarify the learning-teaching mechanism that occurs during the intended reflection moments. To make sure that reflection at the end of a LT activity takes place, we propose the following. In the beginning of a LT activity, the teacher looks ahead to the reflection moment. To legitimise this reflection, the teacher emphasises the reason(s) for reflection. Furthermore, the teacher needs a questioning strategy, which he can use to structure a classroom conversation during such a reflection moment. This type of questioning strategy can help the teacher during a classroom conversation to formulate adequate follow-up questions adjusted to students' conceptual understanding. The reference concept map can be used to develop a questioning strategy to reflect on the functionality of propositions in the context.

5.5.2 Generalisation of design principles

In this section, we explore how the design principles, and their elaborations, can be transferred to other settings, meaning that they can be used for the design of other context-based lesson sequences. We consider the measures we took to guarantee external validity of the research design in order to make generalisation of the findings acceptable (Smaling, 2003, 2009).

This research project relies on an "analytic strategy" (Yin, 2003, p. 109) for generalisation of case studies in order to generate a theoretical framework that can be applied to other cases. Theoretical framework is confirmed or adjusted according to the results of multiple case studies. Yin states that "relying on theoretical propositions" (Yin, 2003, p. 111) is the most preferred strategy for ensuring analytic generalisation. We used the results from both case studies to enrich the initial theoretical framework by a process called "replication logic" (Yin, 2003, p. 47). More specifically, we used "literal replication" (Yin, 2003, p. 47) because our case studies were designed to corroborate each other. We describe three distinct measures of our research design to enable analytic generalisation. First, we used learning theories (assimilation theory, cultural historical activity theory, and social constructivism) to predict how the use of contexts promotes the development of conceptual coherence. This resulted in strict definitions of a context, as a representation of a social practice, and conceptual coherence, as the ability to mention propositions from the reference concept map. It is expected that if other researchers use a similar theoretical framework and follow the same definitions of context and conceptual coherence, analogies will be found. Second, we made clear how the theoretical framework (underpinning the design principles) was elaborated in the lesson sequence and in the accompanying research scenario. Subsequently, we analysed the degree in which each activity of teacher and students was performed as intended and how this resulted in students' learning outcomes. Next, we used the research scenario to trace the empirical findings of the students' learning outcomes and the performed activities in the classroom to the theoretical framework of the design. This allows other researchers to follow the influence of characteristics of the educational environment on students' learning process and make generalisations. Third, relevant information about the research setting and participants was given, such as average capacities of the students in both case studies. Moreover, we attempted to keep some variables of the educational environment under control: "Time on task" was kept equal for all students and the teacher was instructed to follow the activities according to the research scenario as strictly as possible. These precautions minimalised the influence of these variables on the learning outcomes. This enables other researchers to find analogies in other research settings.

5.6 Critical retrospective views on the methodological approach

Two specific methodological instruments were developed which were complementary to the design of the lesson sequence: a reference concept map and a research scenario. These two instruments were used for both the design process and the evaluation process. Because these instruments were adapted to the particular design of the domain-specific context-based lesson sequence and its objective of promoting conceptual coherence this ensured–to a certain degree–the validity and reliability of the analysis. Next, the usefulness and limitations of these two instruments are discussed.

5.6.1 Usefulness and limitations of the reference concept map

In this section, we focus on the role of the reference concept map in assessing the students' learning process. We scored the propositions from the reference concept map that students mentioned during the course of the lesson sequence. Due to the design of our research project it was not possible to determine a fixed norm, therefore a norm-reference test was not appropriate for this type of research (Cohen, Manion, & Morrison, 2004). Instead, to assess the development of conceptual coherence, we decided to focus on changes in proposition scores. This is based on the assumption that learning implies change in knowledge structures (Novak, 2010).

In Chapters two and four, we showed that the reference concept map is a useful instrument for revealing how students' conceptual coherence develops during the course of a lesson sequence. Differences in the development of conceptual coherence can be identified separately for each proposition. A strong point of the instrument is the allowance of triangulation. Data from multiple sources and from a variety of sources, including those derived from a naturalistic setting, can be analysed in a unified way. Moreover, because the propositions are strictly defined in the reference concept map, this allows a valid coding procedure, in which students' responses are checked regarding the occurrence of propositions.

Next, we found two limitations related to the way we used the reference concept map to assess the development of conceptual coherence. First, the way in which certain propositions are evoked (e.g., an open or closed question) influences the degree to which students actually mention these propositions. This implies that data from different sources cannot be compared with each other in a quantitative way. Therefore, in this research we only compared the identical pre-test and post-test. For the other measuring moments, we compared the propositions that were actually mentioned with the intended propositions. This enabled us to evaluate measuring moments that occurred in a naturalistic setting. However, it was difficult to determine which propositions were intended for each measuring moment. In future studies, we suggest, in addition to the measuring moments in a naturalistic setting, more identical—and therefore comparable—measuring moments. This can be moments in which students complement and adjust concept maps. Moreover, to determine the robustness of students' conceptual development, the measuring moments have to cover a longer period after the administration of the lesson sequence.

Second, students have maturing conceptual frameworks in which links between concepts begin to form, at least in the beginning of the learning process. As a consequence, they do not immediately succeed in articulating the propositions as strictly as defined in the reference concept map. In an attempt to articulate propositions, they may use common language or articulate single concepts without relating them to other concepts.

Therefore, it is evident that other qualitative data sources are required. For this reason we conducted interviews in the second case study. In further research, we suggest that the reference concept map is used to structure interviews and other qualitative diagnostic instruments in order to discover where links between concepts do form and where they failed to form (i.e., knowledge gaps). Griffard and Wandersee (Griffard & Wandersee, 2001) propose a “think aloud protocol” in which students work on graphic simulations of the process of photosynthesis, in a bid to identify the knowledge gaps. In our lesson sequence, the LT activity in which students study the context visualisation and identify where there is an intake and release of carbon dioxide in the food-production chain (Figure 4.4) seems to be appropriate to identify these gaps. Another useful example is the LT activity in which visualisations of chloroplast and mitochondria are related to photosynthesis and cellular respiration (Figure 4.5). If similar gaps are found between students, the research may gain from a quantitative turn to determine how common are these knowledge gaps.

