Response to Reviewers' Comments on our manuscript "Understanding groundwater – students' pre-conceptions and conceptual change by a theory-guided multimedia learning program" and comments on revision:

REVIEWER 1:

REVIEWER'S COMMENT:
Theoretical background: The MER by Kattmann et al. (1997) and the conceptual change theory served as theoretical frame of the learning program. Yet, the authors' understanding of conceptual change remains unclear. They do not explicitly explain what conceptual change means to them and this causes inconsistencies in the study. They reference a sentence by Stella Vosniadou which I take as a definition for conceptual change: "...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)" (p. 11696, line 14-17). If this definition expresses the authors' idea of conceptual change they should have related their interpretation of the results and conclusions to it.

AUTHORS' RESPONSE:
We rewrote that part (chapter 2.2.) in order to make it clearer.

REVIEWER'S COMMENT:
The authors claim that the design of their learning program was theory-guided in reference to the MER but they do not disclose the methodological path they used when designing their program according to the MER. The crucial point of the MER concerns the process of how to match a science concept to the learners' pre-instructional, often "naïve" conceptions, in order to help them to learn the science concept.

AUTHORS' RESPONSE:
Please see chapter 3.3. that is completed with the new table 1

REVIEWER'S COMMENT:
The authors state that according to the MER "the science contents may not be presented in a simplified ("reduced") manner in science instruction, but a new science content structure for instruction." (p. 11693, lines 1-2). Although this statement is true, the term "new" might be a bit misleading. What do the authors mean by "new"?

AUTHORS' RESPONSE:
We added a more detailed explanation, see p.3, lines 27 – 30 and p.4, line 1

REVIEWER'S COMMENT:
Kattmann et al. (1997) meant that the science content structure has to be reconstructed for learning in schools in a way that it relates the science content to the experiences and the world knowledge of learners who do not have all the background knowledge a hydrologist has and retrieves to. Therefore, the scientific concept and the students' pre-knowledge as well as the role this pre-knowledge plays in the students' knowledge construction process need to be analyzed.
To achieve the educational reconstruction of the science concept in question, the key ideas of that science concept need to be understood and the commonalities and differences between the science concepts and the students' pre-knowledge need to be identified. Unfortunately, the paper does not give any information of how the authors bridged the gap between the structure of the science content and the students pre-knowledge.

AUTHORS' RESPONSE:
We did not do own investigations on students' groundwater conceptions but we built on the many excellent studies as cited in chapter 2.2. (p. 4 – 7). These researchers presented most common conceptions of groundwater in detail. Their results were a very good basis for designing the multimedia learning program – as we extensively described in chapter 3.3. (see p.10 – 13). Furthermore, table 1 (new!) was added that gives an overview about the key questions in the designing process in regards to students' groundwater preconceptions (as far as described in literature), scientific conceptions and multimedia implementation.

REVIEWER'S COMMENT:
On p.11698, lines 12-24 und p. 11699, lines 1-7 key ideas that need to be addressed in the learning process are listed (references?).

AUTHORS' RESPONSE:
The following references are given: Hölting & Coldewey, 2013; Davis & de Wiest, 1966; Hilberg, 2015.

REVIEWER'S COMMENT:

On p. 11700-11701 the key idea, that played a role in the design process of the learning program, are listed. But how are these lists interconnected to each other and to the students' preconceptions? In the journal "Beiträge zur didaktischen Rekonstruktion" or in Reinfried et al. (International Research in Geographical and Environmental Education, 24(3), 237-257) you find examples of how to reconstruct a science concept according to the MER.

AUTHORS' RESPONSE:
We added the required comparison. See Table 1.

REVIEWER'S COMMENT:
Design of the intervention: The efficacy of the learning program was evaluated in an experimental-control group design with two measuring times. However, the paper does not include any information concerning the learning activities of the control group. I suppose that the control group served only to fill in the questionnaire twice. If that is the case, a comparison of the experimental and the control group does not make much sense. It is self-evident that a group of learners' who work with a learning program that is interesting and well conceived make progress and that the progress can be related to the learning program. The question is rather what kind of advantages the learning program can offer in comparison to other learning arrangements and what the conditions are to induce a fundamental conceptual change.

