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Educational reconstruction – a key to progress in geoscience teaching and learning

Sibylle Reinfried

Summary

The model of educational reconstruction by KATTMANN/DUIT/GROPENGIESSER/KOMOREK *(1997) is a framework for the development of classroom instruction on the basis of constructivist teaching and learning. The model served as the theoretical background of a graduate course about constructivist teaching and learning in geography at the University of Education in Ludwigsburg, Germany. The course's focus was twofold: First, the students should gain an understanding of the importance of individual concepts and conceptual change in teaching and learning by working according to the model of educational reconstruction. Second, using the model as a theoretical framework, an entirely new way of seminar instruction should be applied. This involved the understanding of instructional development as a process based on a close interrelation of scientific and educational analysis of a particular subject content on the one hand, as well as individual educational research of the learners' preconceptions concerning that content on the other. This paper describes the model of educational reconstruction, explains its implementation into the course and the outcome of this project. From the experiences gained from the course it can be concluded that it is not sufficient to teach subject matter, pedagogical knowledge and constructivist ideas to enable students to create learning environments that facilitate meaningful constructivist teaching and learning in the geoscience classroom. Additional opportunities should be offered to students to initiate the process of conscious knowledge construction and conceptual change in order to better understand what teaching and learning on a constructivist basis means.*

Introduction

This paper is about a relatively new approach to constructivist teaching - the model of educational reconstruction by KATTMANN/DUIT/GROPENGIESSER/KOMOREK (1997). The model served as the theoretical framework for a newly introduced course based on constructivist concepts of teaching and learning in geography education. The model, which was applied in a graduate course for geography majors in geography education at the University of Education in Ludwigsburg (Germany), seeks to enhance students' awareness of the issue and the importance of conceptual change in order to improve teacher education. The paper firstly describes the model of educational reconstruction and its epistemological position. In a second step it explains how the model was applied to the course and reports about its outcome.

1. Background, aims and framework

Research on students' and teachers' conceptions and their roles in teaching and learning science has become one of the most important domains of science education during the past three decades (DUIT/TREAGUST 2003). Findings from many studies show that learners enter their classes with deeply rooted ideas or beliefs about the natural world that do not correspond to accepted scientific findings. These preconceptions are personal cognitive constructions by individuals attempting to make sense of their social or natural environment. The diagnosis of preconceptions may be seen as a crucial initial step in the process of teacher-facilitated conceptual change at all grade levels. Conceptual change is not an exchange of pre-instructional conceptions, but a fundamental restructuring of the already existing knowledge in order to allow understanding of the intended knowledge, i.e. the acquisition of science concepts (DUIT/TREAGUST 2003).

Research has shown that approaches to conceptual change in science instruction may be more effective than traditional approaches in teaching and learning for learning science concepts and principles (DUIT/TREAGUST 2003). Extended studies concerning teaching and learning processes in classrooms in Germany (PRENZEL/SEIDEL/LEHRKE 2002) proved how restricted teachers' subject-related ideas of teaching and learning still are. Teachers very often dispose of a methodological repertory that is related to the teaching of content knowledge while ignoring the results and findings of subject-related educational research. They still seem to assume that knowledge is directly transferable from the teacher to the learner. Changing teachers' views of teaching and learning from transmissible towards constructivist orientation and the fact that we do not know much about students' pre-instructional conceptions to be aware of when a new geographical or earth science principle is introduced in the classroom, encouraged the author to develop a new course for students in geography education based on a relatively new approach of constructivist teaching and learning, namely the model of educational reconstruction developed by KATTMANN/DUIT/GROPENGIESSER/KOMOREK (1997). The model is seen as a key to progress in teaching and learning because it focuses on subject-related educational thinking (DUIT 1999; DUIT 2004; SHULMANN 1987).

The model of educational reconstruction has proven to provide a useful theoretical framework for integrating empirical research on teaching and learning into instructional development (KOMOREK/STAVROU/DUIT 2003). It allows balancing science content structure with educational issues. The model comprises three interrelated components (Fig. 1):

1. The clarification of a particular

content structure and the analysis of the educational significance of that science content, the analysis of its core and elementary concepts and the reconstruction of its concepts and their relationship from an educational perspective.

2. The empirical investigation of students' perspectives and preconceptions of the respective science content.
3. The construction of the science content's instruction in the classroom.

