Conceptual Change in Physical Geography and Environmental Sciences through Mental Model Building: The Example of Groundwater

Sibylle Reinfried
Department of Geography, Ludwigsburg University of Education, Reuteallee 46, 71634 Ludwigsburg, Germany

This research tested the hypothesis that students' erroneous mental models about groundwater will change towards more valid concepts if they are taught on the basis of a mental model-building strategy that focuses on the clarification of students' misconceptions. To examine the hypothesis a quasi-experimental research design was chosen. The methodology adopted in the study used both qualitative and quantitative methods. To promote conceptual change, a teaching and learning approach aiming at mental model building developed by Taylor *et al.* (2003) was adopted in the experimental group, while the control group was taught in a traditional lecture style. The procedure was applied to investigate the mental models of 30 German undergraduate teacher education students in geography. More than 75% of the students' conceptions were either unclear or incorrect, based on simple, 'common sense' views of groundwater deposits. After the intervention the experimental group revealed significantly fewer misconceptions in their mental models about groundwater than did the control group. Teaching and learning by the mental model-building approach therefore seems to help undergraduate students to improve and refine their mental models of the abstract concept of groundwater occurrence in natures. The findings also suggest that the mental model-building approach could be a feasible strategy to induce conceptual change of other natural and cultural phenomena in geography and environmental sciences.

doi: 10.2167/irgee186.0

Keywords: mental models, conceptual change, mental model building, geography education, environmental education, groundwater

Introduction

Mental model building as an educational process

The growing awareness of the relevance of learners' knowledge prior to formal schooling for learning processes in general is reflected in learning theories based on pedagogical constructivism (Driver, 1981; Pfundt & Duit, 1994). According to this theory, learners' knowledge is individually and socially constructed, complex and varied, and may be structured in large-scale and interlocking conceptions. To the extent that learners attach importance to what they have learnt at school they may or may not generate new and complex conceptions. Existing conceptions may be tenaciously retained for reasons that are

1038-2046/06/01 0041-21 $20.00/0

psychological or social, as they seem plausible and evidence-based (DeLaughter *et al.*, 1998).

According to recent theories in the cognitive sciences knowledge is acquired through the construction of multiple representations. Conceptual knowledge is represented in cognitive schemata that function as instruments for the construction of mental models. A mental model is an internal, personal quasi-object, cognitively representing a specific domain of knowledge, constructed of structural and functional analogies of this knowledge domain (Schnotz, 2001: 77). It is a construction resulting from a subject's own perspective and his or her manipulative and social experience with the world. Mental models are incomplete, imprecise and incoherent with the specific domain knowledge. But they are useful, since they are powerful explicative and predictive tools for the interaction of an individual with the world (Greca & Moreira, 2000: 3ff). Mental models integrate semantic-symbolic, iconic and enactive knowledge and allow the internal simulation of external processes (Edelmann, 2000: 153ff). They can take many forms (spatial relations, events, processes or the operations of complex systems), serve many purposes and are dynamic because they are never complete, but continue to be enlarged and improved as new information is incorporated into them (Johnson-Laird, 1983).

The diagnosis of students' often incorrect preconceptions and mental models may be seen as a crucial initial step in the process of teacher-facilitated mental model building at all grade levels to provide the basis for achieving improved scientific literacy. To correctly diagnose students' preconceptions, teachers themselves should be aware of their own mental models and should have an adequate comprehension of relevant concepts that are scientifically accepted. To promote such conceptual change, educators may employ constructivist teaching which is defined as a process in which learners clarify their own ideas, followed by a revision, reconstruction and validation of their own mental models combining individual knowledge and scientific conceptions in a coherent entity (Morrison & Lederman, 2003; Taylor *et al.*, 2003).

The importance of the issue of groundwater in the teaching of physical geography and environmental sciences

Of all the water in the world, less than 3% is fresh. 'Water will be more important than oil in this century', stated the former UN Secretary General Boutros Boutros-Ghali in an interview with the BBC news on 3 March 2004. Global water consumption has risen almost tenfold since 1900, and many parts of the world are now reaching the limits of their supply (Klaphake & Scheumann, 2001). With world population expected to increase by 45% in the next 30 years, UNESCO predicts that by 2020 water shortage will be a serious worldwide problem. One-third of the world's population is already today facing water problems due to both insufficient quantity and inadequate quality. To increase people's awareness of reasonable, sustainable use and handling of the Earth's freshwater resources, the UN declared the year 2003 the 'International Year of Freshwater'. In a worldwide information campaign, the UN sought to draw attention to the fact that water is essential to life (United Nations, 2001).

Although at least 30% of global freshwater resources are groundwater, exceeding the volume of surface water by a hundred times, people typically don't think of it as important. However, the drinking water supply of many countries depends to a large extend on groundwater (e.g. 80% in India, 70% in Germany, 50% in the United States). In the face of a growing global population, sustainable groundwater use and groundwater protection are, of course, critical.

Therefore people need to understand the nature of groundwater, i.e. how it is formed and stored below the Earth's surface, that it can easily be overused or polluted, and that it is part of a dynamic system, the global hydrological cycle.

Purpose of the Study

This research tested the hypothesis that students' incomplete and erroneous mental models about groundwater will change towards valid concepts if they are taught using a mental model-building strategy that focuses on the clarification of students' preconception. Students who are instructed in a traditional way through lecturing will be more resistant to mental model change. This hypothesis rests on the research findings of Heron (2003) that lecturing promotes memorisation of factual information while more effective instruction that helps students gain functional knowledge requires techniques that assist them in explicitly reconciling their preconceptions with new information.

The Roles of Scientifically Accepted Models in Mental Model-building

To build a learner's mental models, simplified miniatures or enlargements of scientifically accepted models of a concept (which are in fact the mental models of scientists) may be helpful. Positive learning outcomes using models were reported by a variety of studies on all grade levels (Doerr, 1997; Dupin & Joshua, 1989; Gobert, 2000; Kaufman *et al.*, 1996; Stavy, 1991; Treagust *et al.*, 1996; Weller, 1995). Hesse described a way in which mental models evolve by using tangible models (Hesse, 1996, 2001). She suggested that an essential skill for learners is to evaluate their provisional understanding by listing a model's positive, negative and neutral attributes with respect to the learners' mental model. Positive attributes are those properties that both the model and the mental model share while negative ones are those attributes not shared by both. Neutral attributes are simply those not yet classified as positive or negative (Hesse, 1966, 2001). That teachers and learners should jointly review models representing their mental models has also been suggested by Harrison and Treagust (2000). Because learners often use scientists' models to help formulate their own mental models, these ideas were included in the mental model-building approach used in this study.

