

Understanding groundwater – students' pre-conceptions and conceptual change

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Understanding groundwater – students' pre-conceptions and conceptual change by a theory-guided multimedia learning program

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Abstract

Groundwater is a crucial topic in education for sustainable development. Nevertheless, international studies with students of different ages have shown that the basic hydrogeological concept of groundwater defined as water within porous and permeable rocks is not an established everyday notion. Building upon international research a multimedia learning program (“Between the raincloud and the tap”) was developed. Insights from the fields of conceptual change research, multimedia research, and the Model of Educational Reconstruction were specifically implemented. Two studies were conducted with Austrian pupils (7th grade) and teacher training students from the fields of biology and geography in order to ascertain the effectiveness of the learning program. Using a quasi-experimental research design, the participants’ conceptions and knowledge regarding groundwater were determined in a pre- and post-test. The pupils and students greatly profited from independently working through the learning software. Their knowledge of groundwater increased significantly compared to the control group and there was a highly significant increase in the number of scientifically correct notions of groundwater. The acceptance of the program was also generally very high. The results speak for the fact that theory-guided multimedia learning programs can play an important role in the transfer of research results into the classroom, particularly in science education.

1 Introduction

Groundwater is a crucial topic in education for sustainable development. Knowledge about groundwater is an indisputable prerequisite for a sustainable use of water as a valuable natural resource. Reinfried et al. (2012, p. 1365) stress that “‘Water knowledge’ has now become a socio-political and future-oriented necessity”, which is in accordance with Dickerson et al. (2007, p. 45), who see knowledge about groundwater as “a fundamental component of scientific literacy” and an indispensable requirement

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of societal decision-making regarding the use and conservation of groundwater. After all, groundwater is one of our most valuable resources and constitutes an essential element determining the quality of life. But, on the other hand, international studies with students of different ages have shown that the basic hydrogeological concept of groundwater defined as water within porous and permeable rocks is not an established everyday notion. Obviously (young) people have difficulties with correctly understanding groundwater. This is what we aimed to change with the help of our interactive multimedia learning program “Zwischen Regenwolke und Wasserhahn” (Between the raincloud and the tap, Unterbruner and Hilberg, 2012) that we developed in an academic cooperation between the faculties of Geology and Science Education/Biology Didactics at the University of Salzburg. We want young people to engage in the field of hydrogeology, and to prompt a learning process that will stimulate conceptual change towards a scientifically adequate conception of groundwater.

We decided to use new media mainly for two reasons: on the one hand, most young people are enthusiastic for new media and like to work with multimedia learning programs in class and on the other hand, we can offer an innovative tool for groundwater education to the teachers. The complete program consists of four chapters (Water in the Ground, Water in the Mountains, Water in Pipes, Interesting facts about Water). The chapter “Water in the Ground” was tested in this study. Therefore the focus is on this chapter both in describing the design and the evaluation.

As our target groups, we chose pupils aged around 13 for whom the multimedia learning program was primarily developed and teacher training students, who will have to teach about this topic in the future. Our studies were conducted at Austrian schools and the University of Salzburg. In Austrian schools, geological topics are primarily covered as part of the subject of “Biology and Environmental Education”. Hydrogeology is not explicitly mentioned at any school level since the Austrian curriculum (BMBF, 2000) is kept very general. The curriculum for the 7th grade requires pupils to attain “basic geological knowledge that aids in the understanding of the ground and the interaction between animate and inanimate nature” (p. 4). The precise scope of the subject mat-

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ter and the time spent on it for the implementation of this requirement is left up to the teacher.

According to Thompson et al. (2012), we argue for more educational research to improve student centered teaching and learning in the fields of earth sciences (also see Seibert et al., 2013). As our theoretical basis, we chose the Model of Educational Reconstruction and the conceptual change research. These theoretical frameworks have largely been accepted in science education and offer a broad variety of impulses for creating learning environments. Additionally, results of multimedia research constitute an important basis.

In a first step, we developed the multimedia learning program theory-guided. The next step was to analyze the program's efficiency, in particular in terms of the effectiveness of learning regarding the construction and facilitation of a scientifically correct notion of the groundwater concept.

2 Theoretical framework

2.1 Model of Educational Reconstruction (MER)

We adopted the Model of Educational Reconstruction (MER) as our research design. The MER was initially developed as a model for instructional planning in school practice and for curriculum development (Kattmann et al., 1997). It soon became obvious that this model could be useful in a much broader scope of application and became an important framework for research and development in science education (Duit, 2007; Duit et al., 2012; Reinfried et al., 2009). Thus, the MER has become the major theoretical perspective in science education research in various science education groups in Europe.

The MER is based on a constructivist epistemological position. A balance between science-related issues and educationally oriented issues is considered a necessity in effective teaching and learning. The key message of the model is that science contents

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may not be presented in a simplified (“reduced”) manner in science instruction, but a new science content structure for instruction has to be found in an iterative process between the analysis of the scientific content and the learners’ perspectives, preconceptions and experiences.

The MER integrates three significant components of science education research: (1) the clarification and analysis of science content, (2) research on teaching and learning with a particular emphasis on the role of students’ pre-instructional conceptions in the learning process and (3) the design and evaluation of teaching and learning environments (Duit, 2007; Duit et al., 2012). In our study, all three components are relevant (see Fig. 1): we considered the definitions pertaining to the topic of hydrogeology and the interpretation of the research results regarding the groundwater conceptions of pupils and students. Based upon this, we devised the design of our multimedia learning program. The ascertainment of the effectiveness of the multimedia tool began with an examination of the groundwater concepts of our target groups in order to investigate the extent to which conceptual change and knowledge gain was possible by working through the learning program.

2.2 Learners’ perspectives of groundwater and conceptual change

Numerous studies show that children come to class with a broad variety of preconceptions, many of them inadequate in relation to the scientific concepts. Everyday conceptions usually resist change. People are familiar with them and because they have become so established in everyday life they are considered to be adequate or at least not harmful. Numerous studies show that new information is incorporated into existing ideas for as long as possible and thus retained even in light of obvious contradictions. This can lead to barriers to knowledge reconstruction (e.g. Vosniadou, 2013).

Regarding groundwater, research has shown that common conceptions of groundwater are seldom based on scientific findings and that incorrect concepts of hydrogeology are very prevalent. The following preconceptions dominate (Dickerson and

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Dawkins, 2004; Dickerson et al., 2005, 2007; Ben-zvi-Assarf and Orion, 2005; Reinfried, 2005, 2006a, b; Schultz, 2006; Schwartz et al., 2011):

- groundwater is stored in underground lakes;
- groundwater flows in underground rivers, streams or water veins;
- groundwater accumulates in caves or cavities in the ground.

The ideas that groundwater flows in pipes (Dickerson et al., 2005; Schultz, 2006) or that it is a layer of water at the bottom of water bodies (Reinfried, 2006b) are less common. There is also the representation of groundwater as part of the water cycle, in which the focus is on the processes between clouds and the earth's surface while those that occur within the ground are often not considered (Shepardson et al., 2009; Reinfried, 2006b).

Dickerson et al. (2005), in their study with 17 and 18 year olds, asked for an indication of size in order to better classify the depictions of the youths. Over 60 % of the respondents imagined the groundwater lakes and rivers to be similar to water bodies on the earth's surface and of considerable size (also see Cheek, 2010).

The idealized notion pertaining to the quality of the groundwater is also worth mentioning. Reinfried (2006b) and Reinfried et al. (2012) report from their research with 13 year olds, that many of them generally believe groundwater, and especially spring water, to be clean and drinkable. Suter et al. (2007) also reported adults to share this notion. An awareness regarding the threat to groundwater quality and its conservation seems to be lacking.

The mentioned misconceptions about groundwater as an underground lake, river or accumulation of water in cavities are persistent and outliving academic tuition. Groundwater is an abstract phenomenon that is neither visible nor able to be experienced. Therefore, one tends to explain it through well-known structures and occurrences at the earth's surface. Aside from this tendency to explain the world through analogies, metaphorical explanations are also often sought. In this sense, we speak of – in keeping with the theory of experience-based understanding of Lakoff and Johnson (2003)

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– water veins in the ground in an analogy to the veins that transport the blood through our body.

