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Future Elementary School Teachers' Conceptual Change Concerning Photosynthesis

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The purpose of this study was to examine conceptual change among future elementary school teachers while studying a scientific text concerning photosynthesis. Students' learning goals in relation to their learning outcomes were also examined. The participants were future elementary school teachers. The design consisted of pre- and post-tests. The study revealed that student teachers have severe misconceptions concerning photosynthesis. However, the results indicated that a coherent expository text works as an effective support in the learning process. Further, results showed that students who express high-level learning goals are more likely to undergo conceptual change than students with low-level learning goals. The study highlights the importance of science education in teacher training at universities.

Keywords: conceptual change, learning goals, science learning, teacher education

The focus of this exploratory study is to examine future elementary school teachers' preconceptions and conceptual change concerning the topic of photosynthesis.[1] Conceptual change is a process where some previous conceptions are abandoned under access to new information, and knowledge structures are rearranged (see, e.g., Duit, 1999). Conceptual change can be perceived as a complex process in which an individual reorganizes existing knowledge structures (Limon & Mason, 2002; Posner, Strike, Hewson, & Gertzog, 1982). Conceptual change suggests some kind of goal-oriented activity, and hence can be called an intentional process (Sinatra & Mason, 2008). Many earlier studies on conceptual change have revealed that children experience considerable difficulties in understanding scientific phenomena (see, e.g., Duit, 1999; Roth, 1990; Vosniadou, 1994; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001).

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[1]In Finland, elementary school teachers study at least 5 years at university and graduate with a Masters of Education. The curriculum consists of courses on educational science, research methods, the didactics of different subjects, teaching practises and a master's thesis.

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Conceptual Change in Science Learning—the Case of Photosynthesis

One of the very well documented problematic themes in science classrooms is photosynthesis. Young learners seem to think that plants take their ready-made "food" from the soil (Hatano & Inagaki, 1997; Mintzes & Wandersee, 2005; Roth, 1990). Serious misconceptions concerning photosynthesis are often based on everyday notions that are in conflict with the scientific model, such as water for plants being viewed as the same as food for animals (see, e.g., Duit & Treagust, 2003; Mintzes & Wandersee, 2005; Roth, 1990; Vosniadou, Vamvakoussi, & Skopeliti, 2008). Photosynthesis is an example of an extremely complex phenomenon that is studied many times during the primary school years. It can be considered one of the most important topics in the biology curriculum, as all life on Earth depends on the ability of green plants to produce oxygen and to transform solar energy into chemical energy, which is then used by animals as an energy source.

Chi (2008) proposes that conceptual change is difficult to achieve because it often demands changes in and rearrangement of one's fundamental frame theories, which form the basis of knowledge structures and are highly resistant to change (Vosniadou, 2007a, 2007b; Vosniadou et al., 2008). A typical naïve frame theory concerning photosynthesis is derived from the assumption that plants take their nourishment ready-made from their environment, as animals do, and thus the learner is not aware of the ontological difference between plants and animals. Very often, it requires a huge reorganization of knowledge structures to understand that plants enable the existence of animals by storing solar energy as chemical energy and by producing oxygen and consuming carbon dioxide.

Difficulties in learning at school frequently seem to derive from tenacious misconceptions constructed in everyday interactions, which offer enough explanatory power in that context. For example, we know, based on everyday experiences, that a houseplant will die if we forget to water it. However, understanding the scientific explanation for why plants need water and what they do with it in a process called photosynthesis usually requires conceptual change. Further, scientific concepts are often used differently among science teachers and students (e.g., paralleling the greenhouse effect and climate change), which may result in misunderstandings and difficulties in the conceptual change process (see Wiser & Amin, 2001). Misconceptions have been studied and documented mostly among children, but it has been suggested that some of these misconceptions exist even among adults (see, e.g., Mintzes & Wandersee, 2005). It seems also that future elementary school teachers' misconceptions and problems with conceptual change are an unexplored research area. Hence, in this study, we try to identify what kind of misconceptions future elementary school teachers have concerning photosynthesis and discover if they are able to undergo a conceptual change.

Learning Goals and Metaconceptual Awareness as a Mediator of Conceptual Change

Students adopt different goals and purposes for their studying, and these have been documented to have an important role in learning (see, e.g., Entwistle & McCune, 2004; Pintrich, Marx, & Boyle, 1993). Setting high-level learning goals and monitoring them requires metaconceptual awareness, which means that one is aware of his/her previous conceptions and possible misconceptions (Vosniadou, 1994). This kind of intentional learning is usually considered a prerequisite for successful learning, such as that which occurs in conceptual change (Chi & Roscoe, 2002; Limón & Mason, 2002; Sinatra & Mason, 2008).