Based on these three components, educational reconstruction can be characterized as a cyclical process of theoretical reflection and conceptual analysis accompanied by small-scale curriculum development and classroom research on teaching and learning processes (Fig. 2) (comp. LIJNSE 1995).

The model of educational reconstraction is based on a constructivist epistemological position that starts out from the idea that there is no such thing as a "true" content structure of a particular content area. What is termed here "the science content structure" denotes the consensus of a particular science community. In the process of educational reconstruction issues concerning a science content's signifi-

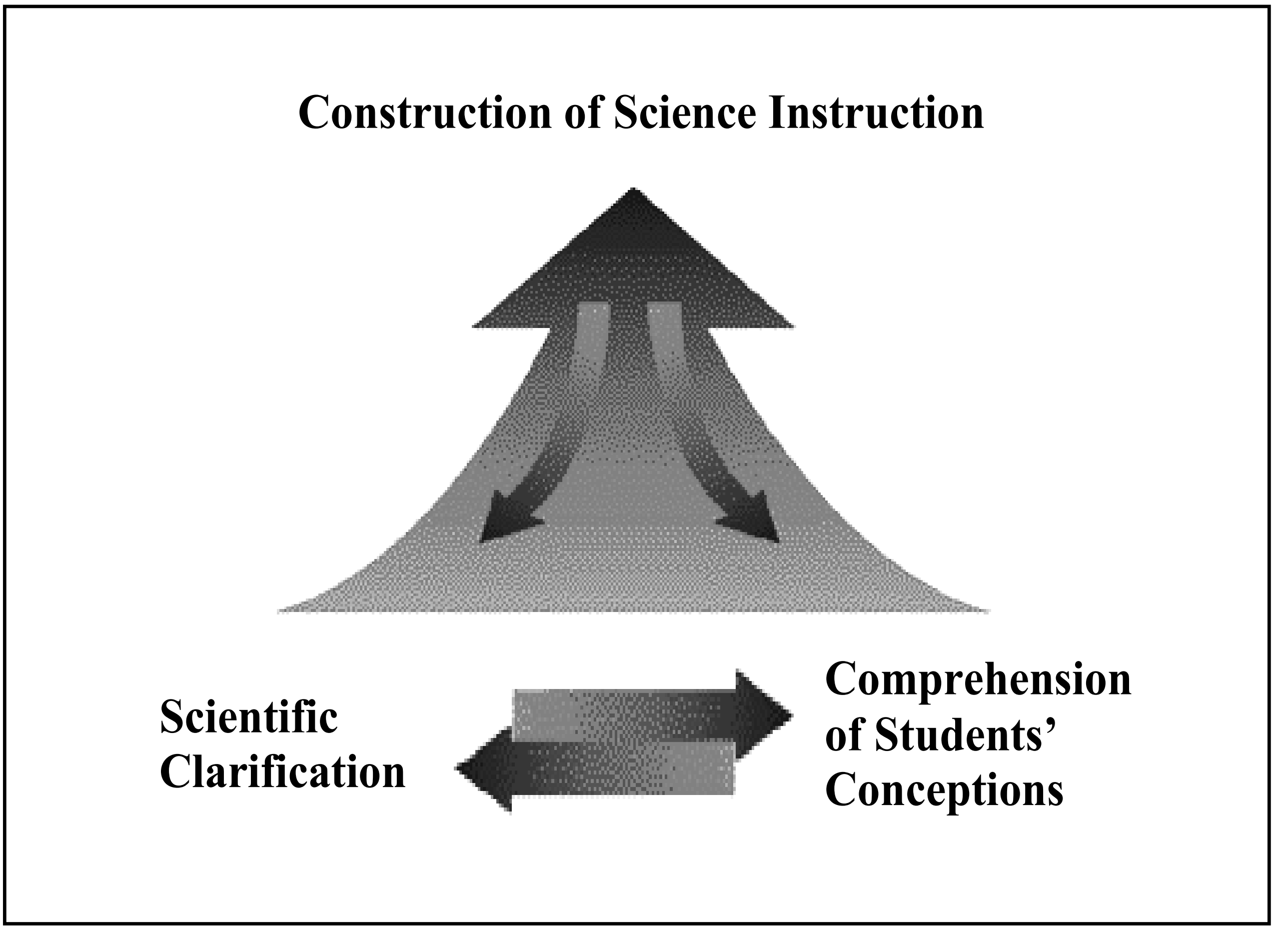

Figure 1: The model of educational reconstruction (Source: KATTMANN/DUIT/GROPEN-GIESSER/KOMOREK, 1997)