These metaphors and body-related constructions can also be traced through the historical views of groundwater concepts: as early as 2500 years ago, Pythagoras described the earth as resembling the human body, and Leonardo da Vinci and Johannes Kepler compared the earth's water to the blood of an organism (see Reinfried, 2006a, p. 54; 2006b, 40–42). The idea of an underground water network existed up until the mid-19th century (subaerial river model), and it was the beginning of the 20th century before the present-day perception was established. In colloquial language, however, the millennia-old metaphors remain, irrespective of geological expertise.

Mainstream popular science television, literature and schoolbooks reinforce these metaphors. The authors, without reflecting on the consequences, display an aquifer in the geologic tradition as a homogenous blue area, which is then interpreted by the layman in the sense of the described misconceptions (Schwartz et al., 2011). Inadequate or incorrect depictions of groundwater in schoolbooks further impede the development of scientifically accurate concepts. Shepardson et al. (2009) criticize the prevailing depictions of the water cycle in American school books that display a stylized landscape with mountains and coastlines which the pupils are unable to relate to their actual surroundings and that are not practical for communicating a deeper understanding of the water cycle and the role of groundwater. Reinfried (2006a) also sees schoolbook figures as a source of misunderstandings. The arrows that depict the groundwater movement from land to the sea could, for example, be interpreted by the pupils to represent rivers or water veins. Wampler (1998, 2000), Dickerson et al. (2007) und Duffy (2012) also report on illustrations that are too simplified or simply negligent. All these points of criticism are also relevant for Austrian schoolbooks as a recent analysis of 23 schoolbooks confirms.

Teachers are not always capable of compensating for the shortcomings of the school books due to the fact that their conception of groundwater often does not differ from the preconceptions of their pupils (Dickerson and Dawkin, 2004; Duffy, 2012). Schwartz

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et al. (2011), in their study as part of the Arizona Water Festival 2009 with a school program, discovered that pupils performed better when their teacher had taken part in an accompanying training workshop.

2.3 How can conceptual change theory foster teaching about groundwater?

In science education, the conceptual change theory has largely been accepted and numerous studies have led to remarkable insights into the thought patterns and conceptions of children and youths in various subfields of science. Researchers agree that it is one of the most important aims of science instruction to develop students' pre-instructional conceptions towards the intended scientific concepts. Interesting learning environments have been derived from the results of conceptual change studies, in the fields of earth sciences e.g. about hydrogeology by Reinfried (2006a) and Reinfried et al. (2013), about climate change by Niebert and Gropengießer (2014) or glacier by Felzmann (2014).

From the constructivist point of view, science learning does not require the replacement of an "incorrect" by a "correct" concept, "but the ability on the part of the learner to take different points of view and understand when different conceptions are appropriate depending on the context of use" (Vosniadou, 2007, p. 58). Vosniadou (2014) argues that "framework theories" – abstract, naive knowledge structures that ground our deep ontological commitments in terms of which we understand the world – do not seem to go away but continue to exist and interfere with access to scientific concepts even in skilled adults.

What are the recommendations by conceptual change researchers for supporting learning processes? Strike and Posner (1992) postulate that conceptual change can only take place under certain circumstances. The first prerequisite is that a cognitive conflict arises. The students must become dissatisfied with their own (inadequate) conception and must realize that they cannot sufficiently explain the respective phenomenon. Furthermore, the new offered concepts must seem intelligible and plausible to the students, as well as being effective in regard to explaining the various phenom-

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ena. In accordance with Strike and Posner, Sinatra (2005) also identifies message characteristics that can foster or hinder conceptual change: the learners must find the message comprehensible, coherent, plausible and rhetorically compelling.

However, the implementation of research findings in the classroom context often lags behind the expectations (Limón, 2001; Chan et al., 1997; Duffy, 2012). This is partly explained by the fact that conceptual change processes demand from the students a higher level of cognitive engagement than “normal” class instruction, a higher level of motivation, epistemological beliefs, good learning strategies and beneficial social factors, not to mention the guidance and support through teachers, because a cognitive conflict in the absence of knowledge-building activity will not produce conceptual change.

In this sense, Sinatra and Pintrich (2003) and Sinatra (2005) go beyond Strike and Posner’s stringent focus on cognitive processes and depict conceptual change as a complex and dynamic interaction of affective, motivational, and contextual factors. The specific conditions of the individual, such as background knowledge, motivation and interests, emotional involvement, self-efficacy, need for cognition and engagement are focused on. Additionally, as an important detail, Sinatra (2005) defines three key aspects of a student’s existing background knowledge: (1) the strength of preconceptions – the stronger the ideas are, the more connected they are in their brain, the less will they change, (2) the coherence – less coherent ideas are more susceptible to change and (3) the commitment – ideas to which an individual is strongly committed are less likely to change.

Coming back to the topic of groundwater, we can assume that a learning program that aims to give children, youths or adults a scientifically accurate understanding of groundwater must take the existing preconceptions into consideration. With reference to Sinatra (2005), the students’ preconceptions of underground lakes, rivers and water-filled caves are expected to be “strong ideas” – not least because they have existed for centuries – while the coherence and the commitment with the topic groundwater probably are at relatively low levels. In Austria, the awareness for groundwater is not

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very present in everyday life, and not are probably the motivation and engagement for groundwater, because of its permanent availability – independently of whether knowledge about groundwater is a crucial topic in education for sustainable development. With the use of new media in hydrogeology education however, a higher level of motivation can be expected.

In the following, the underlying deliberations for the theory-guided designing of the multimedia program will be presented.

3 Theory guided designing of the multimedia learning program

3.1 What youths need to understand about groundwater

The multimedia learning software deals with various questions concerning groundwater in unconsolidated rocks, where it occurs in the pores between the mineral grains. In the sense of an adequate model of groundwater, youths need to understand the following:

1. Rainwater seeps into the ground through cavities between the mineral grains and accumulates in permeable and porous sediments above an impermeable layer. The characteristics of the pore space and, therefore, suitability as a groundwater aquifer, depend on the grain size. Larger grains constitute larger pore spaces while smaller grains are surrounded by smaller pore spaces. It generally applies that the more pore space available, the more groundwater can be transported and stored therein. Very small grain sizes (silt and clay) constitute pore spaces that are too small to allow water to percolate and hence form an aquiclude.
2. Groundwater flows within the pore spaces.
3. After a certain depth, which can be a few decimeters or a few hundred meters under the surface, depending on annual rainfall and position of the surface water, the pores between the grains are entirely filled with water (aquifer).

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4. The groundwater surface is the boundary between the unsaturated zone (ground air) and the aquifer, which is not in a fixed position but rather fluctuates depending on influx and discharge into and out of the aquifer.
5. Wells are used for the extraction of groundwater.
6. Pollutants from e.g. unsecured waste sites and agriculture can contaminate groundwater.
7. Groundwater needs to be protected from such pollution.

3.2 The general design of the learning program based on multimedia research

When designing the learning program, theories of multimedia learning (Mayer, 2009; Moreno, 2006) constitute an important basis. One of the main messages is that meaningful learning can be fostered by considering the “architecture” of humans’ information processing and the characteristics of the working memory. When designing multimedia programs, Mayer (2005, 2009) and Mayer and Moreno (2003) recommend several principles of multimedia learning we paid attention to: we implemented a good balance between auditory and visual presentations of information. The texts are kept short (no scrolling) and the criteria for comprehensibility by Langer et al. (2011) were taken into consideration in the text presentation. As to the motivation, a geologist takes the user through the program in the role of a “pedagogical agent” (Mayer, 2005). She offers explanations, asks questions and gives instructions for the interactive tasks as well as feedback regarding the test questions.