It is difficult for learners to become aware of conflicts that exist between their own explanations of scientific phenomena and the actual scientific model, as most learning is based on everyday observations. This is because naïve models are usually very robust and they offer a satisfying explanation in everyday life (Mikkilä-Erdmann, 2001; Vosniadou, 2007b). Hence, previous studies have revealed that years of intentional teaching and learning are ordinarily demanded to achieve a conceptual change (see, e.g., Chi & Roscoe, 2002; Chinn & Brewer, 1993; Duit & Treagust, 2003; Vosniadou, 1994, 2007a, 2007b). This is often the case when photosynthesis is the topic, as it is an example of a scientific phenomenon for which a scientific explanation is impossible to learn through observation. Because of that, it may be suggested that students' learning goals may operate as mediators in the process of conceptual change, so that students who set more ambiguous learning goals that challenge their previous conceptions are more willing to undergo a conceptual change than students who aim to focus on more superficial things, such as enriching the amount of detail (see Pintrich et al., 1993).

Sometimes the restructuring of knowledge structures and conceptual change may not succeed. The learner may try to add new information to old knowledge structures without recognizing conflicts between old conceptions and new information. This may lead to the development of a synthetic model that has characteristics of both scientific and naïve explanations (Vosniadou & Brewer, 1992). In synthetic models concerning photosynthesis, one may know that green plants do not take ready-made nourishment from the environment, but still think that in the spring a farmer spreads nutrients onto the field so that plants get "food" to grow (paralleling water and food: see, e.g., Mintzes & Wandersee, 2005; Roth, 1990). In cases like this, the learner may confuse everyday notions and scientific knowledge. The scattered nature of the synthetic model destroys the coherence of the mental knowledge structure and causes confusion in the learner's mind (Vosniadou, 1991). Therefore, one may on some level be aware of the importance of photosynthesis but still not deeply understand how photosynthesis is related to global problems such as famine in many poor countries. In this study, our purpose is to design diagnostics to evaluate student teachers' prior knowledge and conceptual understanding concerning photosynthesis and consider the role of learning goals in conceptual change among future elementary school teachers.

The Elementary School Teacher as a Science Educator and as a Science Learner

The elementary school teachers' role as science educator is crucial, because they are responsible for instruction in all the natural sciences during children's first 6 school years in Finland. Thus, teachers have to master basic knowledge in many scientific fields such as physics, chemistry, and biology. These years are crucial for children's science learning, because young children are typically inherently interested in their environment (Wood-Robinson, 1995). From a university pedagogical point of view this is a challenge, because before teachers are able to recognize misconceptions among their students, they should become aware of their own misconceptions, and achieve conceptual change by abandoning whatever previous misconceptions they may have in any of several different scientific fields. Only after that are they able to pay attention to students' learning difficulties and support conceptual change in their own science classrooms.

The most important instrument for teachers is the textbook, as a great part of the learning required in the school context occurs through successful text reading (Mason, Gava, & Boldrin, 2008; Mikkilä-Erdmann, 2002). Textbooks also dominate science instruction in the school (Hynd, 2001; Mason et al., 2008). The problem is that textbooks usually present scientific models and concepts as if learners had no prior knowledge, or only relevant prior knowledge, about the topic to be learned. Traditionally, textbook texts do not take readers' preconceptions into consideration (Mikkilä & Olkinuora, 1995; Mikkilä-Erdmann, 2002). That makes it difficult for the learner to compare his/her own ideas with those presented in the textbook and to notice when changes in their own conceptions are needed. These kinds of texts often cannot support deep learning and, typically, students just learn to reproduce the text instead of achieving conceptual change (van Dijk & Kintsch, 1983; Kintsch, 1986).

In university studies, the role of textbooks and other learning materials is even more important than in elementary school, because university courses require a lot of independent study from the student. Thus, the elementary school teacher's role as a science educator as well as a science learner presents extreme challenges for teacher education. These are the reasons why studying adult students' conceptions concerning scientific phenomena and conceptual change supported by textbook text is important. Further, we suggest that there are individual differences among students as, for example, in their learning goals, which can support or hinder conceptual change.