AUTHORS' RESPONSE:
We added a more detailed explanation about the control group (p. 15, lines 6 – 11).

REVIEWER'S COMMENT:
The expectation that the learners learn something with the learning program was confirmed by the knowledge test, but why did more than 50% of the learners still draw sketches after the intervention that include large open spaces under the surface?

AUTHORS' RESPONSE:
Realistically it is to be expected that only a part of the pupils and students can be guided towards the desired learning effect – even if we can state a highly significant increase of correct answers.

REVIEWER'S COMMENT:
Why did the unclear drawings produced by both the pupils and the students increase after the intervention (see Table 2)?

AUTHORS' RESPONSE:
We added an explanation (p. 22, lines 21 – 31, p.23, lines 1-2).

REVIEWER'S COMMENT:
Results: Unfortunately the authors did not include the questionnaires. Thus, it is not possible to review the learners' knowledge gains. An interesting question concerns for example the scoring of the knowledge questions: Where they all equivalent in terms of cognitive demands?

AUTHORS' RESPONSE:
The items of the questionnaire were targeted on different aspects and competencies of groundwater knowledge. We do not think that there is any need for equivalency in terms of cognitive demands.
If considered as appropriate the questionnaire (6 pages) could be added as supplementary data.

REVIEWER'S COMMENT:
Fig. 10 displays two drawings a pupil has made before and after the intervention. The authors claim that the post-test drawing indicates a fundamental conceptual change. It is evident that the pupil has learned a lot

but he still uses vertical line-shaped structures for the surface water to percolate into the ground and he depicts a sheet-shaped layer of water above the aquiclude. The key idea that clastic sediments serve as water reservoirs which means that all open spaces below the groundwater level are filled with water is not displayed in the drawing. This raises questions. The boy shows a knowledge gain, for sure, but is his sketch sufficient evidence to prove a fundamental conceptual change, especially in terms of the definition given by Vosniadou (referred to above)? From other studies in this field it can be concluded that the research design used in the present study and the research data gained through it is not suitable to answer the research question on p. 11704 "Does conceptual change occur as a result of working with the multimedia learning program¿'

AUTHORS' RESPONSE:
Thank you for this helpful advice. Accordingly, we exchanged the drawings.

REVIEWER'S COMMENT:
Discussion and conclusions: The research clearly indicats a knowledge gain but it does not say anything about the persistence of that knowledge. The students' mental representations displayed in the drawings raise the question whether the learning program can initiate a conceptual change. From a psychological point of view individual learning without phases of co-construction with others runs the risk of overlooking the key ideas provided in the learning material that challenge the deeply entrenched preconceptions. Therefore, data gained from research using a similar setup is according to my knowledge of this research area problematic to infer that a conceptual change has been effected.

AUTHORS' RESPONSE:
It is amazing, indeed, that correct and partially correct drawings of groundwater increased from about 9% to 42% (pupils) and 20% to 50% (students) in the post-test, although the participants just worked on the learning program by their own for about 20 minutes - without support from teachers resp. teacher guided phases of co-construction. And our post-test was not performed immediately after the intervention (as many researchers do), but after a period of 2 weeks.
In our opinion, this underlines the high potential of theory-guided and "didactical" multimedia learning programs. They offer a big variety of possibilities and modalities that apparently can foster conceptual change.

REVIEWER'S COMMENT:
My final remarks concern a few details: - p. 11693, lines 19-20: "Everyday conceptions usually resist change". This is not the case for all everyday conceptions but especially for those that are considered intuitively correct. Review research by Andrea diSessa.

AUTHORS' RESPONSE:
Restriction added (p. 4, line 22 - 23).