Experiences and results of studies with other multimedia learning programs about biological topics were also taken into consideration (Unterbruner and Unterbruner, 2002, 2005; Unterbruner et al., 2008): the learning program is characterized by a clear structure and a row of information units followed by test questions. Three test questions conclude each thematic sub-unit and are designed to give the users feedback on how

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3. How can I envision groundwater?

4. How does rain become groundwater?

5. Why do I need knowledge about groundwater?

1. The challenge-oriented question of what in fact makes up the ground beneath our feet is intended to make the user curious. While showing a picture of people standing in the pouring rain, the Geologist explains that between 10 and 80 out of every 100 raindrops seep into the ground. But where do they end up? To visualize this, she invites the user to a virtual elevator ride into the ground.

A virtual elevator (Screenshot 1) then takes the users into the ground beneath our feet. It makes several stops at different levels and information is provided as to what exactly can be expected at these depths in the ground: at 2 m the pipelines of the sewerage system are shown, at 3 m there is coarse gravel, at 10 m the users find themselves in an underground train station, at 11 m below the surface the lift passes through fine-grained gravel, at 14 m it encounters sand and, finally, at 18 m below the surface the groundwater is reached. Further down, at 25 m the elevator passes through fine-grained wet gravel and at 30 m the elevator ride ends in dry clay.

How geologists attain their knowledge about the subsurface is shown in the following section: pictures of a drill hole are presented and a drill core consisting of gravel, sand and clay can be examined with a magnifying glass. Two further drill cores as well as the corresponding soil profiles are also shown. Then, the Geologist presents a scientific model developed by the company *Ecovia* for the procurement of hydrogeological data. Gravel, sand and clay are layered between Plexiglas panes. The water level, the flow of the groundwater and the input of pollutants can be varied at will and monitored at the glass tubes. This model is referred to a number of times thereafter and is used to illustrate various pieces of information. All animations are programmed based on the layers in the model

(see screenshots 1, 2, 4 and 5). Based on the recommendations of Dickerson et al. (2005), the spatial dimensions under consideration are explicitly addressed. Houses are shown after presenting the model in order to illustrate the magnitude of the layers displayed in the subsurface, and then the distance the virtual elevator travelled is also indicated (see red figure in Screenshot 2).

2. What processes lead to the underground layers and how it is possible to deduce information regarding their formation history based on the sequence of layers are the themes of the next interactive section. The formation of the subsurface layering is demonstrated based on a concrete example of an alpine river. Information can be obtained by moving the mouse over the appropriate sections.

3. Only now, after the geo-scientific concept of “sediments” has been elaborated upon sufficiently, is the topic of groundwater broached. Four people explain how they envision groundwater. Thereby, aside from the technically correct definition of “water that flows between gravel- and sand grains”, the three most common notions are also presented (underground lake, river/water veins, water in caves). The user is required to choose which statement they consider to be the correct one and the Geologist subsequently gives feedback regarding each of the opinions.

The aim is to activate the user’s prior knowledge about groundwater and to make clear that there might be a discrepancy between the users’ own pre-concepts and the before presented content (cf. cognitive conflict). This further clarifies that there are various notions as to what groundwater is and that not all of them are technically correct. But as not to reinforce any preexisting misconceptions, these are commented on briefly (e.g. “an underground lake does not exist”). In accordance with Sinatra (2005), who said that strong ideas will rather resist change, we tried to avoid a possible emphasis or even consolidation of these inadequate conceptions. Instead, we purposefully steer the user’s attention toward the scientifically correct definition, and rather than repeating the misconceptions the Geologist asks how the pore space between grains come to be filled with water.

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4. How rain becomes groundwater is illustrated through a demonstration experiment showing the permeability of gravel, sand and clay (screenshot 3). The user is required to estimate through which of the three sediments the water will percolate the fastest. In order to foster cognitive activation, their chosen answer is not commented upon immediately, but rather the demonstration begins and the correct answer is only given thereafter in the form of individual feedback.

In the next part, the hydrogeological terms “pore space” and “aquiclude” are explained. We see an accurate understanding of the concept of pore space as a crucial prerequisite for the consolidation of a geo-scientific concept of groundwater. An animation that can be replayed repeatedly shows a raindrop on its way through the layers of the model – in the first run – through concretely and subsequently with explanations regarding the flow rate in each of the different substrates (screenshot 4).

After this detailed view the whole model is shown once again and the Geologist simulates rain using blue-colored water. Subsequently, the flow of groundwater, the interaction between rivers and the groundwater, and the terms “groundwater table” and “aquifer” are exemplified with the help of the *Ecovia*-model.

By this point in the learning program we have portrayed the hydrogeological basics in an interactive and cognitively activating manner. We made sure that the scientifically accurate conception is communicated in an “intelligible and plausible” way (Strike and Posner, 1992).

5. The aim of the last part is to demonstrate how the new conception can be “fruitful”. This is achieved by addressing the topics of groundwater use, the threats it is subjected to, and the protection and conservation of groundwater.

Once again based on the model, the user is asked where wells could be drilled. The user must place small drilling-rig icons and receives feedback as to whether or not the structure of the layered subsurface is suitable at the chosen position. The user is then confronted with a case study in which the mayor receives a pro-

posal to use a plot of land for the deposition of refuse. An animation shows the path which hazardous substances would take in the ground in red color, illustrating whether they would potentially pose a threat to the quality of an existing well (Screenshot 5). Finally, the threat to groundwater through pollution resulting from agriculture is addressed.

Screenshot 6 shows one of the eight exercises/test questions to be completed within this chapter.

4 Research questions

The main research questions we aimed to address are the following:

- Which pre-instructional conceptions do pupils and students have regarding groundwater?
- Does conceptual change occur as a result of working with the multimedia learning program?
- Does knowledge about groundwater increase by using the learning program?
- What is the participants' level of acceptance of the multimedia learning program?

5 Sample

5.1 Pupils/school

This sample consisted of 237 Austrian 7th grade pupils ($n_{\text{female}} = 99$, $n_{\text{male}} = 138$) between the ages of 12 and 14 ($M = 12,48$; $SD = 0,62$), attending a secondary school (Gymnasium and Neue Mittelschule). The group was made up of pupils from 12 different classes across four schools. The pupils of 9 of the classes were assigned to

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the experimental group ($n = 177$) and those from 3 classes were assigned to the control group ($n = 60$). According to their teachers, none of the participating classes had previously been taught about groundwater and hydrogeological issues. The level of knowledge imparted by school education regarding the topic of groundwater can be considered as limited.

5.2 Students/university

This sample consisted of 115 Austrian teacher training students in the first stage of their degree, in the subjects of “Biology and Environmental Education” and “Geography and Economics” at the University of Salzburg. 73 students were assigned to the experimental- and 42 students to the control group. The percentage of female students (70 %) was considerably higher than the percentage of male students, which corresponds to the general gender distribution in these two fields of study. The average age was 21.4 years ($SD = 3.99$). All of these students had received their high school qualification at a higher secondary school. Since the higher secondary schools do not explicitly cover the topic of hydrogeology in the curriculum, it can be assumed that their academic tuition on this subject matter was likely marginal. Based on their choice of further studies, however, it can be assumed that this group possesses a particular interest in Biology and/or Geoscience.

6 Methodology

The quasi-experimental design of the research regarding the effectiveness of the multimedia learning program was made up of a pre-test and a post-test to evaluate pre-conceptions, knowledge and attitudes regarding groundwater, as well as the individual process of working through the program, and a questionnaire for its formative evaluation. In order to control repeated measurement effects, participants of each sample

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group (pupils and students) were randomly assigned to an experimental or control group (see Table 1).

The teaching staff of the schools and university provided the time for the participants to take the pre- and post-tests (T1 and T3) and to work through the program (incl. T2) (see Table 1). The participating pupils and students were thus in their familiar educational environment, but were motivated to engage in a scientific research study. The multimedia learning program was not implemented in class. The participants worked through the program individually (using headphones) and at their own pace.

In agreement with the teaching staff, no other work on the topic of groundwater was carried out during the investigation period. The post-test was, therefore, no examination (in a school or university context) and it was not to be expected that the pupils/students would individually engage with the topic in order to receive a good grade. In order to ascertain long-term – as opposed to short-term – knowledge acquisition, the post-test was conducted two weeks after the participants had worked through the program.