Research Methods

Sample and procedures

To examine the hypothesis a quasi-experimental research design was chosen. The interpretative methodology adopted in the study used both quantitative methods (to establish students' development of groundwater conceptions) and qualitative methods (to investigate the process by which students change groundwater conceptions). The context chosen for the interventions consisted of standard introductory classes at a German college for teacher education, featuring two groups of undergraduate students not assigned at random (experimental group n = 16, control group n = 14, totalling 30 students). The students were in their first year of college education striving for a minor or a major in geography, but still all attending the same courses at that level of their college education. They prepared to teach geography on elementary and middle school level. The two groups of students attended two parallel introductory courses held in physical geography on the same day of the week, one in the early afternoon and the other in the late afternoon. In order to ensure that the two groups were comparable and equivalent in ability in terms of their university education up to the time when the research was conducted (except for random differences), their status such as age, gender, number of semesters already studied in college, their final grade in geography at the end of their formal school education and the numbers of years in which they attended the subject of geography at school were determined (Table 1). Students who were either repeaters, or had studied geography already for more than two semesters, or who were older than 25 years, were excluded from the samples. In addition, only those students who participated in all phases of the research design were included in the sample. This reduced the entire research population to 30 students. To increase the study's internal validity, data and methods triangulation plus peer review were used. Data analysis used quantitative and qualitative methods such as descriptive statistics and methods linked to case study and ethnography research, e.g. interview protocol analysis, thematic coding, and case-based category development (Kitchin & Tate, 2000).

The two groups of students completed a specially designed pencil-and-paper pre-test a week before the intervention to determine their existing knowledge and mental models about groundwater. Subsequently the experimental group (group 1) was taught according to the model-building teaching strategy while the control group (group 2) was taught in a traditional lecture-style way using overhead projector transparencies and the blackboard. The teaching intervention comprised a two-hour session with each group by the author. Two weeks after the instruction (in the first week after the instruction the classes were cancelled due to a national holiday) both groups took a post-test. The students were assured that the survey results wouldn't affect their course grades.

Data about the group members' mental models of groundwater necessary for qualitative and quantitative methodology were generated by the pre- and

Table 1 Comparison of the two researched groups

Sample variables	*Experimental group*	*Control group*	*Population*
	(group 1; n = 16)	(group 2; n = 14)	(N = 30)
Age (mean)	21	21.8	21.4
Gender (f = female, m = male)	f = 62.5% (n = 10) m = 37.5% (n = 6)	f = 50% (n = 7) m = 50% (n = 7)	f = 56.7% (n = 17) m = 43.3% (n = 13)
Numbers of semesters	2	2	2
Final grade in geography at the end of formal schooling (mean) 1 = excellent, 6 = failed	1.9	1.5	1.7
Amount of geographical education at secondary school (mean) 1 = less than 4 years; 2 = 4–7 years; 3 = more than 7 years	1.4	1.7	1.5

post-test procedures. The pre-test consisted of three sections: the first section was a questionnaire asking students to give a written description of their understanding of groundwater, the second section asked students to draw a sketch of their ideas concerning groundwater occurrence in nature, and the third section showed different block diagrams representing four different types of groundwater deposits (Figure 1) from which the students should select the diagrams that seemed the most plausible to them (multiple answers were possible). The term plausible was used here in the context of 'the student understands the concept and believes it'. To make sure that the students did not change their own drawings (section 2) after they had seen the block diagrams (section 3) they were asked to hand in their sketches before they were given the sheet with the block diagrams. The concrete term 'groundwater' not only evokes verbal associations but also images. This is why the design of the questionnaire was such that it asked for verbal descriptions and drawings. Drawings have already been used in previous studies to explore students' mental models (Beilfuss *et al.*, 2004; Dove *et al.*, 1999; Samarapungavan *et al.*, 1996). Specifically Paivio's theory of dual coding (1990) which states that information is coded and represented in the brain visually and verbally served as the theoretical basis for using iconic representations to gain insight into the level of learners' understandings of the issue of groundwater. The block diagrams were used as stimulus to explore students' underlying concepts that were disconnected or not accessible when they worked on the first two sections of the questionnaire.

The post-test questionnaire differed from the pre-test in only the first of the three sections. Instead of asking students again to describe their conceptions of groundwater, the first section consisted of nine precise questions about the information learned during the intervention. The intent of these questions was to test whether the factual knowledge students had gained during the intervention depended on the instructional method. The second section in the post-test was to draw one's mental model of subsurface groundwater deposits. The third question asked students to mark those groundwater deposits that seemed the most plausible to them out of the four block diagrams as they are displayed in Figure 1. To confirm the questionnaires' content-related validity, a second researcher checked them for adequacy and format according to Fraenkel and Wallen (1996: 153ff).

An initial review of students' written answers and drawings revealed interesting erroneous assumptions and ideas. Therefore in-depth oral interviews were conducted with a representative subgroup of four students from each group two weeks after the post-test to explore how students constructed their ideas. Each interview lasted 15 minutes and was taped.

To teach the experimental group the mental model-building strategy developed by Taylor *et al.* (2003) was used (Table 2). Their strategy was considered to be appropriate for this research because it consists of discrete phases that allow to de-construct and re-construct mental models. The mental model-building approach was furthermore considered to be a method helping teacher education students to experience conceptual change personally and thereby acquire pedagogical content knowledge (Shulman, 1986). As Taylor and his team developed their strategy for 11-year-olds, it had to be adjusted in a way that was appropriate for adult learners. The phases according to which the teaching-learning unit was