5.6.2 Usefulness and limitations of the research scenario

A research scenario consists of a detailed prediction and theoretical justification of the hypothesised learning-teaching process (Leach & Scott, 2002; Lijnse & Klaassen, 2004). The research scenario, which was developed in this project, played a crucial role in the design of the lesson sequence, the data collection and the data analysis. The research scenario shows which design principles are elaborated in the teacher and students’ manuals, how this occurred, which teacher and student activities are intended to take place in the classroom, and how it is expected that this was reflected in students’ learning outcomes. In Chapter three, we provided empirical evidence that proves that the research scenario is an appropriate tool to score the degree of correspondence between actual and intended activities of teacher and students. This is what we call evaluation of practicability. We have shown that seeking explanations of these scores generates detailed information on the teaching-learning process and aspects that seem to promote or hinder the development of conceptual coherence.

Furthermore, we used the research scenario to structure the data collection. We indicated for each activity in the lesson sequence which data were collected and how they were collected. This resulted in collection methods that were adjusted to the design. For example, we aligned each question in the semi-structured interviews with the preceding lesson activity, to determine the possible influence of the activity on students’ learning outcomes. Such alignment between the specific intervention and the data collection contributes to the reliability and validity of the data analysis in case studies (Yin, 2003).

There were also limitations of the use of the research scenario. One limitation concerns the relation between the intended activities in the classroom and the intended conceptual learning goals. Although the research scenario that we developed was extensive and detailed, it appeared not sufficiently specific to link the influence of each activity in the classroom to the development of certain propositions from the reference concept map. Possibly, more cyclic case-studies are required to describe, with more precision, the didactical function and expected learning effect of each activity. Furthermore, in the research scenario, we prescribed the activities of the teacher strictly in an attempt to limit –to a certain extent–the influence of uncontrollable variables in the teachers' actions. This was done because the aim of our research was to relate characteristics of the contexts (and embedded LT activities) to students' learning outcomes. However, this also resulted in a limitation of the flexibility and creativity of the teacher in response to unforeseen circumstances. In order to make a research scenario useful for other research settings or for other educational practices, ideally it has to provide the teacher with more freedom of choice.

5.7 Implications for education and directions for future research

The current challenge in Dutch biology education is to change educational practice regarding the intended context-based innovation. Currently, new editions of textbooks for secondary biology education are available, which provide teachers with ideas for education according to the concept-context approach. However, this requires current and future teachers to develop the skills to design (or adapt) and conduct lessons and lesson sequences based on the concept-context approach. In order to develop, practice and reflect on these skills, a support system for teachers during the process of implementation is highly recommended (Bennett, Graesel, Parchmann, & Waddington, 2005). Next, we formulate three implications of this research that can be integrated in such a support system. We focus on the interplay between contexts, LT activities and conceptual coherence. Moreover, we provide two directions for future research.

5.7.1 Implications for teacher education and secondary education

The first implication concerns the ways in which the four design principles can help teachers and educational developers to create future contexts. Many decisions have to be made when choosing an authentic social practice and transforming it into an adequate context. This refers to "contextual transposition" (Boersma, 2011, p. 45). We expect that the design principles that were developed in this research are supportive of decisions about the following choices: (1) the choice of an authentic social practice, (2) the choice of a focal event defined as: "an important or typical event that draws the attention of learners while remaining imbedded in its cultural setting" (Gilbert, Bulte, & Pilot, 2011, p. 819); (3) the choice of perspectives of participants within a context; (4) the choice of LT activities within the context; (5) the choice of an underlying conceptual framework and (6) the choice of intended learning goals.

The second implication concerns the role of a reference concept map in the development of future context-based lesson sequences. In our opinion, it is essential that designers (for example pre-service teachers) construct a reference concept map during the design of a context-based lesson sequence. During this dynamic process, the designers are enabled to think through each of the propositions as a representation of the conceptual learning goals. Because the reference concept map reflects learning goals, it can legitimise the–otherwise implicit–decisions that have to be taken during the design process and to provide a clear focus in this process. These decisions refer to the choices and the structuring of contexts and LT activities. Furthermore, the construction of a reference concept map is expected to be very useful when designing contexts that contain concepts from different domains in biology. The Biology Concept Framework (Khodor, Halme, & Walker, 2004) in which biological concepts from different domains are organised hierarchically, may serve as a useful source to develop a reference concept map in correspondence with a specific context. The reference concept map can also connect concepts that cover different science subjects and, in this way, contribute to the strengthening of coherence between science curricula (Boersma, Bulte, et al., 2010). Moreover, because each reference concept map is adjusted to, and therefore specific for, a context-based lesson sequence, it allows the designers to identify the propositions that appear problematic to teach or learn. Subsequently, the relevant elements of the lesson sequence can be revised in order to enhance the learning results.

The third implication concerns the role of a research scenario in the design, conduction and evaluation of context-based lessons. There are many factors that influence students' learning outcomes in context-based education. For (future) teachers it is often difficult to recognise and identify how their own actions influence students' actions, and eventually, students' learning outcomes. We expect that a research scenario is an adequate instrument for teacher education. When future teachers are instructed to develop and use a research scenario accompanied by the design of a context-based lesson (series), we expect that this has much potential to contribute to the development of their meta-cognitive skills and their research attitude and skills. Therefore, in our opinion, the research scenario offers excellent opportunities for integrating research components and reflection components in teacher education.

5.7.2 Directions for future research

The first direction for future research concerns an aspect of the concept-context approach that was beyond the scope of this research: recontextualisation (Van Oers, 1998). It has been suggested that when students recontextualise concepts from one context to another, this fosters their conceptual understanding (Wierdsma, 2012). Therefore, future empirical studies should provide more insight into the influence of recontextualisation on the development of conceptual coherence. An element of our research which can be useful in such research is the reference concept map. In Appendix C, we have presented which concepts and propositions from the reference concept map were embedded in each context. For recontextualisation, each concept must be embedded in at least two contexts. Such research could provide valuable information for the development of a spiral curriculum (Boersma, Kamp, Van den Oever, & Schalk, 2010). In a spiral curriculum, complex core concepts are introduced in a simple form at the lower secondary level and are further elaborated at the higher levels. We recommend focusing such research on core concepts that are required for a deeper understanding of the few "big ideas" in science. To identify these concepts, a recently developed framework of eight fundamental science principles (referred to as "eight plus one") can provide guidance (Schmidt et al., 2011).