6.1 Instruments

6.1.1 Pre-/Post-test (T1, T3)

The questionnaire served the purpose of data collection pertaining to

1. pre- and post-instructional conceptions of groundwater,
2. knowledge about hydrogeological topics.

(1) Pre- and post-instructional conceptions of groundwater

Since drawing is an effective method to capture mental representations (see Schwartz et al., 2011, p. 148; Dove et al., 1999; White and Gunstone, 1992), the participants were asked to draw how they envisioned groundwater. They were also asked to verbalize (open question) their perceptions of groundwater. The question and instructions for the

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drawing were worded very broadly in order to avoid influencing the content as far as possible.

The drawings from the pre- and post-tests (T1, T3) were analyzed and double coded by experts (science education, geology; excellent interrater reliability: Cohen's kappa for students: $k = 0.91$, for pupils: $k = 0.86$, cf. Fleiss and Cohen, 1973) based on the following categories:

Hydrogeologically correct conception:

1. water in porous and permeable rocks (Fig. 2),
2. partly correct: water in porous and permeable rocks, but an important detail e.g. the aquiclude, is missing (Fig. 3).

Hydrogeologically inadequate conceptions:

1. groundwater as a subterranean river, stream or water vein (Fig. 4),
2. groundwater as a subterranean lake (Fig. 5),
3. groundwater stored in caves or cavities in the ground (Fig. 6),
4. groundwater as part of the water cycle,
5. groundwater as water at the bottom of water bodies,
6. other conceptions such as e.g. surface waters, water in pipes,
7. vague drawings.

The answers to the open question regarding the participants' conceptions of groundwater were analyzed in terms of accuracy and the level of detail – ranging from very broad (e.g. water in the ground) to specific and with the mention of various details (e.g. rainwater percolates into the ground, seeps through the soil, and is collected above an impervious layer).

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(2) Knowledge about hydrogeological issues

The questionnaire in the pre- and post-test (T1, T3) contained 16 items pertaining to the geological concepts relevant to the understanding of groundwater, namely sediments, porosity, flow of groundwater, groundwater surface, aquifer and aquiclude. Furthermore, a question regarding the use of groundwater and a transfer-task with a narrative example of agricultural use of fertilizer and its potential threat for groundwater were posed. The wording of these items was closely related to the contents of the program, and the items were identical, but the language was adapted accordingly for pupils and students.

Three questions were open while the rest were multiple-choice questions or statements that had to be classified as either being correct or incorrect. The multiple-choice questions were supplemented by a scale from 1 to 10 on which the participants had to indicate how sure they were about their answers. The aim of this was to evaluate whether the answer was merely a guess (low value) or whether, according to the participants' subjective rating, they were confident about their knowledge. By this means, an increase in knowledge could be determined when correct answers were given in both the pre- and post-test, but the subjective confidence rating increased significantly.

6.1.2 Questionnaire for formative evaluation

The participants were given a questionnaire (T2) and asked to evaluate the program straight after having worked through it. They were asked to rate it using 18 items on a Likert-scale. The degree of usability, the subjective success rate, the enjoyment as well as how understandable and interesting the program was perceived to be, were evaluated. The internal consistency of the evaluation questionnaire, measured by means of Cronbach's Alpha, was given in both groups, with values of $\alpha = 0.81$ (pupils) and $\alpha = 0.74$ (students).

All data were analyzed using IBM SPSS 22.0.

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7 Results

7.1 Pre-instructional conceptions of groundwater

According to the international studies described above, the results of the drawing exercises of the pre-test showed that the dominating preconceptions of students and pupils were the academically incorrect concepts of an underground river (students: 30 %, pupils: 47 %) and an underground lake (students: 31 %; pupils: 15 %). Other concepts were rarely mentioned. The scientifically accurate conception of water within porous and permeable rocks was drawn by 11 % of students and only 3 % of pupils (see Table 2).

The verbal descriptions of groundwater were conveyed correctly by 60 % of the pupils and 89 % of the students. This discrepancy has its origin in the mostly very short and general verbal descriptions of groundwater (e.g. “water in the ground”) and did not express nor allow conclusions as to the underlying conceptions.

7.2 Conceptual change

The scientifically adequate concept of groundwater was significantly more prevalent in the post-test. The percentage of correct and partially correct drawings rose from 9 to 42 % for the pupils and from 20 to 49 % for the students. The evaluation of the graphical representations of the participants showed a statistically highly significant shift from inadequate preconceptions to the correct conception. An evaluation of the verbal descriptions of groundwater yielded similar results but from a much higher baseline (Fig. 7, see also Table 2).

When examining the expressed preconceptions of the underground river and lake in detail, the Wilcoxon-test showed that these perceptions were significantly reduced in the post-tests of both pupils and students (Fig. 8).

The degree to which this effect can be attributed to the effectiveness of the multimedia program is shown by the comparison of the experimental- and control groups.

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The concept scores (= sum of the points achieved in the concept tasks, max. 4) of the pre- and post-tests of both groups were calculated and analyzed. This showed that the participants from the experimental group significantly improved their scores while the scores of the control group even saw a slight decrease (pupils – experimental group: +1.20 points; control group: –0.03 points; students – experimental group: +1.27 points; control group: –0.07 points) (Fig. 9).

7.3 Knowledge acquisition

In order to verify the overall increase in knowledge, all items testing knowledge are combined to a total knowledge score. Every correct answer is worth two points, making a maximum total knowledge score of 24 points possible in both the pre- and the post-test. The overall increase in knowledge (or decrease, as the case may be) is determined by the difference between the total knowledge score of the pre- and post-test.

A comparison with the control group was once again used to show that the increase in knowledge was in fact attributable to the use of the multimedia learning program. On average, students from the experimental group increased their scores by 3.29 points while those from the control group only achieved an increase by 0.89 points. The ANOVA revealed a highly significant difference between the two groups ($F(1,86) = 12.35$; $p < 0.01$; $\eta^2 = 0.13$). In the case of the pupils, the experimental group achieved an increase by 5.31 points compared to 3.82 points ($F(1, 120) = 5.88$; $p < 0.05$; $\eta^2 = 0.05$) in the control group.

The increase in knowledge regarding the fundamental geological concepts of “porosity” and “sediments” was shown to be especially high in both experimental groups. Pupils and students performed best in the topics “sediments”, “Flow rates in gravel, sand and clay” and in depicting the groundwater surface.

The ANOVA also showed that the participants in the experimental group were significantly more confident in their answers (on all items where confidence was controlled) in the post-test compared to the participants of the control group.

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increase in correct groundwater conceptions and knowledge achieved during a one-off session with the multimedia program (15 to 20 min) and without any accompanying instruction in class or as part of a university course. These results indicate that our didactic concept with reference to conceptual change research was useful in order to foster learning about groundwater.

As an example of successful learning with the multimedia learning program, the results of a 12 year old boy regarding conceptual change and knowledge increase are shown in Fig. 10. In the pre-test he had imagined groundwater to be a huge subterranean lake and defined groundwater as “The water that comes from the mountains, that is huge”. Two weeks after working with the multimedia program his drawing looked quite different. He produced a hydrogeologically correct drawing of groundwater and wrote: “Groundwater is water that runs through gravel and is gathered above clay.” The considerable refinement in his understanding of groundwater was also obvious in his retention performance. In the pre-test he answered 7 of the questions correctly, 9 incorrectly, and the problem-solving transfer was missing. His post-test contained 14 correct and 2 incorrect answers and the problem-solving transfer was answered correctly.

In a similar way, 42 % of pupils and 49 % of students in the experimental group drew the concept of groundwater correctly or partially correctly in the post-test as opposed to the pre-test, in which a mere 9 and 20 %, respectively, demonstrated a correct understanding. Highly significant differences between the experimental and control group could be established. The highest knowledge scores were achieved on the basic geological concepts of “sediments” and “pore space”, which were mainly dealt with during the first part of the multimedia program. In addition, pupils and students from the experimental group also performed better in the transfer task. Being able to use the knowledge gained in various everyday situations is one of the primary objectives of science education. Additionally, the participants’ subjective certainty when answering the questionnaire was significantly higher in the experimental group.