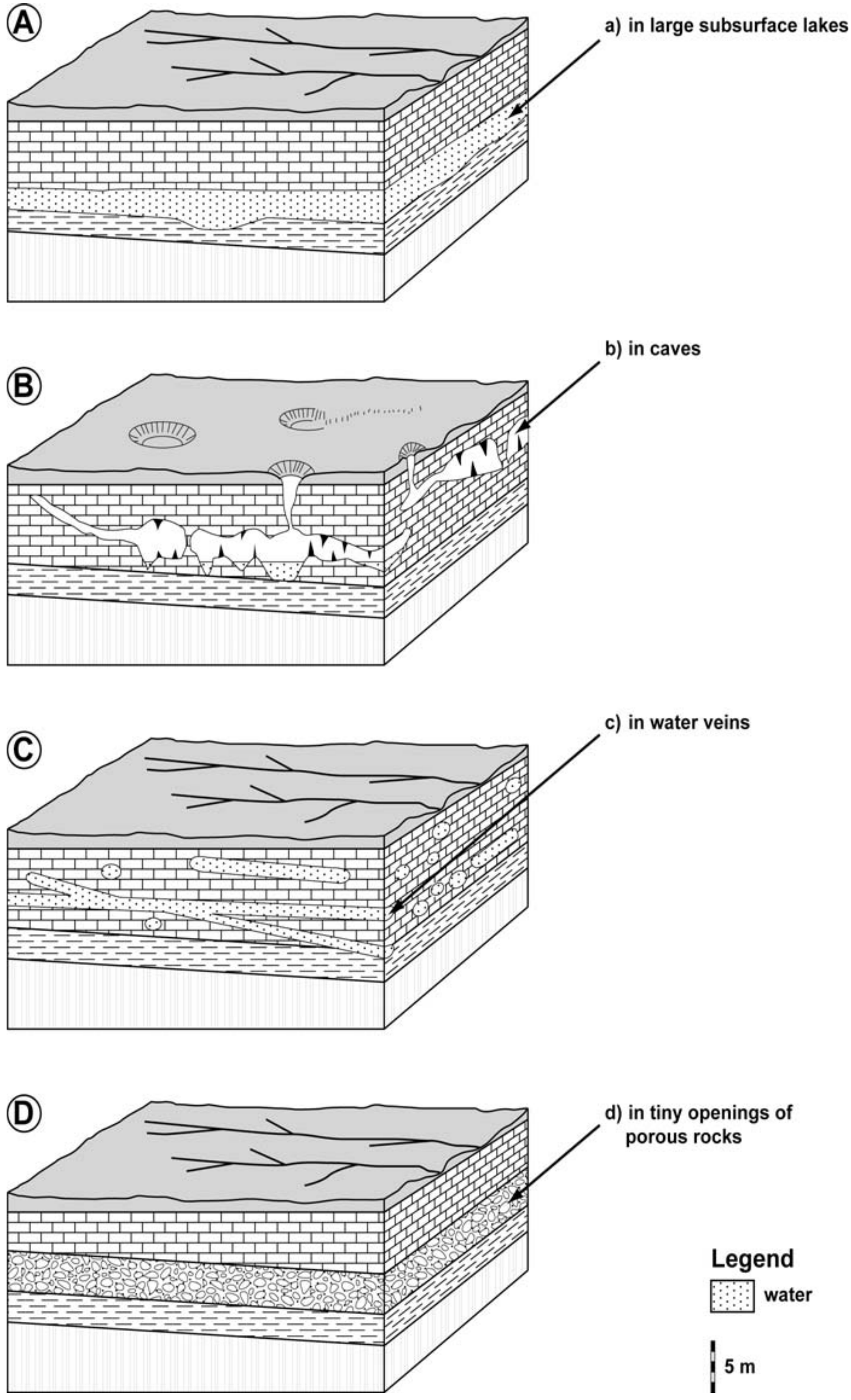


Figure 1 Block diagrams of groundwater deposits

Table 2 The mental model-building strategy

Phase	*Instructor's activity*	*Students' activity*
Pre-phase: **Preparation**	Ascertains students' views from the literature; finds out the current scientists' model; surveys all the class and interviews a sample of class to find out about pre-instructional students' mental models.	The whole class completes a pre-test. Sample of class is individually interviewed.
Phase 1: **Focus on the mental models**	Establishes an appropriate context in the classroom to discuss the issue; probes and interprets students' prior mental models.	Articulate and compare their prior mental models within their groups and within the class.
Phase 2: **Mental model-building and evaluation**	Clarifies what scientists mean by 'model'. Explains scientists' approach to representing and testing scientifically accepted models (Hesse 1966, 2001). Asks students to compare the mental models articulated in the class, using the scientists' model testing process.	Use a real scientific model to understand how it works. Compare it with their own conceptions. Interpret the evidence in light of its positive, negative and neutral aspects with their own mental models.
Phase 3: **Using mental models to solve problems**	Selects activities in which the scientists' model is applied to solve different situations, predictions or problems.	In their groups, use miniature models to solve problems that are novel to them. Prepare to report their findings to the rest of the class.
Phase 4: **Reflection**	Encourages the rest of the class to critically evaluate the solutions and explanations.	Groups report findings to the rest of the class, using an interactive approach, on how their mental and scientific model best explains the data and solves the problems.

Source: Taylor *et al.*, 2003; modified

structured were all applied to the topic of groundwater. The lesson started with a drawing on the blackboard of the global hydrological cycle. A large groundwater model (Williams, 2002) that allowed the simulation of a wide range of groundwater features and processes was used (e.g. the formation of groundwater as a part of the global hydrological cycle, changes of the groundwater table, porosity and permeability, the structure of aquitards (impermeable layers that hinder or prevent water movement) and aquifers, the movement of groundwater, ways of groundwater pollution). Because all students were expected to be active in phase two and three of the mental model-building strategy (Table 3) they not only observed and operated the large groundwater model but were also offered a variety of tools to create their own small groundwater models with plastic cups with which they carried out group experiments to solve groundwater related problems.

The control group was instructed through traditional instructor-centred lecture explaining the global water cycle, the distribution of groundwater, changes of the groundwater table, porosity and permeability, aquitards and aquifers, the movement of groundwater and ways of groundwater pollution using overhead transparencies (McKnight, 1999: 262; Miller, 1995: 260ff; Tarbuck & Lutgens, 1999: 270ff) and the blackboard. The procedure was such that the instructor explained subject matter using the transparencies or making drawings on the backboard, asking or answering students' questions.

Data Analysis and Results

Students' preferences of block diagrams and their correct or false answers to the fact-based post-test questions (variables 'correct / false answers t2' in Table 4, see p. 55) were analysed by using descriptive statistics (means, frequencies, standard deviation). Their written descriptions of groundwater from the pre-test were thematically coded using 9 codes (variables 'correct / false descriptions of groundwater t1'), while their drawings were case-based categorised. Twenty categories were developed gradually from the analysis of student work concerning groundwater deposits and formation. As soon as new categories needed to be created all the previously analysed texts and drawings were re-analysed in order to check whether some parts could be categorised in a different way. Thus all drawings were analysed many times. The categorisation comprised 15 categories that stand for the variables 'true concepts', while five categories measured false concepts (variables 'false concepts'). The codes and categories were subjected to descriptive statistics and correlational research (Pearsons r), parametric inferential statistics (t-test) and multivariate statistics using SPSS. The interviews were transcribed word-for-word, and analysed using procedures of thematic coding according to Kelle and Kluge (1999: 67).

Sample variables

To check the samples' homogeneity, variables such as age, gender, final grade in school-geography and the amount of schooling in geography were compared (Table 1). The experimental group was on average slightly younger ($m = 21$) than the control group ($m = 21.8$) and consisted of 12.5% more females; it also had a slightly lower average grade in geography ($m = 1.9$ vs. 1.5 out of 6, with 1 being the grade for excellence and 6 for failed) and was exposed to slightly less schooling ($m = 1.4$) than was the control group ($m = 1.7$). All in all the two groups proved to be relatively homogeneous.

Study group students' definitions of groundwater

In general, the study group students' knowledge about groundwater is poor and incomplete. The majority of the students described groundwater as clean drinking water, originating from rainfall, being stored underneath the Earth's surface, reaching the Earth's surface in wells and fountains, being perched above a hard layer of rocks and stored in the soil or in subsurface openings that can be grouped in:

Table 3 The intervention scheme used in the experimental group

Steps	*Student-Instructor Activities*
Phase 1: Focus on mental models	
Step 1	Class discussion about individual mental models; the students were made aware of the range of views in the class.
Step 2	Major types of mental models were identified; students who shared the same type of model formed a group and made a drawing of their mental model on a poster.
Step 3	Groups shortly explained their posters in class; students compared and identified the differences between the posters.
Phase 2: Mental model-building and evaluation	
Step 4	Instructor explained the general ideas of mental models and scientists' models and introduced and operated a large groundwater model as an example; students observed, operated and evaluated the model.
Step 5	Students identified shared and unshared attributes between the physical model and their mental models. They discussed whether all mental models shown in class could be explained with the physical model.
Phase 3: Using the mental model to solve problems	
Step 6	Students applied some simple concepts related to the physical model carrying out experiments* in small groups. They built their own small groundwater models in plastic cups consisting of loose sediments of various grain sizes (pulverised clay, silt, sand and gravel). Students acted, observed and finally discussed their findings in the groups.
Phase 4: Reflection	
Step 7	Student groups reported their findings to the rest of the class and answered criticism. The reasons for differing results were identified and clarified.
***Students' tasks in step 6:** Work in pairs or small groups. 1. Take a plastic cup and fill it with clay, silt, sand and gravel in an order that seems to make sense to you. 2. Fill your cup with water and observe what happens. 3. How is the water distributed in the sediments and between the layers? 4. Identify the water table in your model. 5. How can one prove that groundwater moves? 6. In which way are the groundwater movement and the water table connected? 7. One group member uses a straw to suck water out of the model; observe what happens at the instant the water is sucked out. 8. Add dissolved food colour with a straw either from the surface or blow it between two layers. Observe.	