REVIEWER'S COMMENT:
- p. 11697, lines 4-20: In which way were all these recommendations considered in the design of the learning program?

AUTHORS' RESPONSE:
Please see chapter 3.3.

REVIEWER'S COMMENT:
- p. 11697, lines 21-24: "...the students' preconceptions of underground lakes, rivers and waterfilled 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." I do not understand this sentence.

AUTHORS' RESPONSE:
Explanation added (p. 8, lines 7 – 13).

REVIEWER'S COMMENT:

Strike & Posner’s prerequisites for a conceptual change are explained in chapter 2.3. On p. 11703, lines 19-21 the authors write: "We made sure that the scientifically accurate conception is communicated in an “intelligible and plausible” way (Strike and Posner, 1992). Note, that even if authors take Posner’s and Strike’s prerequisites into account, it is the learners who have to find the concept presented in the learning material intelligible and plausible. Was this aspect explored? –

AUTHORS’ RESPONSE:

Yes, it was explored: See the results of formative evaluation in table 4.

REVIEWER’S COMMENT:

p. 11706, lines 12-14: "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.“ An evaluation of the knowledge gains two weeks after the intervention does not say much about the persistence of that knowledge. This time span is just too short.

AUTHORS’ RESPONSE:

If you compare with many other appropriate studies, the interval of 2 weeks between intervention and post-test is longer than usual. The “forgetting curve” is already relevant after this period. Of course, a follow-up-test after 2 or 3 months would be a good thing, but very often it is impossible to realize when you investigate in (Austrian) schools.

REVIEWER’S COMMENT:

p. 11720: Does Table 2 only refer to the drawings? The idea that ground water is stored in large subsurface openings decreased in the pupils only from 68% to 45% and in the students from 60% to 26%. Surprisingly, the number of unclear drawings has more then doubled. The higher figure of unclear conceptions after the intervention indicates that new knowledge has been assimilated but not deeply understood.

AUTHORS’ RESPONSE:

We added some details in regards to the unclear drawings (p. 22, lines 21 – 31. P.23, lines 1-2).

REVIEWER’S COMMENT:

Because others have researched conceptual change issues concerning groundwater and groundwater related concepts extensively, I advise the authors to clearly mark their own new and original contribution to that research and to carefully distinguish it from the research of others.

AUTHORS’ RESPONSE:

We developed and evaluated our multimedia learning program about groundwater based on international scientific work about conceptual change and teaching & learning hydrogeology. We discussed and cited the considered literature about these topics in a scientifically correct way. We do not know any comparable learning programs.

REVIEWER’S COMMENT:

Questions concern for example the list on p. 11698, lines 12-24 and p. 11699, lines 1-7. The references are missing here.

AUTHORS’ RESPONSE:

References are given to Hölting & Coldewey, 2013; Davis & de Wiest, 1966; Hilberg, 2015.

REVIEWER’S COMMENT:

The title should be honed by addressing the fact that the paper describes the learning progress achieved with the learning program (not conceptual change).

AUTHORS’ RESPONSE:

Sorry, but here we must contradict: Our results demonstrate that conceptual change has occurred. Highly significantly more pupils as well as students drew correct sketches of groundwater after having worked with the learning program. How could you explain these results without a change of conceptions? It clearly can be seen that there are no more underground lakes, rivers or water

filled caves. The drawings can be traced to a new underlying conception: that of water within porous and permeable rocks.

REVIEWER'S COMMENT:
Final conclusion: The learning program is very interesting and the educational aims of the authors related to it are entitled to be discussed. Unfortunately, the paper includes many inconsistencies and unexplained observations. The research design of the study is only in parts unsuitable to answer all of the research questions. Additionally, the paper does not clearly explain how the theoretical foundations on which the learning program is based have been implemented. Due to these substantial weaknesses the paper should be rewritten without a focus on conceptual change.