Members of the experimental groups, in particular pupils with little or no prior knowledge about groundwater, mostly improved their performance by working with the pro-

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gram. Similar results have been reported from other studies on the efficiency of multimedia learning programs (Unterbruner and Unterbruner, 2005; Unterbruner et al., 2008). We believe that a key factor is that (well designed) multimedia learning programs can reduce or even avoid cognitive overload, because individual information processing occurs at the user's own pace and is therefore adapted to his/her own reading and listening competency. On the other hand, learning in class is often adjusted to the average pupil's skills. In addition, the program's interestingness and comprehensibility were rated very highly by the participants. Particularly learners with little prior knowledge benefit from comprehensible, coherent and well-arranged texts, pictures and animations (cf. Mayer, 2005, 2009).

The fact that the conception of groundwater as an underground river or lake is a very "strong idea" is obvious. In about half of pupils and students proved to be resistant towards the new concept of groundwater as water within porous and permeable rocks. In these cases, working with the program as a singular intervention was not sufficient. In future studies we will examine how an incorporation of the multimedia learning program as part of a learning environment in class might enhance its effectiveness. Another reason for the lack of success in these cases may be the factor of user behavior. Some participants "rushed" through the program. Their motivation for attentively working on the program may also be stronger if the multimedia program was implemented in class.

In accordance with Schwartz et al. (2011), our data led to the conclusion that the incorporation of drawing in assessments is a meaningful tool in order to understand conceptions of groundwater. The drawings more often revealed an incorrect or vague understanding of the groundwater system and enabled a better understanding of the participants' mental models of groundwater. Dickerson and Dawkins (2004) also found that students could state ideas about groundwater and the water cycle using correct terminology to describe incorrect thinking. Schwartz et al. (2011) emphasize that students' ability to conceptualize the groundwater system, as evidenced by drawing, seems to be "a much stronger predictor of content mastery than the ability to answer objective questions" (p. 148).

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Critics point out that drawing ability can be a limiting factor. Participants may, for example, leave out certain details which they are unable to draw (Dove et al., 2014). Based on our detailed analyses, we think that it is not primarily the drawing ability that is limiting, but rather a vague or missing conception of the respective topic. As many pupils’ and students’ drawings show, a few lines based on a clear mental model suffice for depicting groundwater, and artistic skills are not required. Additionally, many drawings clearly showed where working with the multimedia learning program had resulted in an improved understanding of the concept of “groundwater”, and details in the drawings made clear where conceptual change had taken place (see Fig. 10).

In summary, the theory-based multimedia learning program presented here can improve teaching and learning of hydrogeological concepts. The results of our study demonstrate that it is a powerful tool to foster meaningful learning about groundwater in terms of both conceptual change and improved knowledge. It has proved to be an appropriate tool for pupils in class as well as students in teacher training.

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References

- Ben-zvi-Assarf, O. and Orion, N.: A study of junior high students’ perceptions of the water cycle, *J. Geosci. Educ.*, 53, 366–373, 2005.
- BMBF: Lehrpläne der AHS und Hauptschule (HS, NMS), Bundesministerium für Bildung und Frauen, Wien, available at: <https://www.bmbf.gv.at/schulen/unterricht/lp> (last access: 26 Aug 2014), 2000.
- Chan, C., Burtis, J., and Bereiter, C.: Knowledge building as a mediator of conflict in conceptual change, *Cognition Instruct.*, 15, 1–40, 1997.
- Cheek, K. A.: A summary and analysis of twenty-seven years of geoscience conception research, *J. Geosci. Educ.*, 58, 122–134, 2010.

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- Dickerson, D. L. and Dawkins, K.: Eighth grade students' understanding of groundwater, *J. Geosci. Educ.*, 52, 178–181, 2004.
- Dickerson, D. L., Callahan, T. J., Sickie, M. V., and Hay, G.: Students' conceptions of scale regarding groundwater, *J. Geosci. Educ.*, 53, 374–380, 2005.
- 5 Dickerson, D. L., Penick, J. E., Dawkins, K. R., and Sickie, M. V.: Groundwater in science education, *J. Sci. Teach. Educ.*, 18, 45–61, 2007.
- Dove, J. E., Everett, L. A., and Preece, P. F. W.: Exploring a hydrological concept through children's drawings, *Int. J. Sci. Educ.*, 21, 485–497, doi:10.1080/095006999290534, 1999.
- Duffy, D.: The Nature and Role of Physical Models in Enhancing Sixth Grade Students' Mental Models of Groundwater and Groundwater Processes, Graduate thesis, UMI number 3529175, Old Dominion University, Norfolk, 2012.
- 10 Duit, R.: Science education research internationally: conceptions, research methods, domains of research, *Eurasia J. Math. Sci. Tech. Educ.*, 3, 3–15, 2007.
- Duit, R., Gropengießer, H., Kattmann, U., Kormorek, M., and Parchmann, I.: The model of educational reconstruction – a framework for improving teaching and learning science, in: *Science Education Research and Practice in Europe: Retrospective and Prospective*, edited by: Jorde, D. and Dillon, J., Sense Publishers, Rotterdam, 13–37, 2012.
- Felzmann, D.: Using metaphorical models for describing glaciers, *Int. J. Sci. Educ.*, 36, 2795–2824, 2014.
- 20 Fleiss, J. L. and Cohen, J.: The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability, *Educ. Psychol. Meas.*, 33, 613–619, 1973.
- Hilberg, S.: *Einführung in die Umweltgeologie*, Springer Verlag, Berlin, Heidelberg, 2015.
- Kattmann, U., Duit, R., Gropengießer, H., and Komorek, M.: Das Modell der Didaktischen Rekonstruktion. Ein Rahmen für naturwissenschaftliche Forschung und Entwicklung, *Z. Didakt. Naturwiss.*, 3, 3–18, 1997.
- 25 Lakoff, G. and Johnson, M.: *Metaphors We Live By*, The Chicago University Press, Chicago, London, 2003.
- Langer, I., Schultz von Thun, F., and Tausch, R.: *Sich verständlich ausdrücken*, Ernst Reinhardt Verlag, München, Basel, 2011.
- 30 Limón, M.: On the cognitive conflict as an instructional strategy for conceptual change: a critical appraisal, *Learn. Instrum.*, 11, 357–380, 2001.

- Mayer, R. E.: Principles of multimedia learning based on social cues: personalization, voice, and image principles, in: The Cambridge Handbook of Multimedia Learning, edited by: Mayer, R. E., Cambridge University Press, 201–212, 2005.
- Mayer, R. E.: Multimedia Learning, Cambridge University Press, New York, 2009.
- 5 Mayer, R. E. and Moreno, R.: Nine ways to reduce cognitive load in multimedia learning, Educ. Psychol., 38, 43–52, 2003.
- Moreno, R.: Does the modality principle hold for different media? A test of the method-affects-learning hypothesis, Journal of Computer Assisted Learning, 22, 149–158, 2006.
- Niebert, K. and Gropengießer, H.: Understanding the greenhouse effect by embodiment – analysing and using students’ and scientists’ conceptual resources, Int. J. Sci. Educ., 36, 277–303, 2014.
- 10 Reinfried, S.: Wie kommt Grundwasser in der Natur vor? Ein Beitrag zur Praxisforschung über physisch-geographische Alltagsvorstellungen von Studierenden, Geogr. Didakt., 33, 133–156, 2005.
- 15 Reinfried, S.: Conceptual change in physical geography and environmental sciences through mental model building: the example of groundwater, Int. Res. Geogr. Environ. Educ., 15, 41–61, 2006a.
- Reinfried, S.: Alltagsvorstellungen – und wie man sie verändern kann, Geographie Heute, 243, 38–43, 2006b.
- 20 Reinfried, S., Mathis, C., and Kattmann, U.: Das Modell der Didaktischen Rekonstruktion – eine innovative Methode zur fachdidaktischen Erforschung und Entwicklung von Unterricht, Beitr. Lehrerbild., 27, 404–414, 2009.
- Reinfried, S., Tempelmann, S., and Aeschbacher, U.: Addressing secondary school students’ everyday ideas about freshwater springs in order to develop an instructional tool to promote conceptual reconstruction, Hydrol. Earth Syst. Sci., 16, 1365–1377, doi:10.5194/hess-16-1365-2012, 2012.
- 25 Reinfried, S., Aeschbacher, U., Kienzler, P. M., and Tempelmann, S.: Mit einer didaktisch rekonstruierten Lernumgebung Lernerfolge erzielen – das Beispiel Wasserquellen und Gebirgshydrologie, Z. Didakt. Naturwiss., 19, 261–288, 2013.
- 30 Schultz, J. W.: Student Conceptions of Groundwater, Graduate thesis, UMI Number 3205252, Faculty of the Graduate School of the University of Minnesota, Minneapolis, 2006.
- Schwartz, K. L., Thomas-Hilburn, H., and Haverland, A.: Grounding water: building conceptual understanding through multimodal assessment, J. Geosci. Educ., 59, 139–150, 2011.