- large reservoirs or lakes;
- channels, rivers or veins;
- caves;
- or in porous layers underlain by impermeable rocks.

Students' drawings

Students' drawings from the pre-test could be differentiated into three groups (Figures 2 and 3):

(1) No concepts: Students only depicted some unrelated features such as a line symbolising the Earth surface, the outlines of a cloud from which raindrops fall and one or two wavy lines below the earth's surface representing the groundwater.

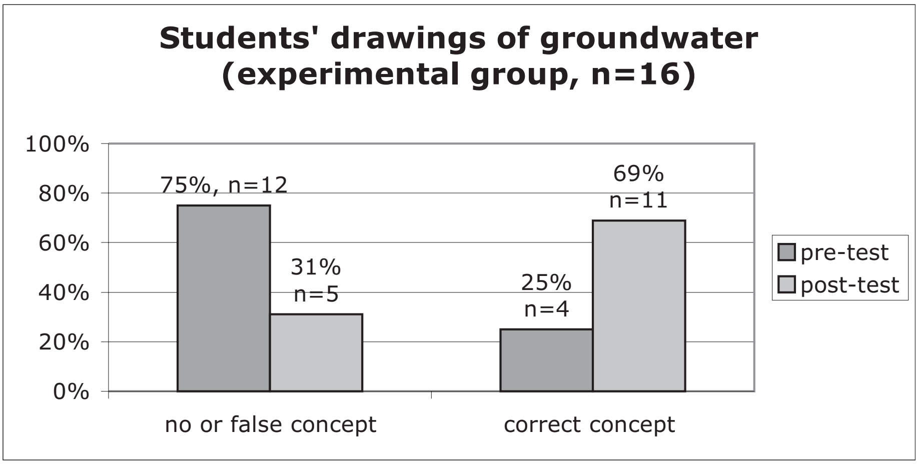


Figure 2 Frequency distribution of students' mental models depicted by the experimental group

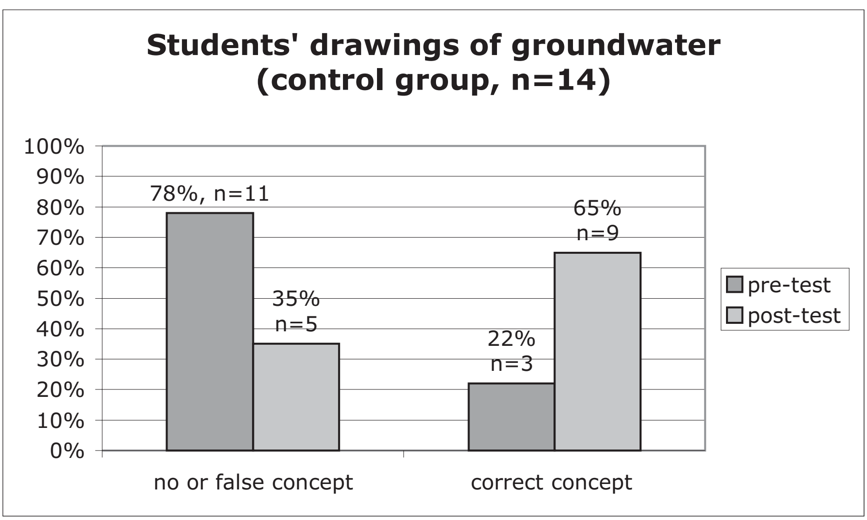


Figure 3 Frequency distribution of students' mental models depicted by the control group

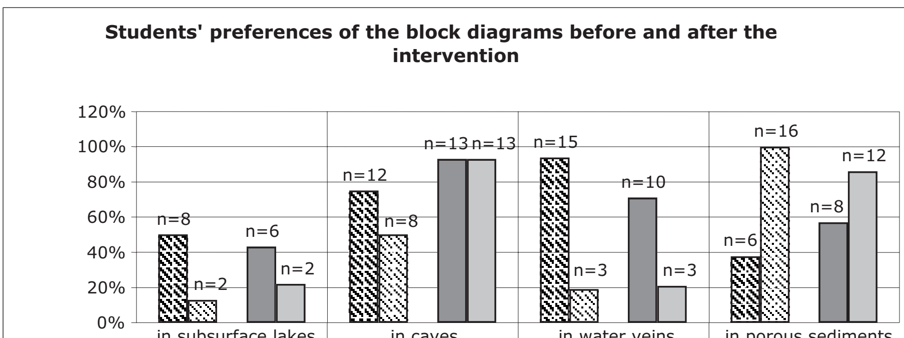
(2) False concepts: The students depicted a stratified Earth crust, a groundwater conducting layer below the surface in the shape of a channel, water veins, undefined openings like caves or subsurface lakes.
(3) Correct concept: In these drawings the Earth crust consists of layers of which one is a groundwater-conducting porous rock that is underlain by an impermeable layer.

In both groups, the experimental and the control group, three-fourths of the students revealed either no concept or a false concept. After the intervention both groups improved their understanding: two-thirds of the students either gained a correct concept or improved upon their false concept. Approximately 25% of the students from both groups did not improve.

Students' drawings revealed some interesting side effects in the control group: some students' drawings looked as if the students had learned the contents of the transparency used in the lecture rather than the concept it was meant to illustrate. They depicted what they saw in the transparency but the features in their drawings did not make sense as a whole. That is because students may lack awareness of the boundary between an illustration or another kind of depiction (model/object) and the reality it is representing (Dyche *et al.*, 1993). Literature reports that the unshared attributes between a representation and its mental model are often a cause of misunderstanding for learners (Thiele & Treagust, 1991).

Students' preferences of the block diagrams

Students' preferences of the block diagrams (Figure 4) before the intervention (t1) show that more than 70% of the students in both groups believed in the existence of subterranean caves and water veins, while over 40% of the students of both groups could also imagine groundwater being stored in subsurface lakes.



	in subsurface lakes	in caves	in water veins	in porous sediments
Group 1, t1	50%	75%	94%	38%
Group 1, t2	13%	50%	19%	100%
Group 2, t1	43%	93%	71%	57%
Group 2, t2	22%	93%	21%	86%

Figure 4 Frequency distribution of students' preferences concerning the block diagrams (group 1 = experimental group; group 2 = control group; t1 = pre-test; t2 = post-test; multiple answers were possible)

The concept of groundwater stored in porous sediments is more prominent in the control group (group 2) with 57%, while it is the concept with the lowest frequency (38%) of all four concepts in the experimental group (group 1).