AUTHORS' RESPONSE:
Sorry, but we cannot understand the reviewer's advice. We have presented how conceptual change research, multimedia research and the approach of MER helped to construct a learning program with a high learning efficiency. In regards to conceptual change and knowledge gain, a large number of both pupils and students had significantly benefited from working with the program.

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<u>REVIEWER 2:</u>

REVIEWER'S COMMENT:
1. Methodology: The manuscript needs to do a better job in explaining the MER model.
For example, last paragraph, page 11692, states that: "A balance between science-related issues and educationally oriented issues is considered a necessity in effective teaching and learning." But what are theses issues specifically? (science-related "issues" and educational oriented "issues").

AUTHORS' RESPONSE:
We added a more detailed explanation (p.3, lines 25 – 30 and p.4, lines 1 - 3).

REVIEWER'S COMMENT:
2. Design of tests and interpretation of results: The new learning program includes aspects related to introducing new and correct scientific contents on groundwater, and introducing such concepts using multi-media means. Can we isolate the effects of these two different aspects, i.e., new content on the one hand, and multi-media elements on the other hand? Can the evaluation research questions and tests isolate the individual effetcs of these different aspects of the intervention? In other words, did the improvement result from introducing new and correct scientific content, or was mainly attributed to the use of multi-media techniques?

AUTHORS' RESPONSE:
Our aim was to investigate the multimedia program's learning efficacy. Indeed, the effects of the new content on the one hand and the multimedia effects on the other hand cannot be seen isolated. The new added table 1 will make this point clearer. We directly combined the content with the potential of multimedia and used many multimedia tools like animations, interactive presentation of contents, an efficient balance between pictures and texts, a so called pedagogical agent and several more. Therefore you cannot take off the content from the multimedia program and implement it into a paper-pencil or "teacher only" version.

REVIEWER'S COMMENT:
3. Manuscript length: the manuscript is a little too long and can benefit from a more concise presentation of background, methodology, and results.

AUTHORS' RESPONSE:

Sorry, but in this point the 2 reviewers were contradictory: Reviewer #1 required more details. We tried to find a good balance.

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REVIEWER'S COMMENT:

4. Writing style: while the manuscript is fairly well-written, it needs a significant revision to improve its readability. For example, there are several places where the language style is a little awkward, sentences are fragmented and repetitive, and there are many problems with punctuations (commas, periods, capital and small letters), etc.

There is also an excessive use of numbering/bullets throughout the manuscript. I included below some examples of these, but the authors need to check the entire manuscript.

Problems with use of punctuations (periods; commas, etc.), sentence lengths and structure (e.g., lines 10-15 on page 11700)

Examples of minor corrections (please check the entire manuscript for more of these):

-Line 10 page 11692: "In a first step, we developed the multimedia learning program theory-guided"; this sentence needs to be re-phrased.

AUTHORS' RESPONSE:

Thank you for this advice. We reduced the numbering/bullets and had a translation agency checking the manuscript with special attention to the above mentioned parts of the manuscript.

Understanding groundwater – ~~students´~~students’ pre-conceptions and conceptual change by means of 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~~across different ~~ages~~age groups 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~~Drawing from international research, a multimedia learning program ~~(„~~(“*Zwischen Regenwolke und Wasserhahn*”, English: “Between the raincloud and the tap~~“)~~”) was developed~~. Insights~~, which incorporates specific insights from the fields of conceptual change research, multimedia research, and the Model of Educational Reconstruction~~ were specifically implemented. Two~~. The effectiveness of the learning program was ascertained by means of two studies ~~were conducted~~ with Austrian ~~pupils (~~7th grade~~) and~~ pupils as well as 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~~of groundwater were determined in a pre- and post-test. The pupils and students greatly ~~profited~~benefited from ~~independently~~ working through the learning software independently. 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~~indicate that theory-guided multimedia learning programs can play an important role in the transfer of research results ~~into the~~to classroom~~, particularly~~ settings, especially in science education.