A second direction for future research is aimed at the reference concept map in relation to conceptual coherence. In this research we regarded the propositions from the reference concept map as the final learning goals. Each activity in the lesson sequence was designed and evaluated with the intention that students would acquire one or more of these propositions. Intermediate learning goals, in terms of propositions that include less specific biological terms (such as terms used in everyday life), were not defined. Moreover, the reference concept map did not point out in which sequence these concepts and propositions are preferably taught and learned. Therefore, we propose that future research focuses on the development and use of reference concept maps that contain different layers, in which each layer reflects a certain level of conceptual understanding. This idea builds on the learning progression approach (Duncan, Rogat, & Yarden, 2009; Jin & Anderson, 2012; Jin, Zhan, & Anderson, 2013; Mohan et al., 2009) and the maps developed by the AAAS Project 2061 (2007) that show a sequence of students' ideas about key topics for science literacy from kindergarten through twelfth grade. This will lead to more reliability and validity in the evaluation procedure.

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Glossary

Term	Definition in this thesis
Concept	Perceived regularity in events or objects designated by a label. Can be descriptive or more theoretical in nature
Conceptual coherence	The ability of a person to establish scientifically accepted and meaningful connections between concepts
Concept-context approach	Approach where students develop conceptual coherence by performing socially interactive activities in contexts
Context	A classroom representation of an existing scientific, professional or real-life community of practice in which participants perform goal-oriented activities and deal with concepts
Contextual transposition	Design process in which an authentic social practice is transformed into a usable context adapted for use in the classroom in such a way that the intended learning goals can be attained
Design principles	Theoretically and empirically grounded constructs linking learning-teaching strategies with intended learning outcomes
Evaluation of practicability	Evaluation of a lesson sequence with a focus on the degree in which actually performed teacher and student activities correspond to the intended performance
Evaluation of effectiveness	Evaluation of a lesson sequence with a focus on students' learning outcomes, in terms of students' ability to mention propositions
Learning-teaching activity	A delimited educational unit that consists of an introduction phase, an action phase and a reflection phase in which students and teacher perform activities
Proposition	Two interconnected concepts labeled with a description. A remark that contains propositions indicates a certain degree of conceptual coherence.
Reference concept map	Concept map that contains all concepts and propositions to be learned in a lesson sequence. Helps to guide the design of LT activities in contexts and functions as a "point of reference" to assess the development of students' conceptual coherence
Research scenario	A detailed prediction and theoretical justification of the hypothesised learning-teaching process. It shows systematically how and where design principles have been elaborated in the teacher and student manual, how this leads—with high probability—to the actions that take place in the classroom and how it is expected that this results in students' learning outcomes. It helps to guide the design of LT activities in contexts and is useful for the evaluation of a context-based lesson sequence on both its practicability and effectiveness.

Appendix A

Outline of the lesson sequence for the first case study

Lesson	Context	Content
1	Family	❖ Role play in which family members share their contradictory ideas on consuming meat and vegetarianism, followed by a classroom conversation sharing own ideas.
		❖ Watching three short movies about consequences of consuming meat. ❖ Formulating guiding question for lesson sequence: *Are we still allowed to consume meat?*
2	Family	❖ Focus on environmental impact of meat consumption. ❖ Filling out a blank concept map. ❖ During reflection, focusing on biological concepts in role play: proteins and energy. ❖ Looking ahead to next context: work of environmental advisor.
3	Environmental advisor	❖ Students perform calculations in which they compare the areas of agricultural land needed for the production of an amount of plant and animal proteins and the amount of greenhouse gases emitted during the production of plant and animal proteins.
4	Environmental advisor	❖ Students have to explain the results of their calculations using biological knowledge. ❖ Teacher helps students by giving information about metabolic cell processes.
5	Environmental Advisor Agricultural researcher	❖ The conclusion of the environmental advisor is shared: with respect to environmental consequences, the production and consumption of animal proteins has to decrease and the production and consumption of plant proteins has to increase. ❖ Looking ahead to next context: agricultural researcher. ❖ Formulating new guiding question: How can lupine plants produce a maximum amount of beans containing proteins?
6,7 & 8	Agricultural researcher	❖ Students perform experiments with bean plants focusing on the role of carbon dioxide and light in the production of biomass. ❖ In a classroom conversation, results are discussed. Teacher triggers students to mention propositions related to photosynthesis and biosynthesis.

Continued

Lesson	Context	Content
9 & 10	Conceptualisation	❖ Introduction of concept mapping activity with the focus question: How do plants store the energy to grow? ❖ Students construct concept maps in groups of three. The teacher gives feedback on request. ❖ Classroom discussion focusing on the relationships students find difficult.
11	Owner of restaurant	❖ Students write an advertisement in which they explain (using given concepts) why consuming (and producing) insects is more sustainable and more efficient (and thus better for the environment) than consuming farm animals.

Appendix B

Outline of the lesson sequence for the second case study

Lesson	Context	Content	Number of examined LT activity
1	Family	❖ Introduction of the issue with respect to consuming meat. ❖ Role play in which family members share their contradictory ideas on consuming meat and vegetarianism, followed by a classroom conversation sharing own ideas. ❖ Formulating guiding question for lesson sequence: *Are we still allowed to consume meat?*	1
		❖ Watching three short movies about consequences of consuming meat.	
2	Family	❖ Focus on environmental impact of meat consumption. ❖ Filling out blank a concept map. ❖ During reflection focusing on biological concepts in concept map: proteins and carbon dioxide. ❖ Looking ahead to next context: work of environmental advisor.	2
3	Environmental advisor	❖ Studying a visualisation of the protein-rich food production chain role with attention to the role of environmental advisor. ❖ Indicating where in the food-production chain there is an intake and release of carbon dioxide.	3
		❖ Indicating in visualisations how animals (and plants) release carbon dioxide and how plants take in carbon dioxide.	
4	Environmental advisor	❖ Studying stomata of soya-plant leaves with a microscope. ❖ Classroom discussion focusing on cellular processes: cellular respiration and photosynthesis	4
5	Environmental advisor	❖ Interactive lecture starting with the task of the environmental advisor ❖ Filling out relationship between processes in empty scheme of an animal cell and a plant cell. Attention was paid to forms of energy and biosynthesis.	
6	Environmental advisor	❖ Introduction of writing assignment from perspective of environmental advisor. ❖ Brainstorm and collection of information from manual in pairs. ❖ Writing one paragraph individually. ❖ Reflection on writing assignment.	5