After the intervention (t2) the frequencies for subsurface lakes and water veins dropped to 22% or less while the concept of porous sediments became important. All students in the experimental group chose that concept, in contrast to the control group, where only 86% of the students selected it. On the other hand, the control group preferred the concept of caves (93%), a response chosen by only 50% of the students in the experimental group. Interestingly also this step of the research procedure showed that a small percentage of the students adhered to false concepts such as subsurface lakes and water veins even after the intervention.

The interviews

In the interviews, all students were individually asked what they had thought when they depicted their drawings and why they had preferred certain block diagrams to others. Many students explained that when answering the pre-test they thought of groundwater as water originating from the Earth's surface, soaked into the ground and stored underground in larger openings such as caves, pipes, channels, rivers or soft rocks, perched above hard rocks. According to the students' understanding hard and impermeable rocks were the same. Limestones and sandstones were classified as hard and watertight, while mud, little stones, gravel and sand were called soft and porous rocks. The term soft was not only used in a sense of pulpy or doughy, but also in the sense of not forming a solid rock. This is a very interesting finding because it explains why students could not imagine that groundwater can also be stored and flow in solid rocks.

The students of the experimental group explained that after having worked with the model and the experiments they could no longer see any sense in the concept of subsurface lakes and water veins. They knew about Karst caves from field trips to nearby limestone areas and therefore also took this concept into consideration. But having worked with the large groundwater model and with their own small experiments they could visualise more accurately how subsurface groundwater deposits are composed and structured.

The students of the control group, who during the intervention only saw the transparencies showing groundwater storing layers, could not easily imagine the structure of an aquifer, although they were told that aquifers are composed of loose sand grains or gravel or of porous and permeable solid rocks. In their drawings the students demonstrated that many of them still believed in some kind of large subsurface water-containing openings. In lecture, students had been shown a transparency of Karst phenomena to understand the difference between water transportation in permeable rocks and in limestone joints and openings resulting from dissolution. The high frequency value (Figure 4) for 'caves' of the control group (group 2) after the intervention suggests that the lecture remarks about Karst apparently confirmed or reinforced students' pre-instructional concept of groundwater flowing in caves. The lecturing seemed to have reinstated the Karst concept, but students also chose the concept of porous sediments to a much greater extent thus demonstrating that they memorised the factual knowledge learnt during instruction.

Students whose drawings were mostly correct, but who considered 'water veins' to be a valid concept – even in the post-test – were asked why. They were surprised to realise that they had done so! They marked it although they knew that water veins do not exist but could not remember why they had done so. One student said: 'I can't remember why I marked the block diagram showing water veins, although you told us in the lecture, that there aren't any. But frankly, I was really shocked when you said that water veins do not exist.' This example illustrated that corrected preconceptions are not easily forgotten and are reinstated quite easily.

Students' sources of knowledge

The students were asked where they had previously learned about groundwater (Figure 5): 56% of the students indicated that they gained their knowledge about groundwater in schools; approximately one-third got (additional) information from their parents, from books and/or from television; five students attended activities related to groundwater; one family dug a well in their garden, another student watched building the foundations for a house and others watched a dowser at work.

From these findings, we can conclude that incorrect drawings and diagrams in textbooks are to some extent responsible for students' mental models of groundwater. Textbook illustrations sometimes use analogies in a misleading way, thereby reinforcing students' misconceptions. In the model of the hydrological cycle, for example, broad arrows are often used to symbolise the groundwater flow from land to sea. Learners interpret these arrows as channels (Reinfried, 2004, 2005). Since 'visually-memorable' Karst phenomena are often described and pictured in textbooks, they might also have an impact on student model building. This might result in the formation of mental models of groundwater lakes and channels, in addition to stratified layers of permeable and

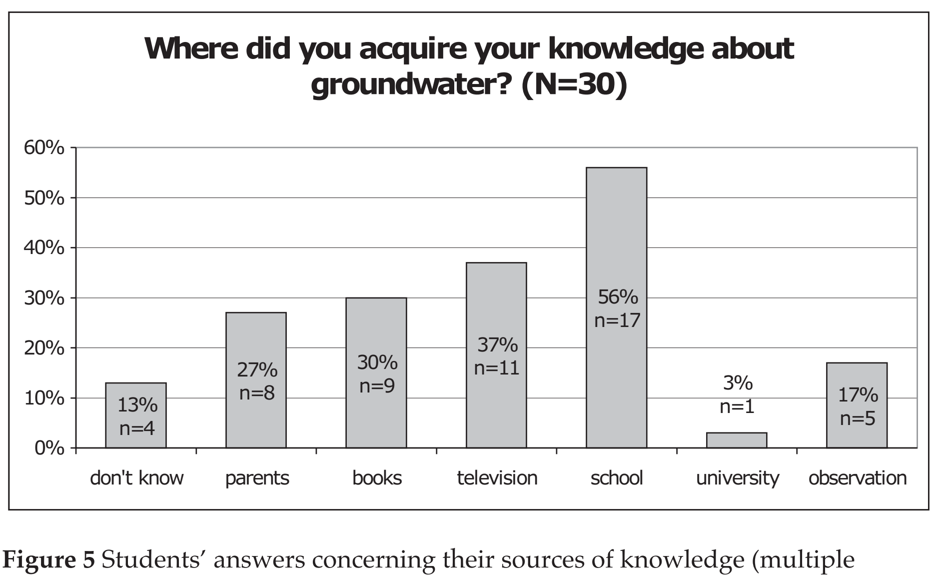


Figure 5 Students' answers concerning their sources of knowledge (multiple answers were possible)

impermeable rocks. It is more difficult to explain the idea of water veins. Groundwater flows nearly everywhere extensively underground in the pore space of loose sand and gravel or in solid rocks if the rocks contain narrow joints or fractures dispersed throughout the rocks or have interconnected pore spaces. Only very rarely and only in Karst regions does groundwater flow in large cracks or flooded cave systems that might vaguely correspond with the idea of water veins. The widely distributed preconceptions of water veins do therefore not match scientific geological knowledge but can be explained as a human habit to 'project' geomorphologic or geological structures visible at certain accessible places, such as subsurface cave systems in mountain areas, onto the entire unseen Earth crust (Gesellschaft zur Wissenschaftlichen Untersuchung von Parawissenschaften, 2004).

In addition, attempts to explain the world by way of analogies based on anthropomorphic ideas is another way to find explanations. Features of the human body are projected on natural phenomena that can neither be seen nor touched. The idea that the Earth can be compared to the human body dates back to Pythagoras (*c*. 580 to *c*. 500 BC) (Perrig, 2002: 469). According to this theory that was widely believed in ancient Greece, waters are permanently generated deep down in the Earth and then flow through the body of the Earth in veins, invigorating and nourishing it. Following this idea, Leonardo da Vinci (1452–1519) and Johannes Kepler (1571–1630) interpreted the Earth as an organism, comparing groundwater with the blood of the Earth (Bayrische Staatssammlung für Paläontologie und Geologie, 2003). Although the vein theorem was questioned since the 17th century and modern scientific research has established once and for all that there are no subsurface water veins (König & Betz, 1989), the construct of water veins widely spread in the Earth's interior persists in many people's minds.