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- Seibert, J., Uhlenbrook, S., and Wagener, T.: Hydrology education in a changing world, *Hydrol. Earth Syst. Sci.*, 17, 1393–1399, doi:10.5194/hess-17-1393-2013, 2013.
- Shepardson, D. P., Wee, B., Priddy, M., Schellenberger, L., and Harbor, J.: Water transformation and storage in the mountains and at the coast. Midwest students' disconnected conceptions of the hydrologic cycle, *Int. J. Sci. Educ.*, 31, 1447–1471, 2009.
- Sinatra, G. M.: The “Warming Trend” in conceptual change research: the legacy of Paul R. Pintrich, *Educ. Psychol.*, 40, 107–115, doi:10.1207/s15326985ep4002_5, 2005.
- Sinatra, G. M. and Pintrich, P. R.: *Intentional conceptual change*, Lawrence Erlbaum Associates, Inc., Mahwah, NJ, 2003.
- Strike, K. A. and Posner, G. J.: A revisionist theory of conceptual change, in: *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice*, edited by: Duschl, R. A. and Hamilton, R. J., State University of New York Press, New York, 147–176, 1992.
- Suter, D., Kury, D., Baltes, B., Nagel, P., and Leimgruber, W.: Kulturelle und soziale Hintergründe zu den Wahrnehmungsweisen von Wasserquellen, *Mitteil. Naturforsch. Gesell. Basel*, 10, 81–100, 2007.
- Thompson, S. E., Ngambeki, I., Troch, P. A., Sivapalan, M., and Evangelou, D.: Incorporating student-centered approaches into catchment hydrology teaching: a review and synthesis, *Hydrol. Earth Syst. Sci.*, 16, 3263–3278, doi:10.5194/hess-16-3263-2012, 2012.
- Unterbruner, U. and Hilberg, S.: *Zwischen Regenwolke und Wasserhahn (Between the rain-cloud and the tap)*, CD-ROM and online programm, University of Salzburg, Salzburg, available at: <http://www.multimedialernen.at> (last access: 11 June 2015), 2012.
- Unterbruner, U. and Pfligersdorffer, G.: *Problembasiertes Lernen im Biologieunterricht*, edited by: Zumbach, J., Weber, A., and Olsowski, G., 117–130, 2007.
- Unterbruner, U. and Unterbruner, G.: *Multimedialernen im Ökologieunterricht: Lernprozesse und Programmgestaltung*, in: *Lehr- und Lernforschung in der Biologiedidaktik*, Band 1, edited by: Klee, R. and Bayrhuber, H., StudienVerlag, Innsbruck, 187–198, 2002.
- Unterbruner, U. and Unterbruner, G.: *Wirkung verarbeitungsfördernder multimedialer Programmgestaltung auf den Lernprozess von 10- bis 12-Jährige*, in: *Lehr- und Lernforschung in der Biologiedidaktik*, Band 2, edited by: Klee, R., Sandmann, A., and Vogt, H., StudienVerlag, Innsbruck, 181–194, 2005.
- Unterbruner, U., Pfligersdorffer, G., and Zumbach, J.: natureLe@rn – eine Studie zum problemorientierten Ökologieunterricht via Lernplattform “moodle”, in: *Lehr- und Lernforschung*

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in der Biologiedidaktik, Band 3, edited by: Sandmann, A. and Harms, U., StudienVerlag, Innsbruck, 199–215, 2008.

Vosniadou, S.: The cognitive–situative divide and the problem of conceptual change, *Educ. Psychol.*, 42, 55–66, 2007.

5 Vosniadou, S. (Ed.): *International Handbook of Research on Conceptual Change*, Routledge, New York, 2013.

Vosniadou, S.: Examining cognitive development from a conceptual change point of view: the framework theory approach, *Eur. J. Dev. Psychol.*, 11, 645–661, 2014.

10 Wampler, J. M.: Problematic descriptions of ground-water movement, *J. Geosci. Educ.*, 46, 282–284, 1998.

Wampler, J. M.: Misconceptions of the development of cones of depression, *J. Geosci. Educ.*, 48, 239–241, 2000.

White, R. and Gunstone, R.: *Probing Understanding*, The Falmer Press, London, 1992.

15 Zumbach, J., Moser, S., Unterbruner, U., and Pfligersdoffer, G.: Problemorientiertes Online – Lernen im Biologieunterricht: Fähigkeitsselbstkonzept, mentale Anstrengung und Vorwissen als Prädiktoren für Wissenserwerbsprozesse zwischen Instruktion und Konstruktion, *Z. Didakt. Naturwiss.*, 20, 45–50, doi:10.1007/s40573-014-0004-6, 2014.

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Table 1. Research plan (EG = experimental group, CG = control group, T1 = pre-test, T2 = formative evaluation, T3 = post-test).

Group		Phase 1 Start	Phase 2 3 weeks later	Immediately after learning program	Phase 3 2 weeks after learning program
Pupils	EG	T1	learning program	T2	T3
	CG	T1	–	–	T3
Students	EG	T1	learning program	T2	T3
	CG	T1	–	–	T3

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Table 2. Comparison of the conceptions of groundwater of pupils and students from the experimental group in the pre- and post-tests (in %).

	Pupils ($n = 177$)		Students ($n = 73$)	
	pre-test	post-test	pre-test	post-test
Correct conception	3.4	30.4	11.3	43.6
Partially correct	5.7	11.8	8.5	5.6
GW as subterranean river	46.7	33.3	29.6	15.5
GW as subterranean lake	15.1	10.6	31.0	11.3
GW in caves	6.7	1.7	0.0	1.4
Water cycle	1.1	0.6	4.2	0.0
Surface water	8.3	1.7	0.0	0.0
Water pipes	5.5	1.1	1.4	1.4
Other conceptions	5.0	2.8	8.5	8.5
Unclear drawings	2.5	6.0	5.7	12.7

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Table 3. Results of the formative evaluation (Likert-scale from 1 = “strongly disagree” to 4 = “strongly agree”).