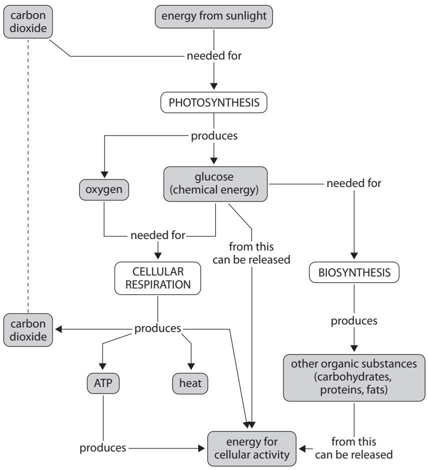
7	Agricultural researcher	❖ Introduction of context of agricultural researcher. ❖ Hands-on activities with soya-plants: weighing all beans of one plant. ❖ Calculating total amount of proteins in beans of one plant and compare this with production of animal proteins. ❖ Classroom reflection: explaining why protein production in animal cells is less efficient than plant cells. ❖	6
8 & 9	Agricultural researcher	❖ Introduction of concept mapping activity with the focus questions: How do plant cells produce proteins? and How do animal cells produce proteins?. ❖ Students construct concept maps in groups of three. The teacher gives feedback on request. ❖ Classroom discussion focusing on the relationships students find difficult.	7
10	Environmental advisor	❖ Writing the second paragraph of advice and revising the first paragraph. ❖ Reflection: reading written products of other students.	8

Appendix C

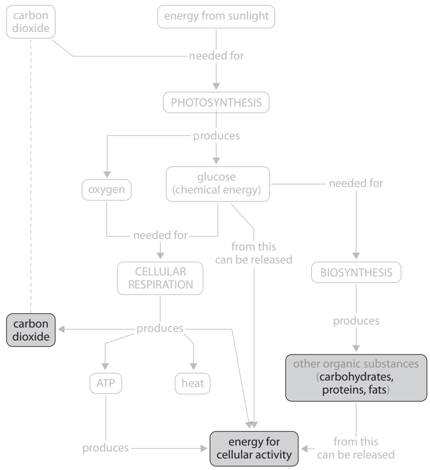
Reference concept map in relation to contexts

The concepts and propositions (**a**) which are the focus in each of the three contexts (**b**, **c** and **d**). These reference concept maps refer to the second case study.

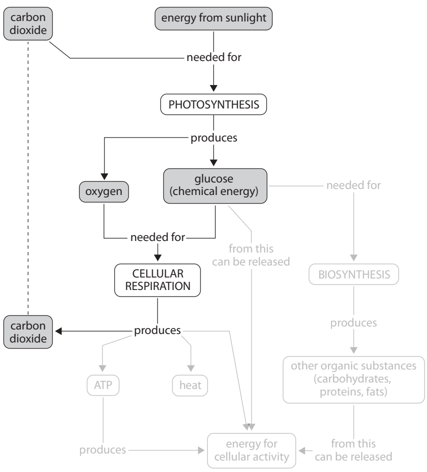
a) reference concept map



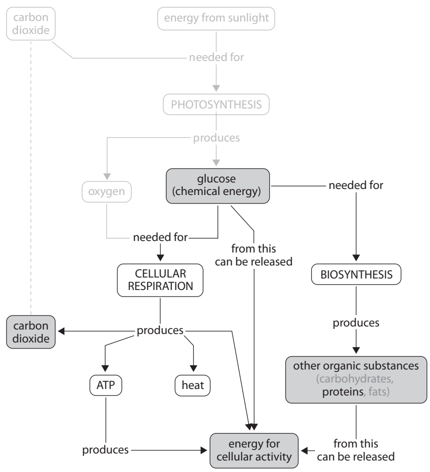
b) context 1: family discussion about vegetarianism



c) context 2: environmental advisor



d) context 3: agricultural research



Summary

Many studies in biology education reveal that, despite the best efforts of teachers, students of all ages and different educational levels have difficulties in understanding how biological systems function. In particular, students are often unable to retrieve and interrelate the biological concepts that are involved in these systems. Context-based approaches have been proposed to contribute to solving this problematic coherent conceptual understanding. These approaches generally improve students' engagement by situating the learning of science in contexts that represent the real world, which helps them to appreciate the role science plays in their own lives and in society. Up to now, there has been limited empirical evidence that relates context-based education to an enhancement in the development of conceptual coherence. The research in this dissertation focuses on the development of conceptual coherence within one specific form of context-based education: the concept-context approach.

In **Chapter one,** we describe the theoretical background underlying the concept-context approach that has been introduced in the current educational reform for biology education in the Netherlands. According to this approach, a context is defined as a representation of an existing scientific, professional or real-life community of practice in which participants perform goal-oriented activities. Within such contexts, it is intended that students perform activities in social interactions and deal with (a network of) biological concepts from the perspective of these participants. At present, the challenge is to transform authentic social practices into usable contexts adapted for classroom use and in which students develop conceptual coherence. Therefore the objective of this research project is to find empirically grounded guidelines to promote students' development of conceptual coherence within biology education based on the concept-context approach. We focus on learning-teaching mechanisms that occur when contexts and (a network of) concepts are offered in relation to each other. To understand such a mechanism, we examined if and when the design and the administration of a concept-context based lesson sequence about a domain-specific topic met its intended learning goals. By determining changes that occurred in students' abilities to relate concepts at specific moments during this lesson sequence, we expected to identify factors that hinder or promote the development of conceptual coherence. The main research question in this dissertation is: *How can the development of students' conceptual coherence be promoted within biology education based on the concept-context approach?*

To address this question we adopted a design research approach. Based on a literature study and explorative empirical research, we formulated four initial design principles which evolved during the course of this research project. These evolved design principles are: 1. Building on familiar concepts; 2. Focusing on core concepts; 3. Stimulating students to interconnect concepts; 4. Reflecting on conceptual relationships within a context. We elaborated the design principles in a lesson sequence about energy and matter

transformation in the metabolic cell processes of photosynthesis, cellular respiration and biosynthesis. These biological concepts and their relationships, called propositions, were depicted in a reference concept map (see the extension of the back cover). The following contexts were chosen: a family context, the context of an environmental advisor, the context of an agricultural researcher and the context of a restaurant owner. Further, promising learning-teaching (LT) activities to promote conceptual coherence were integrated in the lesson sequence. These LT activities were: classroom conversations, concept-mapping and writing activities. The lesson sequence was administered in two iterative case studies and evaluated on its practicability and effectiveness.

