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Designing and Evaluating a Context-based Lesson Sequence Promoting Conceptual Coherence in Biology

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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 conducted in a 10th-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.

Keywords: *Conceptual coherence; Context-based education; Research scenario; Design research*

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

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levels, despite the best efforts of teachers, fail to understand the conceptual foundation of key content areas of biology (e.g. Pearsall, Skipper, and Mintzes 1997; Wandersee, Mintzes, and 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 and Bransford 2005; Songer and 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, and 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 and 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, and 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 and 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 on its practicability?* The construction of a research scenario (Lijnse and 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 and 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, which is 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.

Design Procedure

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.

Build upon familiar concepts. There is general agreement that attention to previously acquired conceptual knowledge is a prerequisite for conceptual development (e.g. Bransford, Brown, and Cocking 2000; Novak, Mintzes, and 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.

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.

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 and Adesope 2006), writing assignments (Keselman 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.

Reflect on meaningful connections between concepts. When students learn concepts within one context, they might not be able to transfer them to other contexts (Bransford, Brown, and Cocking, 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.

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, and Anderson 2009). Even though education has given extensive attention to these processes (e.g. Ross, Tronson, and Ritchie 2006), only few students have the ability to trace matter and energy through hierarchically organised systems by 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. The 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 and 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 and Hu 2003).

Based on these problems, learning objectives were defined in terms of propositions that have been visualised in a concept map (see Figure 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 transformations of matter (carbon and oxygen) and forms of energy. To specify how these forms of energy are captured, transformed and released and how oxygen and carbon are transformed, eight additional

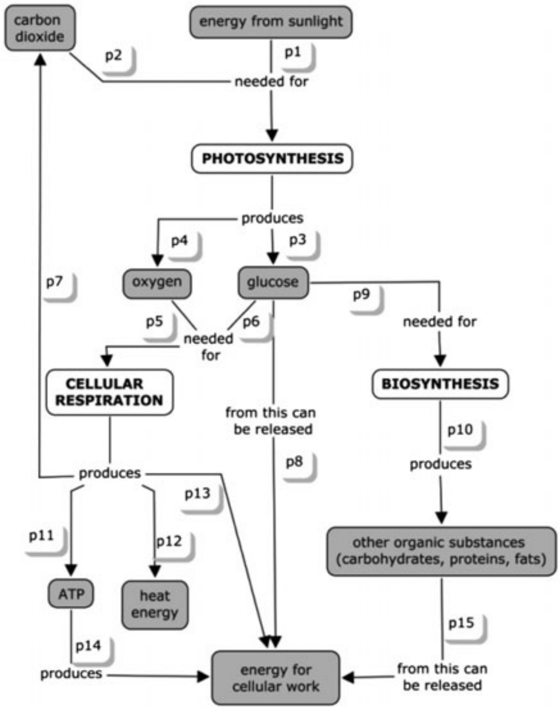

Figure 1. Reference concept map. The relations between three core concepts (white boxes) and eight basic concepts (grey boxes) with an emphasis on matter and energy transformations are presented by proposition codes p1 to p15

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.

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 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 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 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 sustainable restaurateur. This context is expected to be fairly recognisable and suitable to connect the core concepts again in a (guided) writing assignment.

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 contexts; 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 that students are expected to be familiar with: carbon dioxide (in relation to greenhouse gas) and proteins (as an essential nutrient for humans). Students' notions about these concepts are 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 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 upon 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 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 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 propositions 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.

Methodology

Sample

The lesson sequence, containing 11 lessons, was conducted 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.

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 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 transcript; 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 characterized 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 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.

Results

Table 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.

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 animals other 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 of carbon dioxide and proteins. These activities received intermediate scores. The transcript showed that the 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.

Table 1. Part of the 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 that students are expected to be familiar with: carbon dioxide and proteins (1.2). Students prior knowledge regarding these concepts is shared (1.3). Estimated time of duration: 5 min.	1.1	Concludes that consuming meat has an impact on the environment.	+ / +	No relevant observable behaviour	
		Poses this as a problem and formulates guiding question.	+ / +	No relevant observable behaviour	
	1.2	Links the problem to biological concepts that are expected to be familiar to students: carbon dioxide and proteins.	+ / +	No relevant observable behaviour	
	1.3	Evokes notions about proteins.	± / ±	Respond and share initial notions.	+ / +
		Evokes notions about carbon dioxide.	± / ±	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).	2.1	Introduces work of environmental advisor.	+ / +	No relevant observable behaviour	
		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	
	2.2	Emphasizes why an environmental advisor needs specific biological knowledge.	+ / ±	No relevant observable behaviour	

(*Continued*)

Table 1. (*Continued*)

Episodes **Elaborated design principles**	**Fragment**	**Intended activities of teacher**	**Score**	**Intended activities of students**	**Score**
Estimated time of duration: 5 min.		Gives a short overview of relevant metabolic processes: photosynthesis and cellular respiration.	+ / +	No relevant observable behaviour	
		Links carbon dioxide to these processes by mentioning p2 and p7.	− / −*	No relevant observable behaviour	
Episode 3 Design principle 3: stimulate to interconnect concepts.	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.	+ / +
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 time of duration: 20 min.	3.2	Stimulates students to mention propositions (p1-7 and p9-p11) in a classroom discussion.	+ / ±	Mention propositions that describe: cellular respiration (p5-p7 en p11) photosynthesis (p1-p4) biosynthesis (p9-p10).	 + / ± + / ± + / ±
Episode 4 Design principle 4: reflect on the use of propositions.	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.	+ / +
Students calculate how much carbon dioxide is emitted for the production of protein-rich food products. The results show that the carbon dioxide emission is higher for the production of animal proteins (meat) than for plant proteins (4.1).	4.2	Makes an inventory of calculations and summarizes findings.	+ / +	Participate by checking their work.	+ / +
		Triggers students to explain results of calculations by mentioning propositions.	− / −**	Mention some of the propositions: p9&p10, p2&p4, and p6&p7.	− / −**

(*Continued*)

Table 1. (*Continued*)

Episodes **Elaborated design principles**	**Fragment**	**Intended activities of teacher**	**Score**	**Intended activities of students**	**Score**
In a final whole-class discussion they seek for 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 time of duration: 20 min.		Asks how the results of the calculations contribute answering the guiding question (are we still allowed to consume meat?)	+ / +	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 emissions 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.

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 transcript 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 as 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.

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 the 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 as intermediate. After the teacher repeated the question, one of the students responded: ‘by eating less meat’.

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 on 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.

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 and 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 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 of previous 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 played here by carbon dioxide. 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 attention 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.

Role of the 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 conducted 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 a structured interview (Southerland, Smith, and Cummins 2005) to be 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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