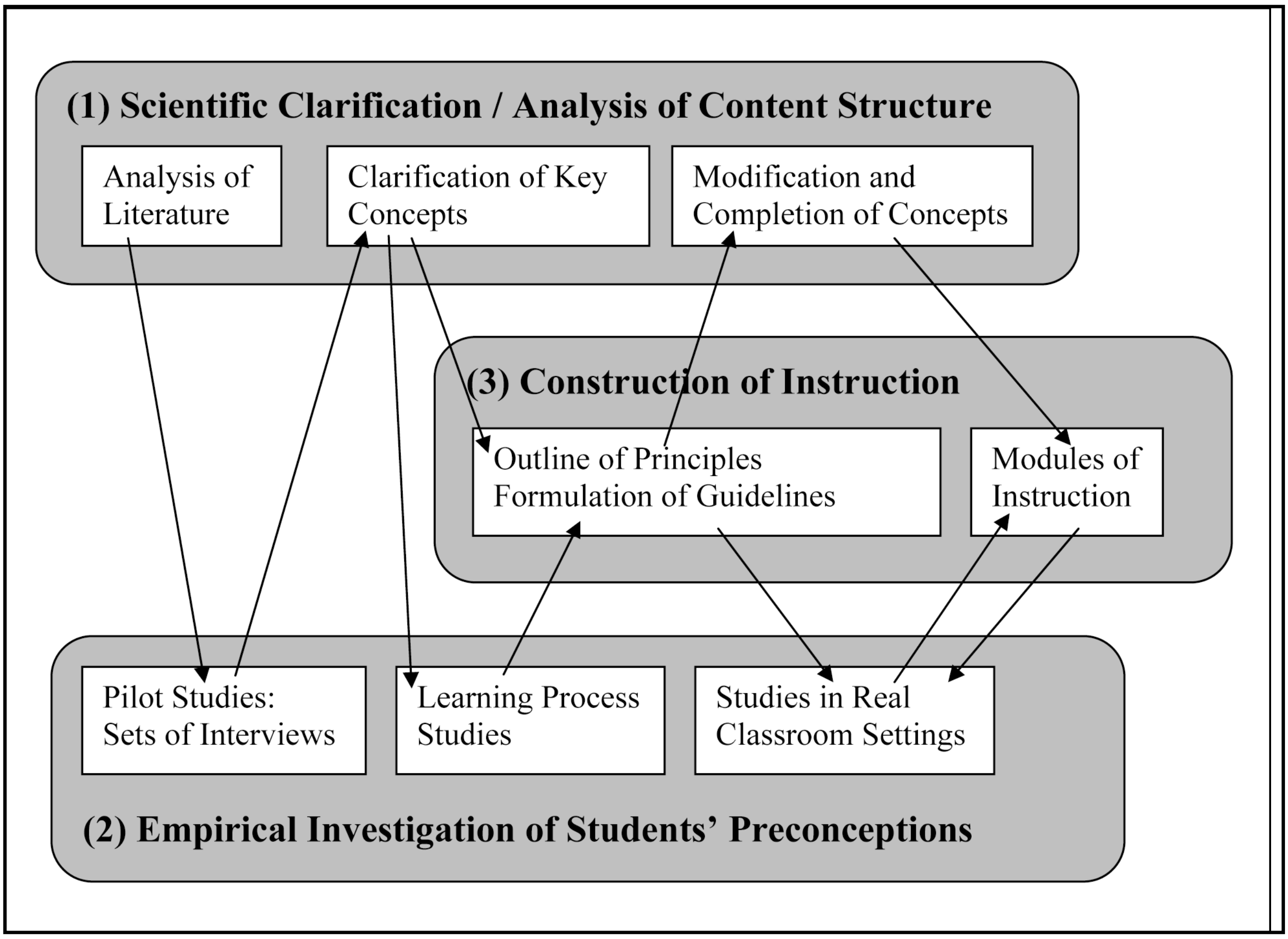

Figure 2: The process of educational reconstruction (Source: Komorek/Stavrou/Duit 2003)

cance from the science perspective and from the students' perspective are intimately connected and influence a curriculum developer's analysis of a particular science content. Included in this analysis are also issues of the philosophy and the history of science as well as educational considerations. The model of educational reconstruction is a powerful framework for the development of instructional units by the teachers. It is also useful as a framework for educational research and curriculum development.