In **Chapter two**, we explore to what extent tenth grade students in senior general secondary education developed conceptual coherence during the lesson sequence based on the concept-context approach. We demonstrate the value of a reference concept map as an instrument to provide insight in the abilities of students to mention propositions at several moments during the course of the lesson sequence. We show that the total number of propositions that students mentioned correctly increased during the course of the lesson sequence and that some propositions fell short of expectations. This concerned in particular the propositions related to the core concepts biosynthesis and energy.

In **Chapter three**, we demonstrate that the four design principles are useful to structure the contexts and develop LT activities that are aimed at learning goals for conceptual coherence, as depicted in the reference concept map. This alignment has been made visible in a research scenario that systematically and accurately describes how the teacher should act to generate student activities that are expected to promote conceptual coherence. We point out that the research scenario is a valid instrument to score the degree of correspondence between intended and actual activities and to seek explanations of the scores. Furthermore, we show how the research scenario provided us with detailed information on the learning-teaching process and how this allowed us to identify aspects of the lesson sequence that had to be adapted.

In **Chapter four**, we show how we elaborated the design principles systematically in the revised version of the lesson sequence. One of the revisions included visualisation of the contexts in a chart. We describe how we combined the research scenario and reference concept map to evaluate the lesson sequence on its practicability and effectiveness. Quantifying the abilities of students to mention propositions during the course of the lesson sequence, combined with data from semi-structured interviews with students, generated in-depth information on students' development of conceptual coherence with respect to the domain-specific topic. We show that students improved in articulating concepts and propositions during the course of the revised lesson sequence. Moreover, we provide evidence that students showed improvement in switching their thinking from the organism level of biological organisation to metabolic process at the (sub-)cellular level. However, individual propositions related to the core concepts of energy and biosynthesis still fell short of expectations. Furthermore, we demonstrate how eight context-embedded LT activities influenced the development of conceptual coherence. One of the conclusions is that the use of the four design principles for the structuring of LT activities in contexts has a high potential to create a powerful learning environment aimed at the promotion of conceptual coherence within contexts.

In **Chapter five**, we use the empirical findings of the case studies to answer the main research question in three parts. First, we focus on the conceptual development with respect to the domain-specific topic. We propose four recommendations for the adaptation of the lesson sequence. One of these recommendations is that a focus on underlying chemical and physical principles is needed for students to be able to understand the concepts and propositions from the reference concept map in contexts. Second, we consider how integration of each of the three LT activities (classroom conversations, concept-mapping and writing activities) in a context has the potential to promote conceptual coherence. For example, a context that is visualised in a chart appears useful to structure a productive dialogic classroom conversation guided by the teacher. Third, we reflect on the evolved design principles and consider points of interest when elaborating these design principles in a lesson sequence based on the concept-context approach. For instance, with respect to the fourth design principle (reflecting on conceptual relationships within a context), we suggest that the teacher has to be equipped with an adequate questioning strategy that helps students to reinforce their sometimes fragile understanding of propositions within contexts. Furthermore, we legitimise why the four design principles that evolved in this research project can be generalised in an analytic way and used for the design of other concept-context based lesson sequences.

This research project suggests several implications for secondary biology education and teacher education. First, the four evolved design principles can help (future) teachers and educational developers to support decisions when creating contexts as representations of authentic social practices. Second, a reference concept map proves to be a powerful instrument for guiding the design of a concept-context based lesson sequence and for evaluating the learning outcomes in terms of articulating concepts and propositions. The reference concept map allows (future) teachers and developers to keep focusing on the ways in which the lesson sequence supports students to develop a coherent understanding of concepts and propositions. Third, a research scenario is a useful instrument to guide the design of LT activities in contexts. Moreover, it allows (future) teachers to reflect systematically on the ways the design and their own actions in classroom effect students' actions, and eventually, students' learning outcomes.

Samenvatting

Uit onderzoek naar biologieonderwijs blijkt dat leerlingen van alle leeftijden en onderwijsniveaus moeite hebben met het begrijpen hoe biologische systemen functioneren. In het bijzonder weten leerlingen vaak niet welke biologische concepten een rol spelen in deze systemen en hoe deze onderling zijn te verbinden. Actueel is de veronderstelling dat onderwijs gebaseerd op contexten bijdraagt aan een oplossing voor deze problematische samenhangende begripsvorming. Het is bekend dat contextonderwijs de betrokkenheid van leerlingen verhoogt, doordat de natuurwetenschappelijke kennis wordt verbonden met contexten die de authentieke situaties representeren. Dit helpt leerlingen in te zien dat natuurwetenschappelijk kennis een rol speelt in hun eigen leven en in de maatschappij. Tot nu toe is er echter weinig empirisch bewijs dat aantoont dat contextonderwijs de ontwikkeling van conceptuele samenhang van leerlingen werkelijk verhoogt. Dit promotieonderzoek richt zich op de ontwikkeling van conceptuele samenhang binnen een specifieke vorm van contextonderwijs: de concept-contextbenadering.