	Pupils		Students	
	<i>x</i>	sd	<i>x</i>	sd
Interest	3.74	0.33	3.36	0.48
Comprehensibility	3.74	0.29	3.49	0.38
Enjoyment	3.42	0.68	3.20	0.77
Subjective achievement	3.61	0.43	3.50	0.47
Usability	3.28	0.73	3.29	0.79

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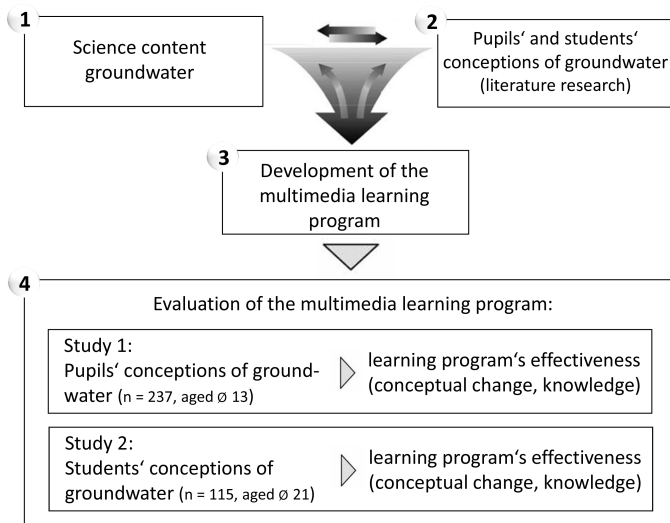


Figure 1. MER-based research design.

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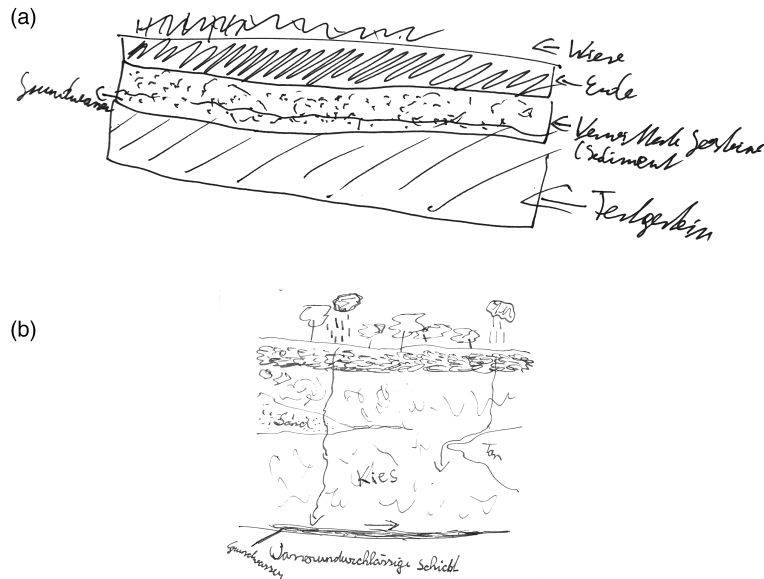


Figure 2. Examples for the categories of analysis. Geologically correct drawings: **(a)** student, **(b)** pupil.

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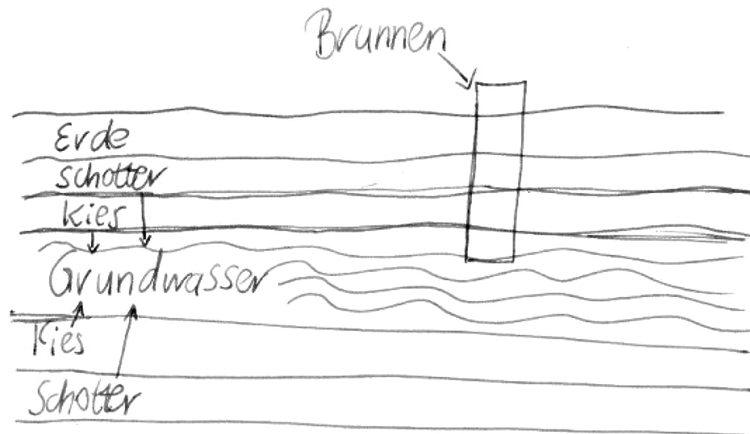


Figure 3. Examples for the categories of analysis. Partially correct representation: the arrows express that the part marked with “Grundwasser” also contains broken stones and gravel; but the aquiclude is missing.

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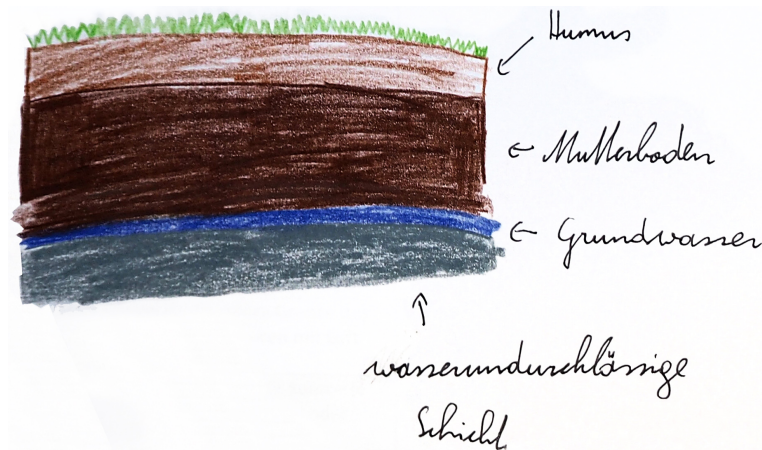


Figure 4. Examples for the categories of analysis. Groundwater as a subterranean river.

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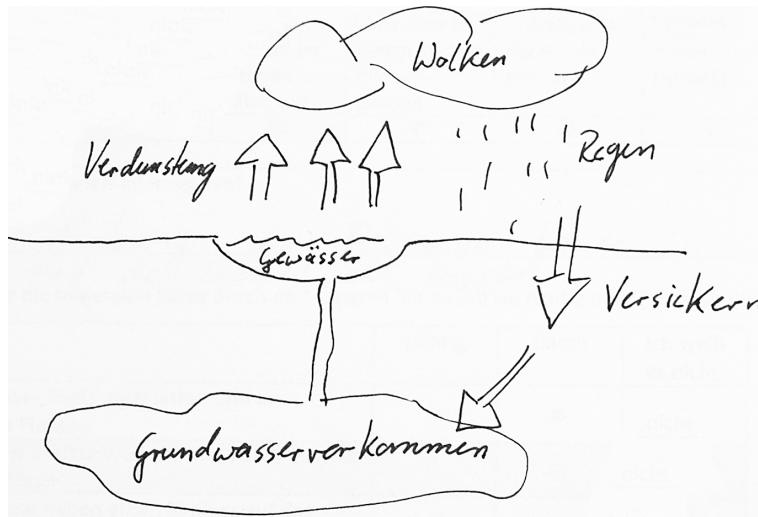


Figure 5. Examples for the categories of analysis. Groundwater as a subterranean lake.

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Figure 6. Examples for the categories of analysis. Groundwater in holes or caverns.

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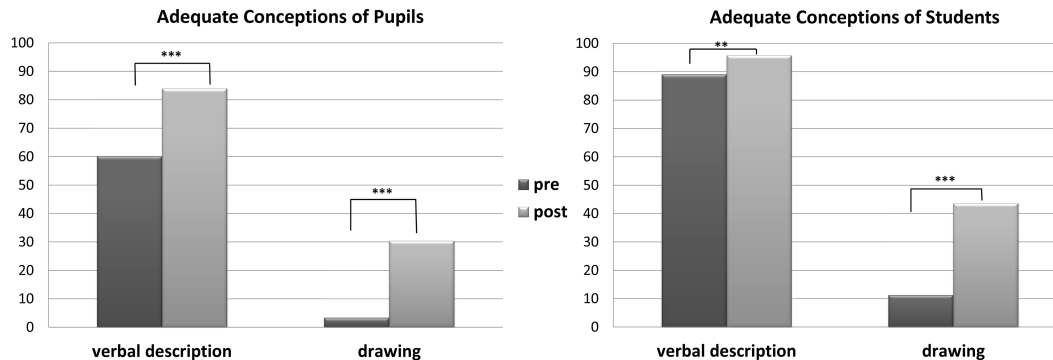


Figure 7. Scientifically accurate concepts pupils and students from the experimental group in the pre- and post-test ($n_{\text{pupils}} = 177$; $n_{\text{students}} = 73$; data in %; Wilcoxon-test/drawings: pupils: $Z = -5.65$; $p < 0.001$; students: $Z = -3.48$; $p < 0.01$; Wilcoxon-test/verbal explanations: pupils: $Z = -5.39$; $p < 0.001$; students: $Z = -4.14$; $p < 0.001$).