At the Ludwigsburg University of Education (Germany) the model of educational reconstruction was applied to a compulsory university course for majors in geography education. We started with the course in 2004 and offered it three times in the last two years. All fifty students who participated in the course till today had some teaching background but were not experienced teachers yet. The content areas on which the model was applied derived from the earth sciences and geography and were partly new to the students (Tab. 1). After an extended introduction into the theory and a demonstration of an example on how to work according to the model of educational reconstruction, the students started their work in groups and chose the

Table 1: Concepts and processes on which the model of educational reconstruction was applied

Earth Science Topics	Geographical Topics	
	Physical Geography	Human Geography
• The extinction of dinosaurs • The rock cycle • Volcanic eruptions • Mountain building (orogeny) • Earth's internal structure • Plate tectonics • The formation of petroleum and natural gas • Groundwater occurrence in nature	• Movement of a glacier • The tides • Ocean currents • The seasons	• North American Indians • The Inuit • The Green Revolution

topic they wanted to work on (Tab. 1). In this paper I will present the application of the model on the content area of groundwater resources. One of the reasons for that is that we did extended research on the preconceptions and on conceptual change regarding groundwater. Therefore the topic of groundwater is well suited to explain the various steps of the model and its application in the classroom.

2. Application of the model of educational reconstruction on the concept of groundwater

2.1 Scientific clarification: analysis of the literature

To teach the content area of groundwater in depth knowledge about the subject matter is necessary. Thus, the students looked at university textbooks and textbooks for schools on physical geography and Earth science and studied the scientific theories, concepts and processes underlying the concept of groundwater occurrence in nature as presented in the books. When they started their work, they where quite convinced, that the information presented therein was correct. They did not critically analyze or question the information or take into consideration that the way aquifers were presented in the textbooks might contain personal views of the authors. More often than not the textbooks revealed that each theory has evolved over time and that sometimes even the authors themselves are not aware of this facts, as for instance when an author obviously labors under the same misconceptions scientists held centuries ago without being aware of them. For the students, this insight was a crucial step in the process of the analysis of the content structure. They then proceeded with their work applying the following questions to the textbook descriptions on groundwater:

- What kind of scientific theories concerning the concept of groundwater exist and where are their limits?
- What origin, function and meaning do the scientific terms related to the concept of groundwater have and in what context are they used?
- What kind of expressions are used to describe the concept of groundwater and which terms are provoking misleading ideas due to their metaphorical character?

Thus, the topic of groundwater was looked at from different perspectives: the theoretical frame of its scientific terms, the historical theories that lead to the recent development of the valid concept, paradigmatic changes that influenced its evolution, interdisciplinary issues around groundwater and ethical and societal implications related to human interactions with groundwater. Working that way, the students not only acquired a lot of factual knowledge but also studied the issue of groundwater on a scientific meta-level. The students analyzed the relevant literature by summarizing, explaining and structuring the scientific content gained from the textbooks.

2.2 Empirical investigation of learners' preconceptions: pilot study

To find out about learners' preconceptions concerning the topic of groundwater the participants of the course asked elementary, middle school, high school and college students to make drawings of their ideas of groundwater, to fill in a questionnaire and they conducted interviews with a small number of students of the specific age group they had chosen to investigate. (The results of the research concerning groundwater have been published in Reinfried 2005, 2006.1). The term "preconceptions" denotes here not only students pre-instructional knowledge but also their ideas, concepts or theories concerning the issue that were constructed by the individual based on his or her everyday experience, analogies or the interpretation of metaphors. When comparing students' preconceptions with scientific notions it is important to identify issue-specific ways of thinking. Typical questions the university students asked in this context were:

- What kind of preconceptions do learners have about groundwater?
- Do these preconceptions originate from everyday experiences or from scientific knowledge?
- What kind of meaning do central terms related to the concept of groundwater have?

Regardless of age or level of education the knowledge the learners revealed of groundwater was either poor, erroneous or incomplete. Most of them believed groundwater to be stored in large subsurface openings, such as reservoirs, caves, lakes, channels or water veins. At the time the learners' made their drawings they had not yet learnt anything about the topic in school or their university education. It was possible to group the more than hundred drawings gained in the last two years into six basic model conceptions that represent the most common ways of thinking concerning groundwater occurrence in nature. These mental models are (REINFRIED 2006.2):

- o the model of groundwater in subsurface caves
- o the model of groundwater in subsurface lakes
- o the model of groundwater in water veins
- o the model of groundwater as a part of the hydrologic cycle
- o the model of groundwater as a layer of water at the bottom of a lake or the sea
- o the model of groundwater as subsurface water in porous and permeable sediments.