Research Questions

Our first research question is *how future elementary school teachers' preconceptions about photosynthesis differ from the scientific model.* Photosynthesis is a prerequisite for living organisms on Earth and thereby is perhaps the most important theme in the biology subject. The Finnish nationwide curriculum pays considerable attention to photosynthesis, and the theme is studied in almost every class year from elementary school to high school (Finnish Educational Government, 2003, 2004). Previous studies concerning children' misconceptions have documented the phenomenon well (see, e.g., Mikkilä-Erdmann, 2002), but it can be further suggested that adult students may also have difficulties in understanding the complex topic of photosynthesis (see, e.g., Ross, Tronson, & Ritchie, 2005). The second question of this study is targeted at examining the role of expository texts in conceptual change. While we know the important role of textbooks in science learning (Mason et al., 2008; Mikkilä-Erdmann, 2002) our second research question concerns *how students' conceptions about photosynthesis change during a text-reading procedure.* Our third research question deals with students' learning goals. We ask *how the level of learning goals students set before text reading is related to learning outcomes.* Based on previous studies, we hypothesize that those students who express high-level learning goals may benefit more from the text than will students with low-level learning goals (see Entwistle & McCune, 2004; Sinatra & Mason, 2008).

Methods

Participants

The participants were 18 students of around 23 years of age from one teacher training school in Finland. All participants except one had studied all of the compulsory courses in biology (15 credits), and two of the participants had studied biology as a secondary subject (35 credits). Three of the participants were men, the rest were women. The participants volunteered to take part in the study and they were able to compensate for certain missing credits in research studies by taking part in the study.

Procedure

The empirical phase was conducted in the laboratory setting using a single case approach. This study was part of a larger research project where the eye tracking method is used.

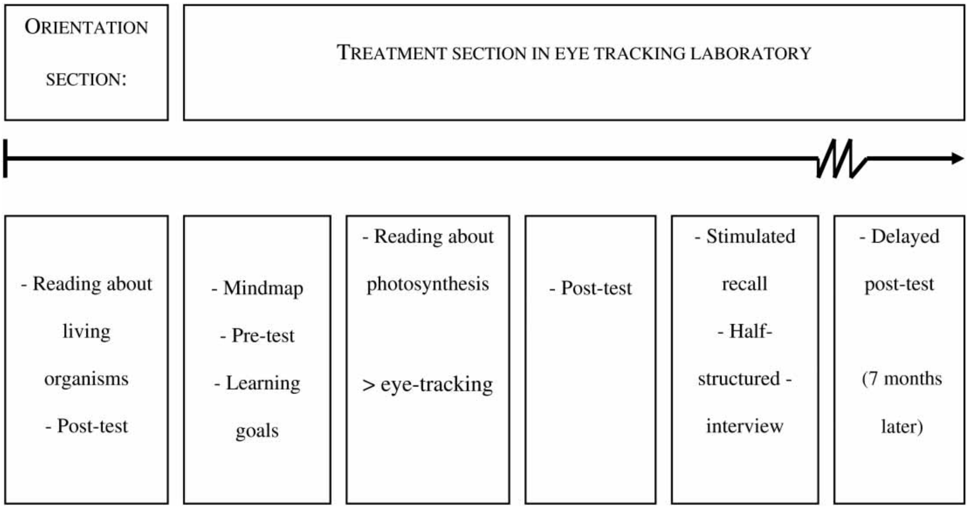

Figure 1. The research design.

The research consisted of two major parts: an orientation section and a study section (Figure 1). The first part of the research design was an orientation section, the purpose of which was to familiarize the participant with the test situation through reading from the computer screen. The study proper began with a task where the participant was asked to draw a mind map or in some other way express his/her ideas about photosynthesis. The purpose of this section was to orient the student to the subject area of the study.

After that, the participant answered nine written questions in the pre-test. All of the questions concerned photosynthesis from different points of view and they were categorized into three groups. The groups were: fact questions, text-based comprehension questions, and generative questions. Answering the fact questions, for example, "Explain the terms a) autotrophic, b) heterotrophic" required nothing more than reproducing of factual knowledge expressed in the treatment text. Successful answering the text-based comprehension questions in the post-test required understanding the connection between concepts that were presented in the treatment text. An example of a text-based question is: "What is the role of plants in food chains? Why?" The most difficult, generative questions required construction of a mental model concerning photosynthesis. Generative questions were, for example: "How do a dandelion, an earthworm (herbivore), and a mole (insectivorous) get their a) nourishment? b) other vital things?" There were no time limitations for the pre- and post-tests. After the pre-test questions, the participant was asked to write down further things s/he would like to know about photosynthesis. It was assumed that the questions of the pre-test would have aroused some questions in students' minds, depending on his/her previous knowledge and learning goals towards photosynthesis.