Descriptive Group Statistics

As seen in Table 4 the experimental group's description (group 1) of groundwater in the pre-test included more correct ($m = 0.81$) and fewer false descriptions of groundwater ($m = 2.38$) compared to the control group ($m = 0.57$; $m = 2.79$). Concerning the drawings that stand for students' iconic concepts of groundwater, group 1 depicted a little fewer correct (true concepts, $m = 4.50$) and more false categories (false concepts, $m = 0.89$) than the control group (true concepts, $m = 5.07$; false concepts, $m = 0.71$). This changed after the intervention: then the experimental group depicted more true categories (true concepts, $m = 8.38$) and fewer false categories (false concepts, $m = 0.38$) than the control group (true concepts, $m = 7.86$; false concepts, $m = 0.86$). In the post-test the experimental group also answered more questions in the first section of the questionnaire correctly ($m = 7.05$) and gave fewer false answers ($m = 1.94$) than did the control group ($m = 6.14$; $m = 2.86$).

If one compares the variables for true concepts before and after the intervention (t1, t2) it becomes obvious that the experimental group improved their mean by approximately 1.5 standard deviations from 4.50 to 8.38 while the mean for their false concepts also decreased by 1.5 standard deviations from $m = 0.89$ to $m = 0.38$, indicating very strong effects. The control group also improved but not as

Table 4 Descriptive group statistics ($t1$ = pre-test, $t2$ = post-test; gw = groundwater)

	Experimental group (group 1, n = 16)			*Control group (group 2, n = 14)*			*Population (N = 30)*	
Dependent variables	*Mean*	*Standard-deviation*	*Standard error of the mean*	*Mean*	*Standard-deviation*	*Standard error of the mean*	*Mean*	*Standard-deviation*
Correct descriptions of gw (t1)	0.81	1.05	0.26	0.57	1.09	0.29	0.70	1.06
False descriptions of gw (t1)	2.38	1.31	0.33	2.79	1.05	0.28	2.57	1.19
Correct answers (t2)	7.05	1.34	0.34	6.14	1.66	0.44	6.63	1.54
False answers (t2)	1.94	1.34	0.34	2.86	1.66	0.44	2.37	1.54
True concepts (t1)	4.50	2.39	0.60	5.07	2.78	0.74	4.77	2.56
False concepts (t1)	0.89	1.15	0.29	0.71	0.47	0.13	0.80	0.89
True concepts (t2)	8.38	2.09	0.52	7.86	2.32	0.61	8.13	2.18
False concepts (t2)	0.38	0.50	0.13	0.86	0.86	0.23	0.60	0.72

much as the experimental group. The mean of their true conceptions rose from $m = 5.07$ to $m = 7.86$ (one standard deviation). The mean of their false concepts did not drop but even slightly increased from $m = 0.71$ to $m = 0.85$. The type of instruction used in the control group obviously did not have an effect on students' misconceptions. These results confirm Heron's (2003) findings that lecturing does not help students to reconcile their false concepts with the new gained information resulting in a change of their preconceptions.

Correlations

A Pearson correlation coefficient was calculated for the relationship between several dependent variables using the entire research population. The variable 'correct description of groundwater t1' and the variable 'true concepts t1' showed a moderate positive correlation (r (28) = 0.600, $p < 0.01$; two-tailed) indicating a significant linear relationship between the two variables. A moderate positive correlation at the 0.05 significance level was also found between the variables 'correct description of groundwater t1' and the variable 'true concepts t2' (r (28) = 0.435, $p < 0.05$; two-tailed). The variable 'false concepts t2' correlated moderately positive with 'wrong answer t1' (r (28) = 0.414, $p < 0.05$; two-tailed).

The causal relationships between these variables support the research hypothesis, thus indicating that the knowledge existing prior to instruction seems to play a major role in the process of conceptual change. Those students who already have a correct but incomplete concept of groundwater seem to be more successful in improving it while students who have misconceptions in their minds seem to retain them even after traditional lecture instruction.

T-Test

An independent t-test comparing the mean scores of the experimental and the control group for a significant difference was used. The result of the difference between the means of the variable 'false concepts t2' consisted of: T (30) = –1.835, $df = 28$, $p = 0.081$ (two-tailed). This result can be considered to be statistically significant because the SPSS output generally includes a two-tailed alpha level.

Because the hypothesis of this study attempted to determine a difference in one direction the significance level in the output has to be divided by two (Cronk, 1999: 52ff; Diehl & Staufenbiel, 2002: 217). Thus, the output level of 0.081 (two-tailed) is 0.04 (one-tailed) indicating that the result would be significant in a one-tailed test. In other words: The mean of the experimental group after the intervention is considered to be significantly lower ($m = 0.38$, $sd = 0.50$) than the mean of the control group ($m = 0.86$, $sd = 0.86$; see Table 4) indicating more false concepts in the control group.

This finding is of great importance because it is interpreted to be an effect of the different interventions. It indicates that the control group (group 2) showed significantly more misconceptions than did the experimental group (group 1) after the intervention. From this result it is concluded that the intervention using the mental model-building approach was more successful inducing conceptual change than was the traditional lecture approach.

Multivariate analysis of variance

A multivariate test of the variance using the General Linear Model (GLM) was calculated examining the effects of five factors on the post-test knowledge using the independent variables 'correct/false answers t2' and 'true/false concepts t2' and the covariates 'correct/false description of groundwater t1' and 'true/false concepts t1'. No significant results were found but the effect of the dependent variable GROUPS (standing for the different treatments in the two study groups) on 'false concepts t2' missed the significance level extremely close (Table 5): F $(1,30) = 4.2$, $p = 0.52$; $Eta^2 = 0.148$.

A follow-up multivariate test of variance (GLM) without the variables 'true concept t2' and the covariate 'true concept t1' was carried out to eliminate their effect on the variance of the other variables (Bortz & Döring, 2002: 545). This is permissible because both 'true concept t1 and t2' correlate with the independent variable 'correct description of groundwater t1' (see section about correlations in this paper). As a result (Table 5), the effect of the treatment on the false concepts

Table 5 Results of the multivariate analysis of variance: the effect of the treatment on post-test knowledge (group1 = experimental group; group 2 = control group)

Source	*Dependent variable*	*Type III sum of squares*	df	*Mean square*	F	*Sig.*	*Eta²*	*Estimated marginal means*	
								Group 1	*Group 2*
Tests of between-subjects effects (a)									
GROUPS	Correct Answers t2	5.590	1	5.590	2.221	0.149	0.085	7.060	6.146
	False Answers t2	5.590	1	5.590	2.221	0.149	0.085	1.940	2.854
	True Concept t2	4.893	1	4.893	1.612	0.216	0.063	8.533	7.677
	False Concepts t2	2.039	1	2.039	4.174	0.052	0.148	0.342	0.895
Tests of between-subjects effects (b)									
GROUPS	Correct Answers t2	6.323	1	6.323	2.613	0.119	0.095	7.073	6.130
	False Answers t2	6.323	1	6.323	2.613	0.119	0.095	1.927	2.870
	False Concepts t2	2.124	1	2.124	4.526	0.043	0.153	0.345	0.891

(a) = covariates 'correct/false description of groundwater t1' and 'true/false concepts t1'
(b) = covariates 'correct/false description of groundwater t1' and 'false concepts t1'

after the intervention was significant ($F(1, 30) = 4.5$, $p < 0.05$; $Eta^2 = 0.153$), with the control group showing significantly more false categories in their mental models ($m = 0.86$, $sd = 0.86$) than did the experimental group (m = 0.38, sd. = 0.50). The effect size (Eta^2) was 15% of the variance confirming a strong effect of the treatment. In other words: the treatment significantly influenced the number of misconceptions in students' mental models.