Searching for explanations for these mental models the university students found that they are based either on

- everyday experience, such as
  - anthropomorphic ideas (i.e. the water veins are seen as an equivalent to blood veins)
  - metaphors (the term groundwater is interpreted word by word as a layer of water at the bottom of a body of water)
- or that they can be related to knowledge gained from textbooks or instruction, such as
  - analogies (the idea of subsurface caves or lakes originating from Karst phenomena)
  - misinterpretations of features in diagrams (the idea of subsurface channels originating in broad arrows drawn in diagrams on the water cycle) or
  - correct concepts of groundwater (which is stored in porous and permeable layers of sediments or sedimentary rocks).

2.3 Scientific clarification: clarification of key concepts

After the university students had analyzed the investigated preconceptions they extracted the following core concepts they considered to be crucial for the understanding of the concept of groundwater:

1. Interactions between the components of the hydrologic cycle: complexity of the water balance.
2. Groundwater distribution, storage and movement: zone of aeration, zone of saturation, porosity, permeability, aquifers, water table.
3. Groundwater quality: taste, temperature, salinity, bacteria, harmless and toxic dissolved minerals and organic constituents.
3. Human interactions: groundwater pollution, overdraft, set-aside of floodplains for groundwater recharge.

The interviews with learners of different age groups they had conducted and analyzed in the meantime gave them a deeper insight into the “misconceptions” of their interviewees so that they wanted to look again at the core concepts and terms they had already found. They realized that the concept of groundwater with all the issues related to it is only understandable if it is studied under the premises of a systemic approach (Fig. 3). Systems analysis is an important tool to arrive at a holistic view of all processes related to human-environment interaction. A groundwater flow system is a part of a system model that allows learning about systemic thinking. Central elements of natural, open, dynamic systems are: input (water, energy), output (water), transformation (movement, cleaning, pollution), feedback loops (positive feedbacks: set-aside of floodplains for groundwater recharge; negative feedback: groundwater overdrafts), and dynamic-equilibrium states. They concluded that accordingly a major objective of their classroom teaching should be to make the groundwater flow system understandable as a natural, open and dynamic system.