During the treatment, the participant read from the computer screen an expository text (366 words) concerning photosynthesis. The researcher advised the student to read the text so that s/he understood the content of the text. The treatment text was specifically created for this study and it resembled a textbook text whilst still being more argumentative and coherent than traditional texts, meaning that relations such as causes and consequences between concepts were better explained. During the reading, there were no time limitations, and one could move backward and forward in the text. After the reading, the post-test was conducted. In the post-test, the participant had an opportunity to compare his/her previous answers, because the questions were identical to those in the pre-test.

Participants were interviewed twice during the treatment. The first interview was a stimulated recall in which the eye movement data were used as a stimulus for the student to explain his/her cognitive processing during the reading. The final section of the study was a half-structured interview where the student was asked to answer a few questions that measured understanding of photosynthesis. All the interviews were video recorded. Two interview recordings failed.

The post-test was repeated after seven months. Participants in the delayed post-test were 12 of the 18 volunteers who had taken part in the earlier intervention. Students were asked to write answers for the same nine written exercises as they had done in the first phase of the study. There were no time limitations in the delayed post-test.

Data Analysis

The data was analysed using both quantitative and qualitative methods. First, we created a scientific conceptual flow chart based on the treatment text (Figure 2). The starting point of the chart was the nourishment supply of living organisms, because that made it possible to point out categorical differences between animals and plants. The chart was used as an analyzing tool, and original links between conceptions were replaced with links that were based on participants' conceptions in the pre- and post-tests and in the interviews. The purpose of this qualitative analysis was to create a chart that would represent the participants' mental representation before and after the test situation as realistically as possible.

Different color symbols were used to represent different kinds of conceptions. Green colored links represented correct conceptions, yellow colored links represented simplified conceptions, blue colored links represented correct but external-to-text conceptions, and red colored links represented false conceptions. The total scores were calculated so that green and blue colored links were each worth two points, and yellow links were worth one point, whereas every red link decreased the total score by two points. The maximum score of the scientific model was therefore 98 points. In theory, the participant could reach an even higher score if he/she had knowledge that was not mentioned in the text and so was not required to know. This flow chart analysis was performed for the results of the pre-test, post-test, and delayed post-test.

An inter-rater assessment was made for 20% of the data to guarantee the reliability of the analysis. An external evaluator, a biologist, performed the analysis twice. First, a training phase was conducted to teach the method for performing the qualitative analysis. The reliability after the second evaluation was 73%. The significance of the differences between the pre-, post-, and delayed tests was analysed statistically. Students' learning goals were classified qualitatively according to their answer to the question "What would you like to know further about photosynthesis?" after the pre-test. The answers were categorized into three groups: learning goals targeting systemic understanding, learning goals intended to learn more factual things, and no specified learning goals. Three researchers classified the learning goals independently, and the reliability was 76%. Learning goals targeting systemic understanding were interpreted as high-level, while goals aiming to remember factual things were interpreted as low-level learning goals.