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1 Introduction

~~Groundwater~~Education on the subject of groundwater is a crucial ~~topic in education~~ for ~~sustainable development~~sustainability. 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~~“‘Water knowledge’ has now become a socio-political and future-oriented necessity~~”, which is in accordance~~”. This view coincides with that of Dickerson et al. (2007, p. 45), who see knowledge about groundwater as “a fundamental component of scientific literacy~~”~~”, and an indispensable requirement 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~~ which determines our quality of life. ~~But, on~~On the other hand, however, international studies with students ~~of~~across different ~~ages~~age groups have shown that the basic hydrogeological concept of groundwater, which is defined as water within porous and permeable rocks, is not an established everyday notion. ~~Obviously~~ In order to help (young) people ~~have~~to overcome their obvious difficulties with correctly understanding the concept of groundwater~~. This is what~~, we ~~aimed to change with the help of~~ developed our interactive multimedia learning program “*Zwischen Regenwolke und Wasserhahn*” ~~(~~(“Between the raincloud and the tap~~,~~”, Unterbruner & Hilberg, 2012) ~~that we developed~~ in ~~an academic cooperation~~a joint effort between the faculties of Geology and Science Education/Biology Didactics at the University of Salzburg. ~~We want~~Our aim is to encourage young people to engage ~~in~~with the ~~field~~subject of hydrogeology~~,~~ and to prompt a learning process that will stimulate conceptual change towards a scientifically ~~edaquate~~accurate conception of groundwater.

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

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As our target groups, we chose pupils ~~aged~~ around the age of 13~~ for whom~~, who are the primary target audience of 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~~,~~ cover geological topics ~~are~~ primarily ~~covered as part~~within the scope 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~~their understanding of the ground, and the interaction between animate and inanimate nature” (p. 4). The precise scope of the subject matter and the time spent on it ~~for the implementation of~~in order to meet this requirement is left ~~up~~ to the ~~teacher~~teacher’s discretion.

~~According to~~In keeping with Thompson et al. (2012), we argue for more educational research to improve student~~-~~-centered teaching and learning in the fields of earth sciences (see 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~~are widely accepted in science education and offer a broad variety of impulses for creating learning environments. Additionally, we included results ~~of~~from multimedia research ~~constitute~~as an important ~~basis~~starting point.

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~~In~~As a first step, we developed ~~the~~a theory-guided multimedia learning program~~ theory-guided. The next step was to analyze~~. Subsequently, we analyzed 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~~framework

2.1 Model of Educational Reconstruction (MER)

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

The MER is based on a constructivist epistemological ~~position~~approach. A balance between science-related ~~issues~~ and ~~educationally~~ education-oriented issues is considered a necessity ~~in~~for effective teaching and learning. The ~~key message~~primary focus of ~~the model is that~~ science-related teaching (e.g. in university lectures) tends to be on the scientific nature of a certain topic. Following scientific conventions and routines, generations of teachers used to present scientific contents ~~may not be presented~~ in a simplified ~~(„~~(“reduced~~“)~~”) manner in science instruction, but the MER focusses on a quite different approach: The key message of this model for education-oriented teaching is that a new ~~science content~~ structure for science instruction has to be found in an iterative process between the analysis of the scientific content and ~~the learners‘~~learners’ perspectives, preconceptions, and experiences.

The MER integrates three significant components of science education research: (1) The clarification and analysis of ~~science~~scientific 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~~were applied (see ~~fig.~~Figure 1): We ~~considered~~took into account the definitions pertaining to the topic of hydrogeology, and the interpretation of the research results regarding ~~the groundwater~~pupils’ and students’ conceptions of ~~pupils and students.~~groundwater. Based ~~upon this~~on these, we devised the design of our multimedia learning program. The ascertainment of the effectiveness of ~~the~~our 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.