In het **eerste hoofdstuk** beschrijven we de theoretische achtergrond van de concept-contextbenadering die inmiddels geïntroduceerd is in het biologieonderwijs in Nederland. Volgens deze benadering wordt een context gedefinieerd als een representatie van een bestaande wetenschappelijke, beroeps- of leefwereld praktijk waarin deelnemers doelgericht handelingen uitvoeren. Binnen zulke contexten wordt beoogd dat leerlingen in interactie met elkaar activiteiten uitvoeren en hierbij (een netwerk van) biologische concepten hanteren vanuit het perspectief van deelnemers. Op dit moment is de uitdaging om authentieke sociale praktijken te transformeren in contexten die in de klas kunnen worden gebruikt en die gericht zijn op het ontwikkelen van conceptuele samenhang bij leerlingen. De doelstelling van dit onderzoeksproject is om empirisch onderbouwde richtlijnen te formuleren die de ontwikkeling van conceptuele samenhang binnen biologieonderwijs gebaseerd op de concept-contextbenadering bevorderen. We richten ons op onderwijs-leermechanismen die optreden als contexten en (een netwerk van) concepten in relatie tot elkaar worden aangeboden. Om deze mechanismen te begrijpen hebben we onderzocht of en op welke wijze het ontwerp en de uitvoering van een domeinspecifieke lessenserie, gebaseerd op de concept-contextbenadering, bijdragen aan de beoogde leerdoelen. We beoogden factoren te identificeren die de ontwikkeling van conceptuele samenhang bevorderen danwel belemmeren door veranderingen vast te stellen in het vermogen van leerlingen om concepten te verbinden op specifieke momenten in de lessenserie. De centrale onderzoeksvraag in dit proefschrift is: *Hoe kan de ontwikkeling van conceptuele samenhang van leerlingen worden bevorderd binnen biologieonderwijs gebaseerd op de concept-contextbenadering?*

Om deze vraag te beantwoorden, hebben we een ontwerponderzoek uitgevoerd. Op basis van literatuurstudie en exploratief empirisch onderzoek hebben we vier initiële ontwerpprincipes geformuleerd die gedurende het onderzoek verder zijn ontwikkeld. Dit

heeft uiteindelijk geleid tot de volgende ontwerpprincipes om concept-contextonderwijs gericht op de ontwikkeling van conceptuele samenhang vorm te geven: 1. Voortbouwen op bekende concepten; 2. Aandacht vestigen op kernconcepten; 3. Studenten stimuleren om concepten onderling te verbinden; 4. Reflecteren op de conceptuele relaties binnen een context. We hebben deze ontwerpprincipes uitgewerkt in een lessenserie over de omzetting van energie en materie bij de metabole celprocessen fotosynthese, aërobe dissimilatie en voortgezette assimilatie. De concepten en hun onderlinge relaties, proposities genoemd, hebben we afgebeeld in een referentieconceptmap (zie de uitklapbare bijlage aan de achterzijde van dit proefschrift). De volgende contexten werden gekozen: de context van een gezin, de context van een milieuadviseur, de context van een landbouwonderzoeker en de context van een restauranteigenaar. Verder werden onderwijsleeractiviteiten die veelbelovend waren voor het bevorderen van conceptuele samenhang, geïntegreerd in de lessenserie. Deze onderwijsleeractiviteiten waren: klassikale onderwijsleergesprekken, conceptmapping en schrijfopdrachten. De lessenserie werd uitgevoerd in twee op elkaar volgende case studies en geëvalueerd op bruikbaarheid en effectiviteit.

In het **tweede hoofdstuk** verkennen we in welke mate havo-4 leerlingen conceptuele samenhang ontwikkelen gedurende de lessenserie gebaseerd op de concept-context-benadering. We laten de waarde zien van een referentieconceptmap als een instrument om inzicht te verkrijgen in het vermogen van leerlingen om proposities te noemen op verschillende momenten gedurende de lessenserie. We tonen aan dat het totale aantal correct genoemde proposities toeneemt gedurende het verloop van de lessenserie. Sommige resultaten blijven echter achter ten opzichte van de verwachting. Dit betreft in het bijzonder de proposities gerelateerd aan de kernconcepten voortgezette assimilatie en energie.

In het **derde hoofdstuk** laten we zien dat de vier ontwerpprincipes nuttig zijn om contexten te structureren en om onderwijsleeractiviteiten uit te werken die gericht zijn op de ontwikkeling van conceptuele samenhang zoals weergegeven in de referentieconcept-map. De vier ontwerpprincipes hebben we uitgewerkt in een onderzoeksscenario dat systematisch en nauwkeurig beschrijft hoe de docent zou moeten handelen om studenten activiteiten te laten uitvoeren, waardoor hun conceptuele samenhang naar verwachting wordt bevorderd. We maken aannemelijk dat het onderzoeksscenario een valide instrument is om de mate van overeenkomst tussen beoogde en werkelijk uitgevoerde activiteiten te beoordelen en te verklaren. Verder laten we zien hoe het onderzoeksscenario gedetailleerde informatie over het onderwijsleerproces kan opleveren. Hierdoor waren we in staat de lessenserie aan te passen.

In het **vierde hoofdstuk** tonen we hoe we de ontwerpprincipes systematisch hebben uitgewerkt in de gereviseerde lessenserie. Eén van deze revisies betreft het visualiseren van contexten in een kijkplaat. We beschrijven hoe we het onderzoeksscenario en de referentieconceptmap hebben gecombineerd om de lessenserie te evalueren op uitvoerbaarheid en effectiviteit. Het kwantificeren van het vermogen van leerlingen om proposities te noemen gedurende het verloop van de lessenserie in combinatie met data van interviews met leerlingen, leverde diepgaande informatie over hun ontwikkeling van conceptuele samenhang met betrekking tot het domeinspecifieke onderwerp. Gedurende het verloop van de gereviseerde lessenserie bleken leerlingen steeds beter in staat om concepten en proposities te noemen. Bovendien konden de leerlingen in hun redeneringen steeds makkelijker wisselen van het biologische organisatieniveau van het organisme naar het (sub-) cellulaire organisatieniveau waar de metabole processen zich afspelen. Het noemen van individuele proposities gerelateerd aan de kernconcepten energie en voortgezette assimilatie bleef echter nog steeds achter ten opzichte van de verwachting. Verder demonstreren we hoe acht onderwijsleeractiviteiten die ingebed zijn in een context de ontwikkeling van conceptuele samenhang beïnvloedden. Eén van de conclusies is dat het gebruik van de vier ontwerpprincipes ten behoeve van het structureren van onderwijsleeractiviteiten in contexten veel potentie heeft om een krachtige leeromgeving te creëren, gericht op het bevorderen van conceptuele samenhang in contexten.