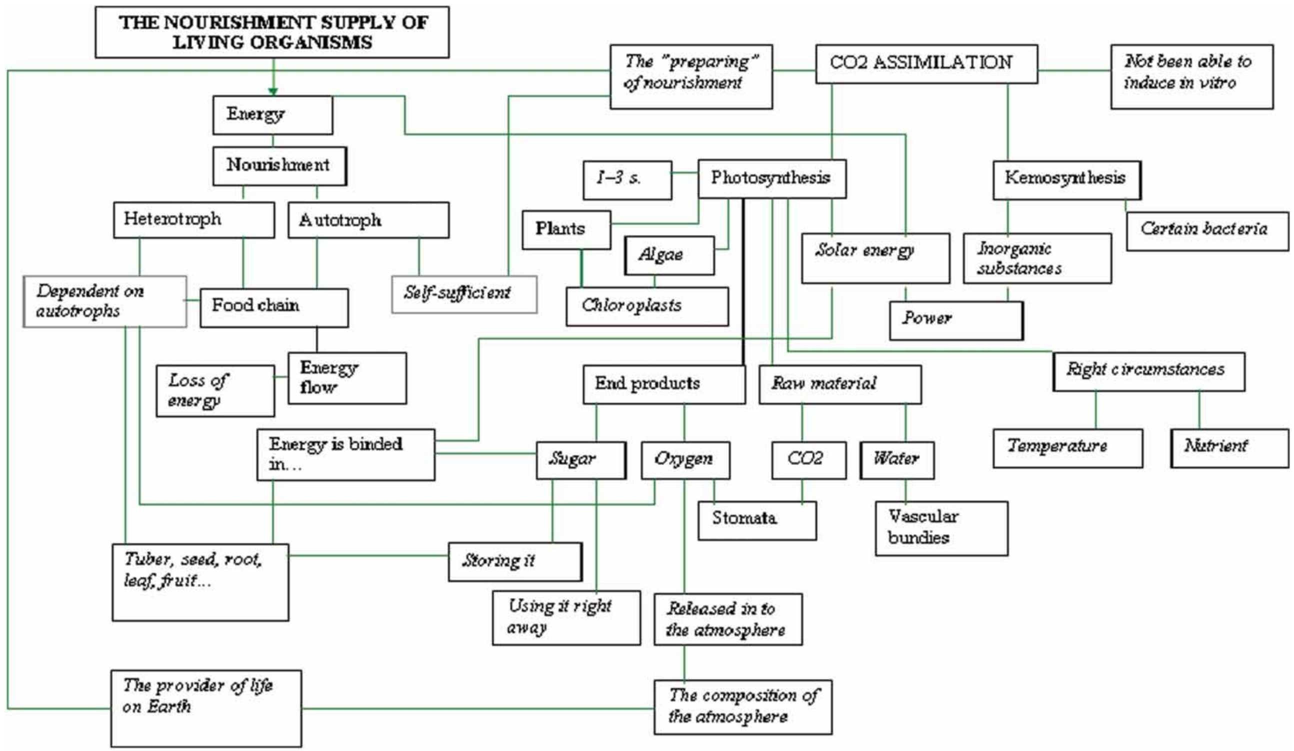

Figure 2. The analyzing tool, a scientific conceptual chart concerning photosynthesis.

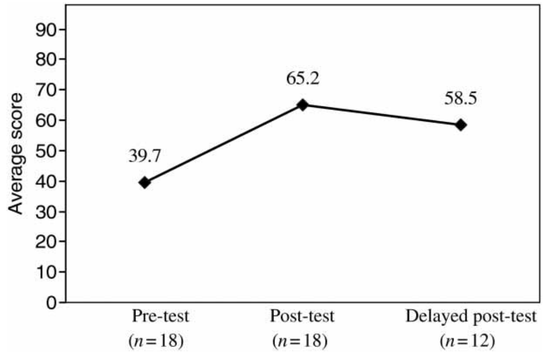

Figure 3. Changes in average scores during the procedure.

Results

Students' Representations Concerning Photosynthesis in Pre- and Post-Tests

In the pre-test ($n = 18$), 9 participants had naïve conceptions concerning the nourishment supply of plants. In these cases, the students thought that plants got their nourishment from the soil via their roots, meaning they thought that water and nutrients are food for plants. In the pre-test, 2 participants expressed both naïve and scientific conceptions concerning the nourishment supply of plants, and so these students were categorized as having a synthetic model. Only 7 participants gave correct scientific representations before reading the text. The average score of the pre-test was 39.7 points and the standard deviation was 18.2 points (see Figure 3).

In the post-test ($n = 18$), none of the participants had naïve conceptions concerning the nourishment supply of plants. All participants had improved their pre-test understanding; thus it may be concluded that everyone learned something new about photosynthesis during the treatment. Four students changed their conceptions so radically between the pre- and post-test that they were categorised as having undergone a radical conceptual change. Five participants had a synthetic representation in the post-test. Three of these students had a naïve model in the pre-test, and so they had only partly succeeded in revising their conceptions. One of the participants represented almost the same kind of synthetic model both in the pre-test and post-test. A total of 10 participants represented flawless and correct representations, though a deficient model, after the reading process. In the post-test, participants' representations improved remarkably; the average score was 65.2 points and the standard deviation was 11.0 points (see Figure 3). A statistically measured difference between pre- and post-tests was highly significant, $t(17) = -7.333$, $p < 0.001$.