Conclusions

The goal of this study is to investigate differences in students' conceptual change due to different teaching approaches. Although there are limitations to any cross-domain generalisation possible from a quasi-experimental research design, including a small sample size and from the fact that it was the author herself who taught the student groups, the study did enable the researcher to explore the extent of conceptual change of a complex system of interrelated concepts – the concept of subsurface groundwater storage. It is not presumed to generalise these findings beyond this sample of students, but these results may provide a basis for further extended research concerning groundwater and mental model development.

The results of this research appear to confirm that students' pre-instructional mental models about groundwater change to more valid concepts if they get an opportunity to clarify their ideas using a hands-on experimental model-building approach. Students who receive traditional lecture instruction appear to be more resistant to mental model change.

The finding that 20–25% of the students even after instruction believe in their preconceptions such as large subsurface lakes or water veins is also known from research in other science disciplines. For some students their strongly held beliefs about nature and the environment are stronger than their knowledge about it. For them it is particularly difficult to change their strongly held preconceptions, especially when their current understanding of a phenomenon is sufficient to explain the real world and fits in with other ideas (Duit & Treagust, 2003: 677). According to Vosniadou and Brewer (1992) concepts are imbedded in cognitive structures which include ontological and epistemological assumptions that have been learnt in a child's early learning biography and have been confirmed again and again in everyday life. The revision of a misconception would have consequences for a number of other assumptions on which the misconception is based and is therefore very resistant to change. Smith *et al.* (1993) argue that persistent misconceptions have their roots in productive knowledge that is useful in a certain context. The fact that it is false from a scientific point of view has no consequences in everyday life. Problems only result if these concepts are used in contexts in which they are not functional. In this study the concept of the water veins stands for a persistent misconception that is both a simple anthropomorphism as well as a plausible analogy that works in everyday contexts, e.g. when a dowser searches for water and really finds it coincidentally.

The results of this research lead to the conclusion that the topics of groundwater formation, groundwater use, the implications of groundwater overuse, groundwater contamination and protection as well as the effects of river channelisation cannot be understood if learners do not possess a correct scientific understanding of groundwater occurrence in nature. Yet, without such correct understanding it is virtually not possible to take action to protect groundwater. Research into other environmental problems, such as the reduction of greenhouse gases by Schuler (2004: 141), has reached the same conclusion.

Understanding is gained only after preconceptions have been clarified in schools and universities. If traditional instruction has only very little effect on conceptual change as has been suggested by Heron (2003), the question arises as to how conceptual change can best be brought about. In teacher education the following issues should be paid attention to:

- As long as instructors are not aware of the existence of preconceptions and of the necessity to clarify them, they cannot help their students to change their misconceptions.
- To understand their own mental models teachers have to fully master subject matter.
- Students mostly see their beliefs or the explanations of science as true pictures of the physical world and do not understand their theoretical and hypothetical nature. Cognitive-developmental research suggests that the acquisition of more sophisticated epistemological knowledge of a scientific concept facilitates conceptual change in students (Vosniadou, 2003: 403).
- Furthermore, teachers are requested to allow individual constructions of contextualised knowledge instead of insisting on teaching de-contextualised factual knowledge.
- Unfortunately teachers often do not know about formal strategies to diagnose misconceptions and they do not have appropriate teaching material that aims at the uncovering of pre-scientific notions (Morrison & Lederman, 2003: 861ff). Such deficits in teacher education should be reduced by taking the findings of cognitive psychology into account in the geographical and environmental science classes at colleges and universities.

Confronting students with their own preconceptions and teaching the significance of constructivist theories for subject content increases their metaconceptual awareness of the issue. Ideally, students in teacher education would personally experience the process of conceptual change during their college or university education, because memorising a factual scientific concept alone does not suffice to fully understand and use it in other contexts (Duit, 2000: 85). The model-building strategy used in this research seems to be a feasible approach to gain such understanding.

Acknowledgements

My special thanks to Stefan Fuss from Ludwigsburg University of Education (Germany) for his advice concerning the research methodology and his help with the multivariate statistics and to Dr Mark H. Bockenhauer from St Norbert College in De Pere, Wisconsin (USA), for his appreciated comments on the paper. I also thank Dr Marianne Landtwing, Kantonsschule Zug (Switzerland), for her help with the illustrations.

Correspondence

Any correspondence should be directed to Prof Dr Sibylle Reinfried, Ludwigsburg University of Education, Geography Department, Reuteallee 46, 71634 Ludwigsburg, Germany (reinfried@ph-ludwigsburg.de).

References

Bayrische Staatssammlung für Paläontologie und Geologie (2003) Von Wasseradern und Wünschelruten. 4/01. *Geo Forum*. On WWW at http://www.iaag.geo.uni-muenchen.de/sammlung/Wasseradern.html. Accessed 18.03.04.

Beilfuss, M., Dickerson, D., Libarkin, J.C. and Boone, W. (2004) Exploring conceptual understanding of groundwater through college student's interviews and drawings. *Proceedings of the NARST 2004 Annual Meeting* 1–3 April, Vancouver, BC, Canada.

Bortz, J. and Döring, N. (2002) *Forschungsmethoden und Evaluation für Human- und Sozialwissenschaftler*. Berlin: Springer.

Cronk, B.C. (1999) *How to Use SPSS*. Los Angeles, CA: Pyrczak.

DeLaughter, J.E., Stein, S., Stein, C.A. and Bain, K.R. (1998) Preconceptions about earth sciences among students in an introductory course. *Eos* 79, 429–32.

Diehl, J.M. and Staufenberg, T. (2002) *Statistik mit SPSS. Version 10+11*. Eschborn: Klotz.

Doerr, H.M. (1997) Experiment simulation and analysis: An integrated instructional approach to the concept of force. *International Journal of Science Education* 19 (3), 265–82.

Dove, J.E., Everett, L.A. and Preece, P.F. (1999) Exploring a hydrological concept through children's drawings. *International Journal of Science Education* 21 (5), 485–97.

Driver, R. (1981) Pupils' alternative framework in science. *European Journal of Science Education* 3 (1), 93–101.

Duit, R. (2000) Konzeptwechsel und Lernen in den Naturwissenschaften in einem mehrperspektivischen Ansatz. In R. Duit and C. von Rhöneck (eds) *Ergebnisse Fachdidaktischer und Psychologischer Lehr-Lern-Forschung* 169 (pp. 77–103). Kiel: Institut für die Pädagogik der Naturwissenschaften an der Universität Kiel.