In het **vijfde hoofdstuk** geven we in drie delen antwoord op de centrale onderzoeksvraag. Hiervoor gebruiken we de empirische bevindingen van beide case studies. Ten eerste richten we ons op de conceptuele ontwikkeling met betrekking tot het domeinspecifieke onderwerp. We doen vier aanbevelingen om de lessenserie aan te passen. Eén van deze aanbevelingen is dat aandacht voor onderliggende scheikundige en natuurkundige principes essentieel is om leerlingen de concepten en proposities uit de referentieconceptmap in contexten te laten begrijpen. Ten tweede bespreken we hoe integratie van de drie onderwijsleeractiviteiten (klassikale onderwijsleergesprekken, conceptmapping en schrijfopdrachten) in een context de potentie heeft om conceptuele samenhang te bevorderen. Zo blijkt bijvoorbeeld dat een context, die is gevisualiseerd in een kijkplaat, houvast biedt om een productieve dialoog tussen docenten en leerlingen vorm te geven in onderwijsleergesprekken. Ten derde reflecteren we op de ontwikkelde ontwerpprincipes en benoemen we aandachtspunten voor de uitwerking van deze ontwerpprincipes in een lessenserie. Zo is het voor het vierde ontwerpprincipe (reflecteren op conceptuele relaties in een context) van belang dat de docent beschikt over een doordachte strategie om vragen te stellen die ertoe leiden dat het, soms fragiele, begrip van verbindingen tussen concepten wordt versterkt. Verder onderbouwen we waarom de vier in dit onderzoek ontwikkelde ontwerpprincipes op een analytische manier kunnen worden gegeneraliseerd. Hierdoor zouden ze gebruikt kunnen worden voor het ontwerpen van andere lessenseries gebaseerd op de concept-contextbenadering.

Dit onderzoeksproject heeft verschillende handvatten opgeleverd voor zowel het voortgezet biologieonderwijs als voor lerarenopleidingen. Ten eerste kunnen de vier ontwikkelde ontwerpprincipes (toekomstige) docenten en onderwijsontwikkelaars ondersteunen in besluitvorming ten aanzien van het vormgeven van contexten als representatie van authentieke sociale handelingspraktijken. Ten tweede blijkt de referentieconceptmap een krachtig instrument om het ontwerp van een lessenserie volgens de concept-contextbenadering te sturen en om de leerresultaten, in termen van het noemen van concepten en proposities, te evalueren. De referentieconceptmap helpt (toekomstige) docenten en onderwijsontwikkelaars om te focussen op manieren waarop een lessenserie de conceptuele samenhang van leerlingen bevordert. Ten derde is het onderzoeksscenario een bruikbaar instrument gebleken om richting te geven aan het vormgeven van onderwijs-leeractiviteiten in contexten. Bovendien kan het onderzoeksscenario (toekomstige) docenten helpen om systematisch te reflecteren op de manier waarop zowel het ontwerp als de eigen handelingen in de klas effect hebben op de handelingen van de leerlingen en, uiteindelijk, de leerprestaties van de leerlingen.

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Curriculum Vitae

Micha Ummels was born in Heerlen, the Netherlands, on August 29th 1977. He attended pre-university secondary education (gymnasium-β) at Serviam College in Sittard, where he graduated in the year 1995. He then studied biology at the Radboud University of Nijmegen and obtained his master's degree in 2001. Next, he followed a training programme at the same university to qualify as a biology teacher at the highest level of secondary school. From 2002 until the present day he has been working as a teacher in biology and natural sciences at the secondary school Nijmeegse Scholengemeenschap Groenewoud. Since 2004, he has been involved in supporting pre-service and in-service teachers to conduct educational research in school practice.

In 2008, Micha started his PhD study at the Radboud Graduate School of Education, University of Nijmegen, as part of the DUDOC programme, which was funded by the Dutch Ministry of Education, Culture and Science. His research took place within the setting of a current educational reform for biology education: the concept-context approach. He focused on ways to develop and conduct education based on this concept-context approach in order to promote students' conceptual coherence.

Since 2014, Micha is conducting a postdoc research project at the NSG in cooperation with the Radboud Graduate School of Education. In this project he examines how a professional learning community in school, aimed at developing, conducting and evaluating context-based education, supports the professional development of participant teachers.

Publications

Ummels, M., Kamp, M., de Kroon, H., & Boersma, K. T. (2013). De ontwikkeling van conceptuele samenhang binnen concept-contextonderwijs. Een case study voor het vak biologie in 4-havo. Developing conceptual coherence within concept-context based education. A case study in senior general secondary biology education. *Pedagogische Studiën, 90*, 19-32.

Ummels, M., Kamp, M., de Kroon, H., & Boersma, K. T. (2014). Designing and evaluating a context-based lesson sequence promoting conceptual coherence in biology. *Journal of Biological Education*. url: http://www.tandfonline.com/doi/pdf/10.1080/00219266.2014.882380

Ummels, M., Kamp, M., De Kroon, H., & Boersma, K. T. (submitted). Promoting conceptual coherence within context-based biology education. *Science Education*.