In the delayed post-test ($n = 12$), 3 of the students represented a naïve model concerning the nourishment supply of plants. However, 5 students improved their achievement in the delayed post-test. In the delayed post-test, the average score was 58.5 and the standard deviation was 12.2 (see Figure 3). Thus, the average score decreased slightly versus the post-test, but most of the students stayed with a mainly scientific model after seven months of text reading. The Friedman nonparametric statistical analysis shows that participants' scores improved significantly during the procedure, $F_R = 13{,}167$, $df = 2$, $p = .01$. A closer look

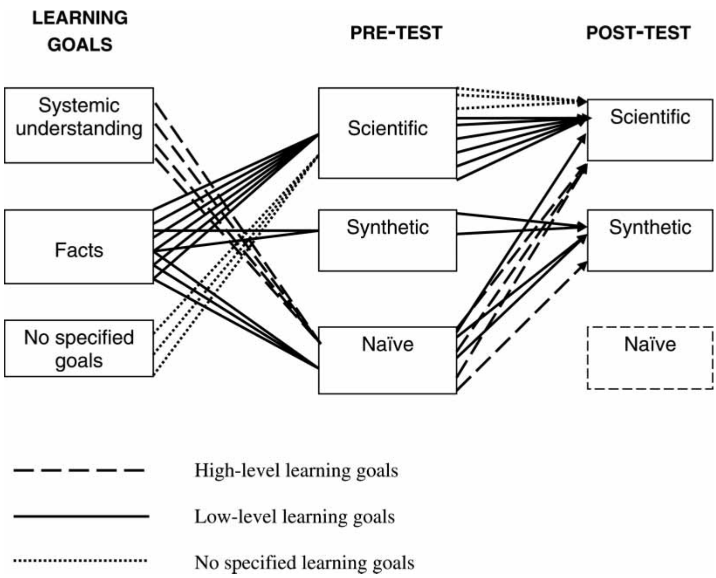

Figure 4. Learning goals related to learning outcomes.

at the results shows that while applying Bonferroni's correction in a nonparametric Wilcoxon test, students got significantly better results in the delayed post-test than they did in the pre-test, $Z = -2{,}747$, $p = .01$. The results also remain significant while comparing groups with different numbers of participants (in the pre-test $n = 18$; in the delayed post-test $n = 12$).

Learning Goals Related to Learning Outcomes

Most of the learners ($n = 11$) expressed low-level learning goals targeted at learning factual things concerning photosynthesis. High-level learning goals targeted at systemic understanding were expressed by four ($n = 4$) students. Three of the participants ($n = 3$) did not specify actual learning goals.

High-level learning goals were, for example: "*What does photosynthesis mean? Why do plants assimilate?*"

These students aimed to understand the entities and global meaning of photosynthesis. However, most of the participants ($n = 11$ students), wanted to learn some facts concerning photosynthesis. They made comments such as: "[I'd like to know] *things more accurately.…Overall, I'd like to maybe study more closely that process of photosynthesis…*". It was common for those who made this type of comment to aim to learn more factual things, such as the chemical formula of photosynthesis. Three of the participants did not name any particular learning goals at all. The learning goals related to learning outcomes are illustrated in Figure 4.

According to Figure 4, high-level learning goals predict high-level learning outcomes. Three out of four of those who aimed to deeply understand reached a conceptual change. Further, only one of those who had aimed to learn more factual things achieved a conceptual change, and two ended up with a synthetic model. Most of the students who already had a scientific model in the pre-test expressed less high-level learning goals.

Discussion

Our study indicates that future elementary school teachers have the same kinds of naïve conceptions concerning photosynthesis as have been observed among children. Before text reading, more than half of our student teachers thought that plants take their nourishment ready-made from the soil. This is an issue of concern, as all of the students except 1 had studied all of the compulsory biology courses in the curriculum. On the other hand, an important result is that a coherent and argumentative expository text supported learning, so that in the post-test none of the participants had any remaining naïve conceptions concerning the nourishment supply of plants. After 7 months, 3 students still had a naïve model concerning the nourishment supply of plants, while in the pre-test the number was 9 students. From the results, we can draw the conclusion that learning outcomes supported by a high-level textbook text remained high.