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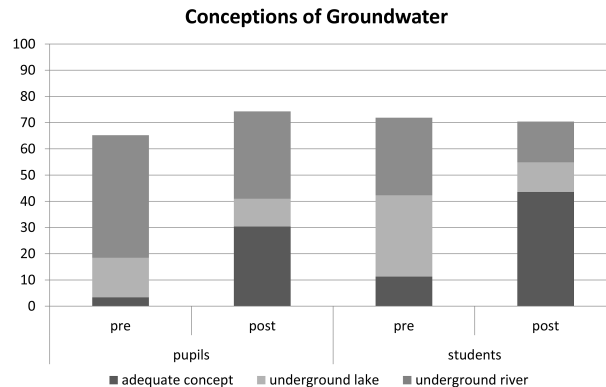


Figure 8. Comparison of the correct and most frequently mentioned incorrect groundwater conceptions (underground lake and river) of pupils and students from the experimental group in the pre- and post-tests ($n_{\text{pupils}} = 177$; $n_{\text{students}} = 73$; data in %; Wilcoxon-Test: groundwater as an underground river: $Z = -3.16$; $p < 0.01$; groundwater as an underground lake: $Z = -2.99$; $p < 0.01$).

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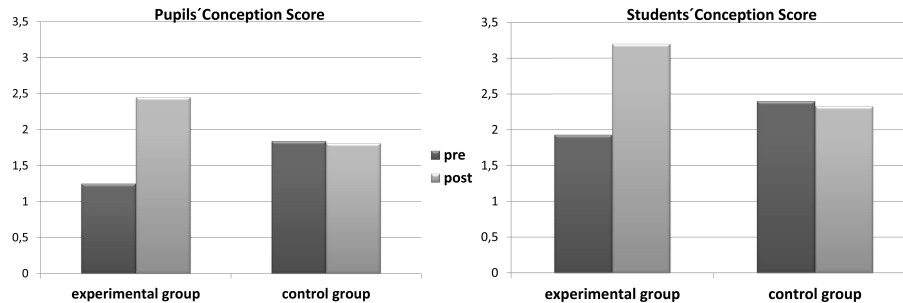


Figure 9. Comparison of the conception score of the experimental- and control groups ($n_{\text{pupils}} = 195$; $n_{\text{students}} = 92$; max. 4 points; ANOVA pupils: $F(1, 195) = 28.28$; $p < 0.001$; $\eta^2 = 0.13$; ANOVA students: $F(1, 92) = 34.96$; $p < 0.001$; $\eta^2 = 0.27$).

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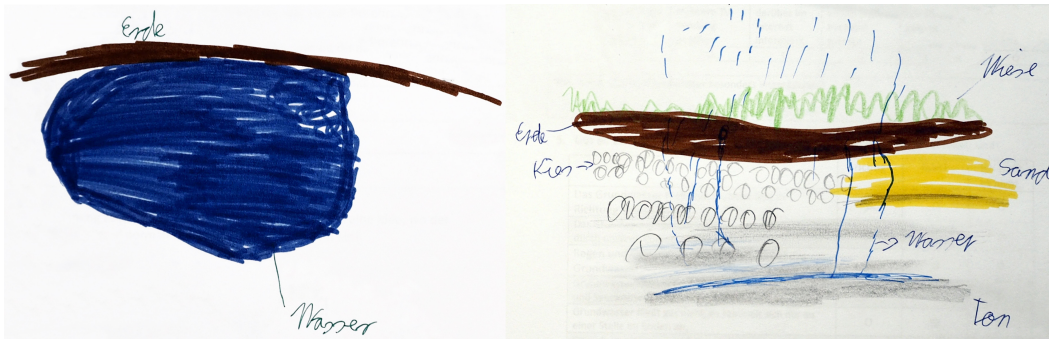


Figure 10. Example for conceptual change by learning with the multimedia program from a 12 year old boy (Pre-test: groundwater as a huge subterranean lake; Post-test: correct drawing of groundwater).

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Screenshot 1. Screenshots from the multimedia learning program. Virtual elevator at its first stop two meters below the earth's surface.

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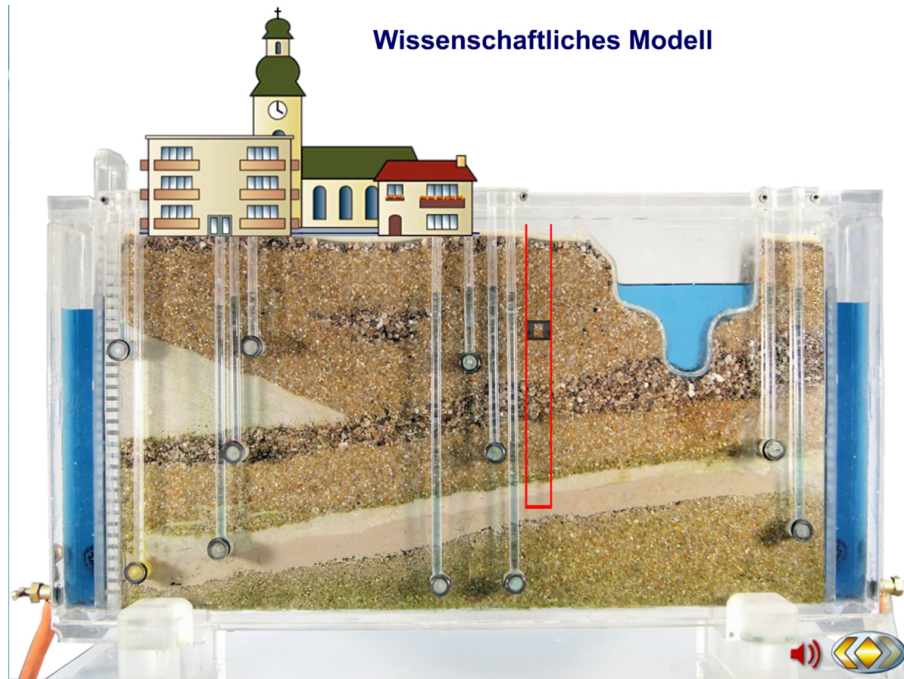


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Screenshot 2. Spatial dimensions of the model and reality.

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Screenshot 3. Demonstration of the permeability of sediments.

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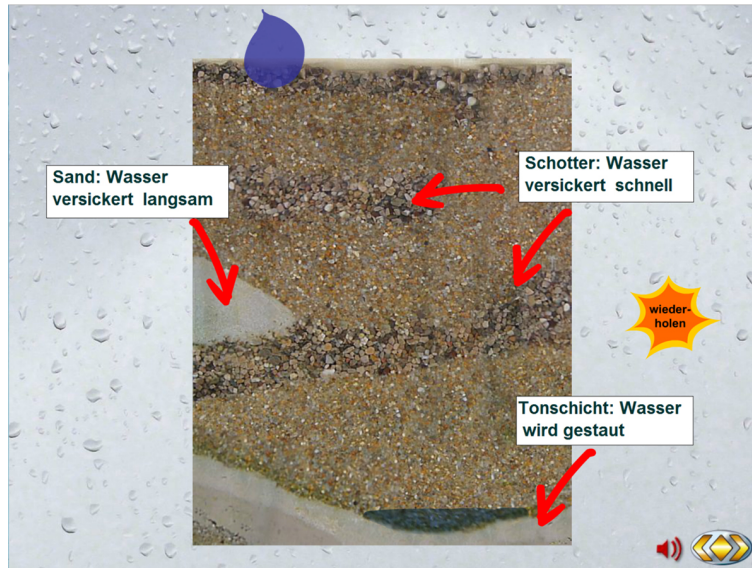
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Screenshot 4. Animation of water flowing through gravel and sand down to the clay.

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Screenshot 5. Animation showing the dispersal of pollutants out of an unsafe waste disposal site.

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Screenshot 6. Example of one of the test questions regarding the formation of gravel and sand.

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