Conference contributions

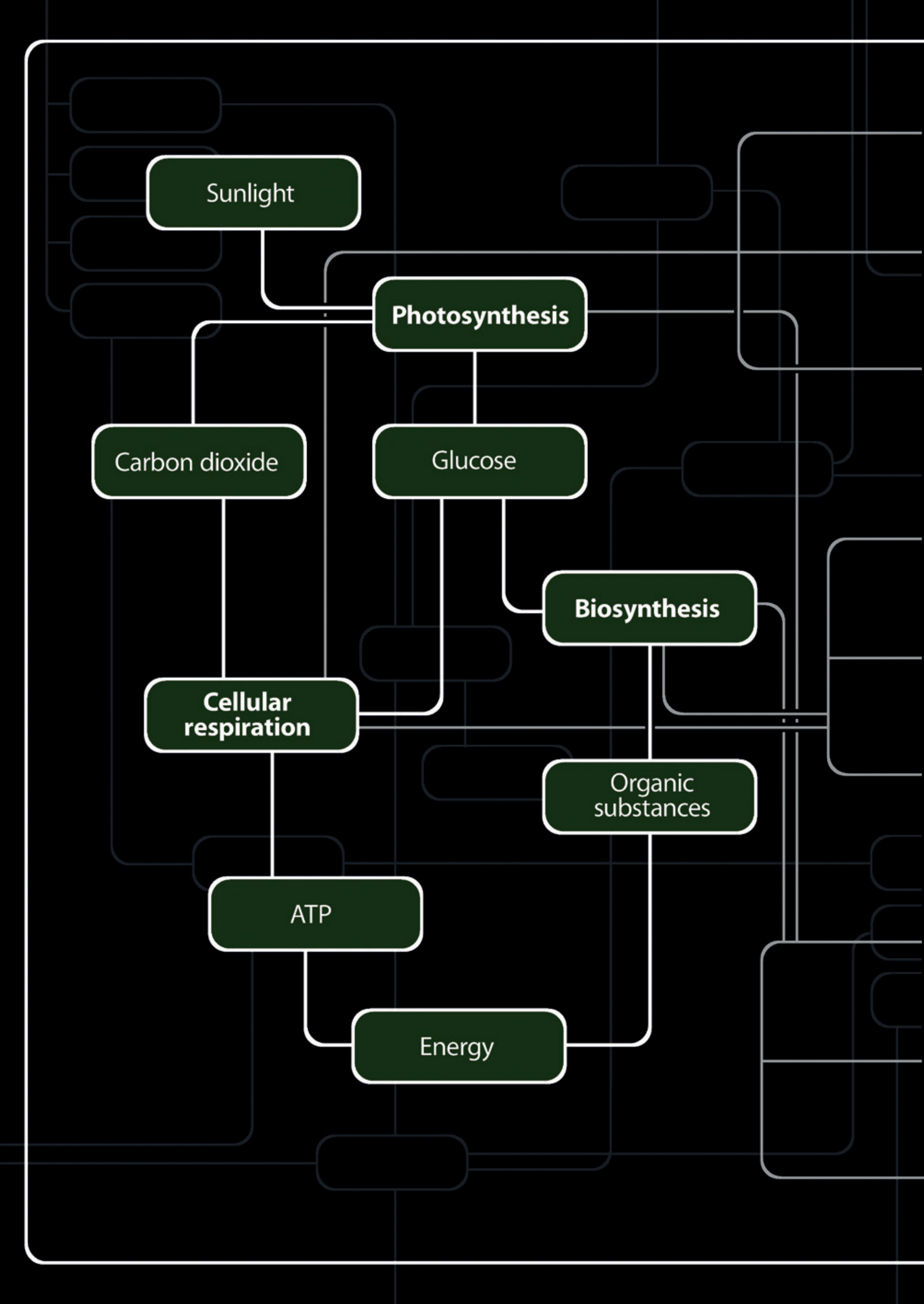
ESERA Conference (2009) Istanbul, Turkey, poster presentation entitled: Promoting cognitive coherence in students' biological knowledge.

ESERA Summerschool (2010) Udine, Italy, oral presentation entitled: Promoting a coherent organisation of biological knowledge.

ESERA Conference (2011) Lyon, France, oral presentation entitled: Structuring learning-teaching activities within context-based education aimed at the promotion of students' conceptual coherence in students' biological knowledge.

ERIDOB Conference (2012) Berlin, Germany, poster presentation entitled: Promoting the development of students' conceptual coherence in biological knowledge.

ORD Conference (2014) Groningen, The Netherlands, oral presentation entitled: Het bevorderen van conceptuele samenhang binnen op de concept-contextbenadering gebaseerd biologieonderwijs [Promoting conceptual coherence within biology education based on the concept-context approach].



Sunlight
Photosynthesis
Carbon dioxide
Glucose
Biosynthesis
Cellular respiration
Organic substances
ATP
Energy

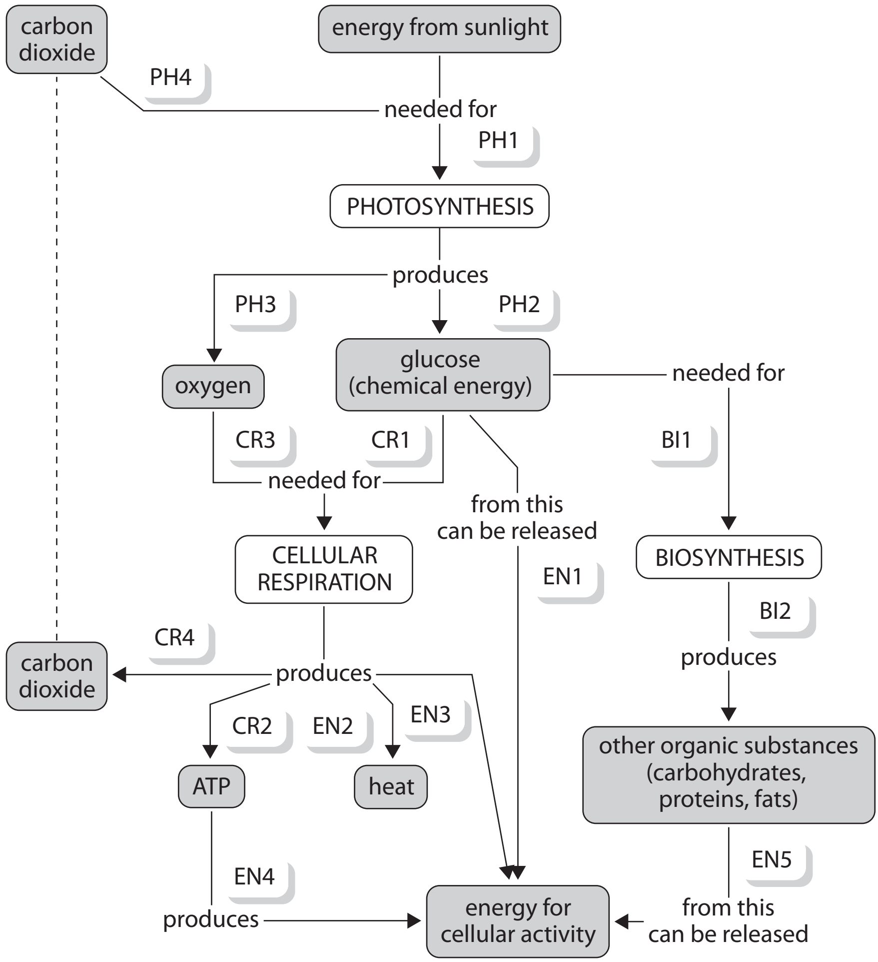


Figure 1.1 Reference concept map.

The relationships between the three metabolic processes (white boxes) with an emphasis on the transformation of forms of energy and matter (grey boxes) are indicated with proposition codes. Four groups of propositions are distinguished that are related to the core concepts of photosynthesis (code: PH1-4), cellular respiration (code: CR1-4), biosynthesis (code: BI1-2) and energy (code: EN1-5).