Furthermore, this study indicates that learning goals seem to have an important role in conceptual change, at least with experienced adult students. Those students who expressed high-level learning goals targeted at deep understanding of the topic were more likely to achieve conceptual change than students with more superficial learning goals. Similar results regarding learning goals have been documented by Entwistle and McCune (2004), who examined, among other things, the kinds of learning orientations of students with different learning goals. The results support previous ideas concerning the role of intentional learning in the conceptual change process (see Sinatra & Mason, 2008). It seems that intentional learning is at least one factor that influences who achieves conceptual change and who remains with a naïve or synthetic model even after years of studying.

Limitations of the Study

This study is a pilot study of a larger research project targeted at testing a new process method, eye-tracking, in investigating conceptual change. Because of this technically difficult and time-consuming method, the number of participants was relatively small. On the other hand, a small sample size enables the ability to mix methods and provide a deep case analysis, in which each student's representation is examined in detail using a flow chart as an analysis tool. Unfortunately, not all participants could be reached for the delayed post-test. Thus, studies with a control group and with a bigger sample size are needed in the future. Further, student teachers are high-level learners and it is possible that certain students reached relatively high scores in the tests by reproducing the text. However, questions that aimed to measure the students' ability to apply the knowledge required a deeper understanding of the content.

In this study, learning goals were identified after answering the questions in the pre-test. This may have had an impact on students' answers, and students' learning goals may have been different if there had not been any preceding stimulus. Nevertheless, this study makes a contribution to the science education of elementary school teachers at the university level. Furthermore, identification of the important role of learning goals for deep learning and conceptual change can be seen as an important result.

Implications of Intervention

The learning process is exposed to problems if an understanding of the scientific model demands changes in one's mental frame theories (Vosniadou, 1994), and this is often the case for the understanding of photosynthesis. Understanding how plants differ from animals is a prerequisite for understanding the importance of photosynthesis in the global ecosystem. Concerning photosynthesis, at first, one has to be aware of the differences between animals and plants in order to understand why life on Earth is dependent on green plants. After that, one still has to be careful not to mix scientific language with everyday language (see Wiser & Amin, 2001). In everyday life, we can often discuss things without using exact scientific concepts. However, with photosynthesis in question, mixing up certain words, such as *nourishment* and *nutrient*, can cause serious misunderstandings. Both the words and their meanings are similar, and they are often used interchangeably in everyday life, which makes mixing them quite easy.

It can be expected that conceptual change concerning photosynthesis occurs in at least two phases. Often young children categorize plants as non-living things (Vosniadou et al., 2008). Later, via everyday experiences, such as when children see that plants can grow, they need to be watered, and they can die, a child learns to re-categorize plants as living things and goes through a conceptual change (Vosniadou et al., 2008). However, another conceptual change is needed, namely an understanding of how animals and plants differ from each other.

Many scientific models are extremely complex and need to be over-simplified in order to provide a scientific explanation that is understandable by all. In addition, the teaching of biology tries to explain all of the anatomical and physiological differences between organisms by comparing the properties of organisms with those of humans. This may cause misunderstandings about such things as water and nutrients as food for plants. Even adults seem to think that plants eat and take nourishment from the environment as humans and other animals do. That is why, in the science classroom, the differences between animals and plants should be made more apparent in order to enable conceptual change.

From the university pedagogical point of view, these results highlight questions concerning the effectiveness of science teaching and learning in teacher education. It is a cause for concern that future elementary school teachers maintain basic misconceptions despite their many years of high-level education. The other important factor illustrated in this study is the teachers' ability to learn from the text. Effective skills for learning from a text are essential for elementary school teachers. They have to independently study new research results in different areas and update their own knowledge and teaching according to the latest findings.

In Finland, there is little science learning material aimed at future elementary teachers, even though they need to master many science subjects. Further, assessing the culture at university should be a target of increasing criticism, because years of education do not seem to be enough to support conceptual change. This may lead to the worrying outcome that teachers are not able to correct misconceptions in their classrooms or, even worse, that they may teach the wrong things to their students. Therefore, science learning materials at the university level should be designed so that handbooks concerning basic scientific phenomena are available to school teachers.

In science, it is common that new theories replace previous ones, and thus the abandoning of previous conceptions is essential. Teachers, as researchers, should maintain elastic knowledge structures so that conceptual change can occur again and again when new information comes to light. Metaconceptual awareness is a prerequisite for teachers to be able to understand their own, as well as their students', difficulties in learning. In addition, teachers have to constantly be able to evaluate new, and sometimes revolutionary, research results and integrate them into their teaching. Thus, just like students, teachers must also be continuous learners.

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