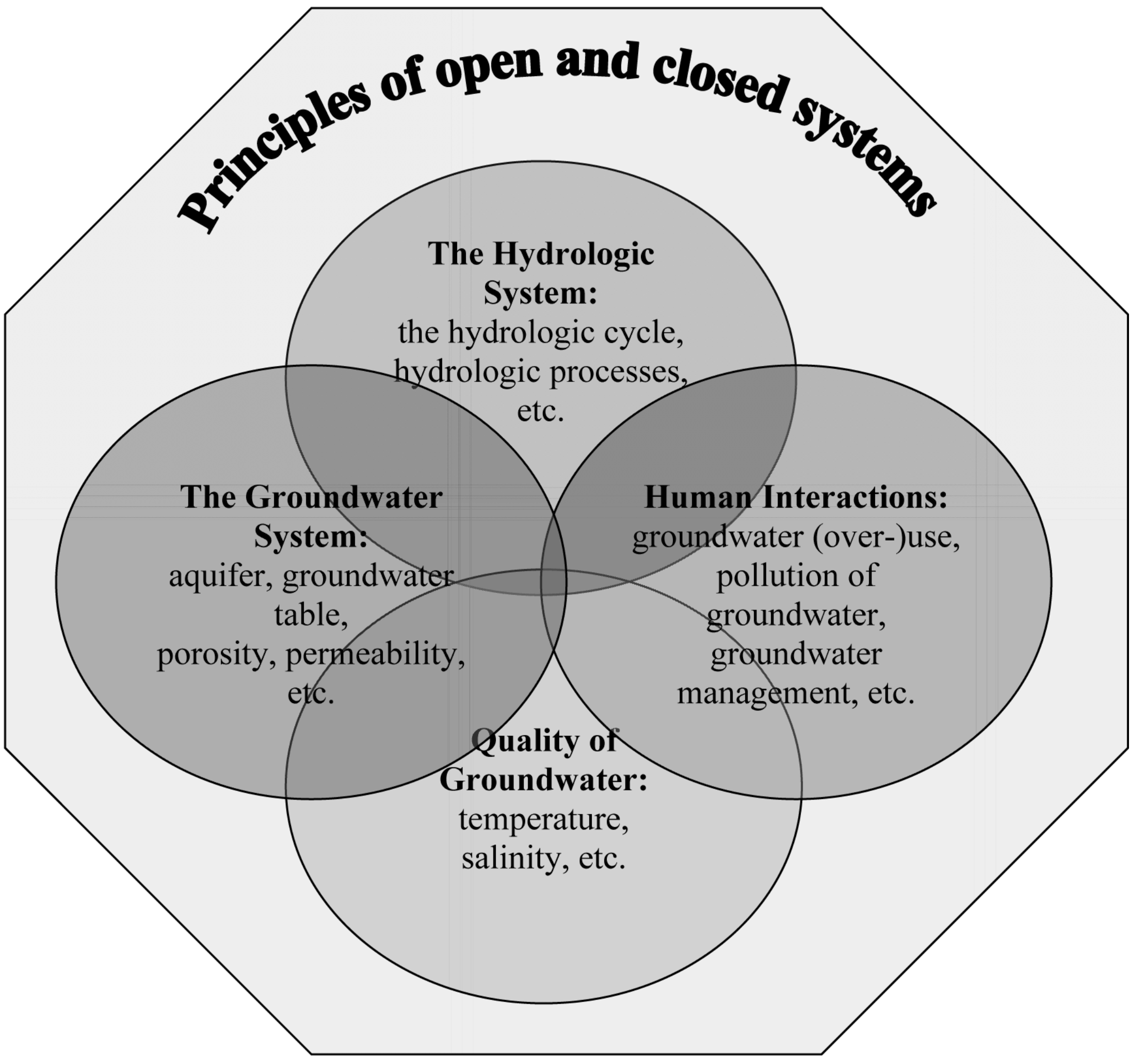

Figure 3: The groundwater flow system as a part of a system model.

2.4 Construction of instruction: a constructivist teaching strategy

The basis of the construction of instruction is the combination of the scientific clarification and the results gained from the investigation of the learners' preconceptions. The generalized scientific ideas are compared to the learners' ideas and linked to each other systematically and in a structured way. Emphasis should be put on the characteristics of the perspectives of both sides, the correspondent views of both sides that are helpful for learning and the foreseeable learning difficulties. The educational reconstruction is a gradual and cyclic process, which is related to the following questions:

- Which corresponding views and strategies for teaching result from the comparison of scientific facts and learners' ideas?
- Which of the students' perspectives are to be taken into consideration during the teaching of terms and concepts?
- Which meta-scientific and meta-cognitive teaching strategies are conductive to effective learning?

A successful strategy for conceptual change that mirrors the elements of the educational reconstruction is the mental model-building strategy published in 2003 by TAYLOR/BARKER/JONES. We modified it to adjust it to the model of educational reconstruction and applied it on the university and secondary level (REINFRIED 2006.2). The strategy consists of discrete phases that allow to de-construct and re-construct mental models (Tab. 2). Mental

Tab. 2: The mental model-building strategy – a constructivist teaching strategy.
Source: REINFRIED (2006.2, modified).

The Mental Model-Building Strategy for Conceptual Change	
Pre-phase:	Preparation - to find out about learners' pre-instructional conceptions and mental models.
Phase I:	Identification of differences between learners' mental models and scientists´models.
Phase II:	Mental model-building and mental model evaluation (comprehension)
Phase III:	Use of newly constructed mental models to solve problems (application).
Phase IV:	Reflection

models are a person's internal representation of a scientific concept. They are highly individual, simplified, schematized and graphic analogy-models and display the reality only in a limited way. Schnotz (1994) describes mental models as internal "quasi-objects" that allow internal simulations of external processes to cope mentally with tasks and problems (Reinfried 2006.3).

The mental model-building strategy for conceptual change (Tab. 2) starts from the premise that the construction and reconstruction of knowledge in the classroom is comparable to the epistemological process in history that was driven basically through paradigmatic changes. For the epistemological process in history as well as for the learning process in the classroom it is true that as soon as new knowledge is available ideas and concepts valid till that moment have to be clarified, revised and developed further. Therefore an important objective of the learning process is to gain the capability to compare one's mental model of an issue with the scientific model, in order to identify similarities and differences. Similar to the researcher, the learner thus clarifies a concept, a theory or an explanation of a phenomenon. According to the findings of the theory of learning this should not only happen cognitively but also include action and emotions, similar to the mental model-building strategy presented here. The strategy seems to promote conceptual change of groundwater occurrence in nature and to reduce misconceptions on groundwater more significantly than does traditional teaching (Reinfried 2006.1).