Duit, R. and Treagust, D.F. (2003) Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education* 25 (6), 671–88.

Dupin, J.J. and Joshua, S. (1989) Analogies and 'modeling analogies' in teaching: Some examples in basic electricity. *Science Education* 73 (2), 207–24.

Dyche, S., McClurg, P., Stepans, J. and Veath, M.L. (1993) Questions and conjectures concerning models, misconceptions, and spatial ability. *School Science and Mathematics* 93 (4), 191–7.

Edelmann, W. (2000) *Lernpsychologie*. Weinheim: Beltz.

Fraenkel, J.R. and Wallen, N.E. (1996) *How to Design and Evaluate Research in Education*. New York: McGraw-Hill.

Gesellschaft zur wissenschaftlichen Untersuchung von Parawissenschaften (2004) *Erdstrahlen*. On WWW at http://www.gwup.org/themen/texte/erdstrahlen/. Accessed 03.03.05.

Gobert, J.D. (2000) A typology of causal models for plate tectonics: Inferential power and barriers to understanding. *International Journal of Science Education* 22 (9), 937–77.

Greca, I.M. and Moreira, M.A. (2000) Mental models, conceptual models, and modeling. *International Journal of Science Education* 22 (1), 1–11.

Harrison, A.G. and Treagust, D.F. (2000) A typology of school science models. *International Journal of Science Education* 22 (9), 1011–26.

Heron, P. (2003) The recognition of students' preconceptions and their resistance to corrective teaching. In National Research Council (ed.) *Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics: Report of a Workshop* (pp. 32–7). Washington DC: National Academies Press.

Hesse, M.B. (1966) *Models and Analogies in Science*. Indiana: University of Notre Dame Press.

Hesse, M.B. (2001) Models and analogies. In W.H. Newton-Smith (ed.) *A Companion to the Philosophy of Science*. Oxford: Blackwell.

Johnson-Laird, P. (1983) *Mental Models*. Cambridge: Cambridge University Press

Kaufmann, D.R., Patel, V.L. and Magder, S.A. (1996) The explanatory role of spontaneously generated analogies in reasoning about physiological concepts. *International Journal of Science Education* 18 (3), 369–86.
Kelle, U. and Kluge, S. (1999) *Vom Typus zum Einzelfall*. Qualitative Sozialforschung 4. Opladen: Leske + Budrich.
Kitchin, R. and Tate, N. (2000) *Conducting Research into Human Geography*. Harlow: Prentice Hall.
Klaphake, A. and Scheumann, W. (2001) Politische Antworten auf die globale Wasserkrise: Trends und Konflikte. *Politik und Zeitgeschichte* 48/49, 1–12.
König, H.L. and Betz, H-D. (1989) *Erdstrahlen? Der Wünschelruten-Report*. München: Eigenverlag H.L. König und H-D. Betz.
McKnight, T.L. (1999) *Physical Geography – A Landscape Appreciation.* New Jersey: Prentice Hall.
Miller Jr., J.T. (1995) *Environmental Sciences: Working with the Earth*. Belmont: Wadsworth.
Morrison, J.A. and Lederman, N.G. (2003) Science teachers' diagnosis and understanding of students' preconceptions. *Science Education* 87 (6), 849–67.
Paivio, A. (1990) *Mental Representations: A Dual-Coding Approach* (2nd edn). New York: Oxford University Press.
Perrig, A. (2002) Landschaftsmalerei in Mittelalter und Renaissance oder die Schwierigkeit, mit Bergen und Flüssen ins Reine zu kommen. Kunst- und Ausstellungshalle der Bundesrepublik Deutschland (ed.) Erde. *Schriftenreihe Forum / Band 11, Elemente des Naturhaushalts III*, 452–82.
Pfund, H. and Duit, R. (1994) *Bibliography – Students' Alternative Frameworks and Science Education* (4th edn). IPN Reports-in-Brief. Kiel: Institute for Science Education.
Reinfried, S. (2004) Can we achieve scientific literacy in geography without understanding learners' mental models? IGU-CGE Symposium Expanding Horizons in a Shrinking Worlds, 13–15August 2004. *Symposiums Proceedings*, 360–2.
Reinfried, S. (2005, in print) Wie kommt Grundwasser in der Natur vor? – Ein Beitrag zur Praxisforschung über physisch-geographische Alltagsvorstellungen von Studierenden. *Geographie und ihre Didaktik* 33 (3).
Samarapungavan, A., Vosniadou, S. and Brewer, W.F. (1996) Mental models of the earth, sun, and moon: Indian children's cosmologies. *Cognitive Development* 11, 491–521.
Schnotz, W. (2001) Conceptual change. In D.E. Rost (ed.) *Handwörterbuch Pädagogische Psychology* (pp. 75–81). Weinheim: Beltz.
Schuler, S. (2004) Alltagstheorien von Schülerinnen und Schülern zum globalen Klimawandel. In E. Kross (ed.) Globales Lernen im Geographieunterricht – Erziehung zu einer nachhaltigen Entwicklung. *Geographiedidaktische Forschungen* 38, 123–45. Nuremberg: HDG.
Shulman, L. (1986) Those who understand: Knowledge growth in teaching. *Educational Researcher* 15 (2), 4–14.
Smith, J., Di Sessa, A. and Roschelle, J. (1993) Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of Learning Sciences* 3, 115–63.
Stavy, R. (1991) Using analogy to overcome misconceptions about conservation of matter. *Journal of Research in Science Teaching* 28 (4), 305–13.
Tarbuck, E.J. and Lutgens, F.K. (1999) *Earth – An Introduction to Physical Geology*. New Jersey: Prentice Hall.
Taylor, I., Barker, M. and Jones, A. (2003) Promoting mental model building in astronomy education. *International Journal of Science Education* 25 (10), 1205–25.
Thiele, R.B. and Treagust, D.F. (1991) Using analogies in secondary chemistry teaching. *Australian Science Teachers' Journal* 37 (2), 10–14.
Treagust, D.F., Harrison, A.G. and Venville, G.L. (1996) Using an analogical teaching approach to engender conceptual change. *International Journal of Science Education* 18 (2), 213–29.
United Nations (2001) International Year of Freshwater, 2003, Resolution A/55/196. On WWW at http://www.un.org/events/water/. Accessed 12.03.05.
Vosniadou, S. and Brewer, W.F. (1992) Mental models of the earth. *Cognitive Psychology* 24, 535–85.

Vosniadou, S. (2003) Exploring the relationship between conceptual change and intentional learning. In G.M. Sinatra and P.R. Pintrich (eds) *Intentional Conceptual Change* (pp. 377–406). Mahwah: Lawrence Erlbaum.

Weller, H.G. (1995) Diagnosing and altering three Aristotelian alternative conceptions in dynamics: Microcomputer simulations of scientific models. *Journal of Research in Science Teaching* 32 (3), 271–90.

Williams, R. (2002) Rivers Project. Groundwater models. On WWW at http://www.siue.edu/OSME/river/Ordering%20Materials/groundwater.htm. Accessed 16.03.05.