The idea behind that strategy is such, that a learner's mental models can be modified through the use of simplified miniatures or enlargements of scientifically accepted models of a concept. They are in fact the mental models of scientists and do no entirely represent reality. Applied to the topic of groundwater, restructuring of learners' concepts starts with phase 1 of the strategy during which the learners articulate and compare their preconceptions within groups and within the class (Tab. 2). Subsequently, in phase 2, a large groundwater model that allows the simulation of a wide range of groundwater features and processes is used (Williams 2002). The learners discover convergences and divergences between their mental models and the scientific model. The confrontation triggers intentionally a cognitive conflict, a vital prerequisite for conceptual change according to Posner/Strike/Hewson/Gertzog 1982. Because conceptual change is not possible through mere instruction the learners work hands-on in phase 3 with a variety of tools to create their own small groundwater models in plastic cups with which they carry out experiments to solve groundwater-related problems. In the final evaluation phase the study-groups present their findings to the class. The research-based way to solve problems delivers a variety of solutions that the groups explain in front of the plenary and defend them against criticism. The discussion finally leads to an agreement on knowledge-based interpretations of the problem. This process helps the learners to adjust their personal mental model to the scientific model.

4. Results and implications

The intended aim of the course to enhance students' awareness of constructivist teaching and learning and its importance for conceptual change could fully be achieved. The students learnt about the theoretical background of the model of educational reconstruction, they conducted their own small empirical study to find out about learners' preconceptions and constructed a teaching sequence based on their research findings. Because not all Earth science and geographical themes listed in table 1 were suitable to be applied on the mental model-building strategy the students developed a variety of ways of teaching that all displayed characteristics crucial for situated learning. Considering learners' prior knowledge and their preconceptions, these learning environments encouraged activities such as the generation of hypotheses, experimentation and exploration allowing discovering new principles and explanations, thus contributing to active sense making by the learners.

The evaluation of the course (discussion in focus groups and a questionnaire) provided useful results about the students' learning processes and their processes of conceptual development in a cooperative setting.

In unguided situations teacher students normally try to construct a unit before analyzing the content structure and before thinking about the educational aims of the teaching and learning sequence. They just search for material about a topic in textbooks and other secondary resources and put it together in a way that makes sense to them. In the guided process of the course described here they firstly studied the literature, learnt about the recent valid theories of a scientific concepts, how it developed over time and its limitations. They clarified the key terms and key concepts of an issue and developed a tool (e.g. a questionnaire) that they considered to be useful to find out more about learners' pre-instructional ideas. Before using it in the classroom, they tested the tool in the course, discussed it in the plenary and subsequently improved it. This step revealed that university students' ideas about basic scientific concepts were similar to those of their pupils in schools.

During the process of the scientific clarification of the content structure the students discovered that many theories are based on assumptions that have not yet been proven or that scientist may have different, often contradicting perceptions of one and the same phenomenon. They also realized that scientific knowledge and the discovery of scientific principles have always been and still often are embedded in philosophical and historical contexts that have influenced scientists´ perceptions. The students understood the meaning of paradigmatic changes and realized that science is not necessarily a linear process but a series of paradigms changing in a revolutionary manner (Kuhn 1970). The students also reported about their own preconceptions, such as teleological, deterministic, anthropomorphic or religious beliefs that they had come across during their work. They learnt about the process of scientific inquiry, became aware of the current frontiers of science and were able to draw conclusions from what they had explored. Apart from this they experienced the process of constructing meaning during their group discussions that gave them insight into their learning process and conceptual development. Unfortunately, one crucial step, namely the test in classroom of all the teaching and learning modules developed by the university students', could not be realized due to the lack of unlimited access to schools. Nevertheless, the results gained from this course give valuable hints for future courses in teacher education. Fundamental is the insight that it does not suffice to teach future teachers content knowledge, pedagogical knowledge and constructivist ideas. At the same time opportunities to experience conceptual change in person must be offered as well, if the concept of teaching and learning as constructional processes is to be understood in depth.

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