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Figure 1. MER-based research design

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2.2. Learners’ perspectives ~~of~~on groundwater and conceptual change

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Numerous studies ~~show~~have shown that children come to class with a ~~broad~~wide variety of preconceptions in relation to scientific concepts, many of ~~them~~which are inadequate ~~in relation to the scientific concepts.~~(e.g. Vosniadou, 2013; Hammann & Asshoff, 2014; Kattmann, 2015). Everyday ~~conceptions usually resist~~ preconceptions are often resistant to change~~. People~~, especially if they appear to be intuitively correct. Because people are familiar with ~~them~~these preconceptions and ~~because~~ they have become ~~so~~firmly established in everyday life, they are often considered to be adequate or at least not harmful. ~~Numerous~~Preconceptions or "framework theories" (Vosniadou, 2014) are abstract, naive knowledge structures resulting in deep ontological commitments in terms of how we understand the world. They can impede knowledge restructuring and be resistant to change.

Conceptual change theory is widely accepted in science education, and numerous studies have led to remarkable insights into the thought patterns and conceptions of children and adolescents in various subfields of science. A number of studies show that new information is incorporated into existing ideas for as long as possible and thus retained, even ~~in light of~~if there are obvious contradictions. 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. ~~This can lead to barriers to knowledge~~ Vosniadou (2014) holds that these framework theories do not seem to disappear, but continue to exist and interfere with access to scientific concepts, even among skilled adults. Therefore, from a constructivist point of view, science learning cannot be understood as the replacement of an "incorrect" by a "correct" concept (Vosniadou, 2007). Referring to these complex learning processes, Duit & Treagust (2003) and Kattmann (2005) prefer to use the term "conceptual reconstruction ~~(e.g. Vosniadou, 2013).~~" instead of "conceptual change".

~~Regarding~~With respect to groundwater, research has shown that common conceptions of groundwater are seldom based on scientific findings and that there is a strong prevalence of incorrect hydrogeological concepts ~~of hydrogeology are very prevalent.~~. The following represent dominant preconceptions ~~dominate~~ (Dickerson & Dawkins, 2004; Dickerson et al., 2005; Ben-zvi-Assarf & Orion, 2005; Reinfried, 2005, 2006a, 2006b; Schultz, 2006; Dickerson et al., 2007; 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.

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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 of the earth, while those ~~that~~processes which occur within the ground are often ~~not considered~~disregarded (Shepardson et al., 2009; Reinfried, 2006b).

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

The idealized notion pertaining to the quality of ~~the~~ groundwater is also worth mentioning. Reinfried (2006b) and Reinfried, Tempelmann & Aeschbacher (2012) report from their research ~~with~~involving 13~~–~~-year~~–~~-olds, that many of ~~them~~the respondents generally ~~believe~~believed that groundwater, and especially spring water, ~~to be~~was clean and drinkable. According to Suter et al. (2007~~)~~), this notion is also ~~reported~~shared by adults. There appears to ~~share this notion. An~~be a lack of awareness ~~regarding the threat~~concerning threats to groundwater quality and its conservation~~ seems to be lacking.~~.

The above-mentioned misconceptions ~~about~~of groundwater as an underground lake, river, or accumulation of water in cavities are persistent and ~~outliving~~outlast academic tuition. Groundwater is an abstract phenomenon that is neither visible nor ~~able to~~can it be experienced. ~~Therefore, one~~It therefore tends to ~~explain it through~~ be explained by means of well-known structures and occurrences ~~at~~above the ~~earth's~~ surface~~.~~ of the earth. Aside from this tendency to explain the world ~~through~~by means of analogies, we also often resort to metaphorical explanations~~ are also often sought.~~. In ~~this sense, we speak of — in~~ keeping with ~~the~~ Lakoff & Johnson's (2003) theory of experience-based understanding~~ of Lakoff & Johnson (2003) —~~, for example, we frequently refer to water veins in the ground in ~~an~~ analogy to the veins ~~that transport the~~transporting blood through our body.

These metaphors and body-related constructions can also be traced ~~through the~~throughout historical ~~views~~conceptions of groundwater~~ concepts~~: as early as ~~2500~~2,500 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~~cf. Reinfried, 2006a, 54; 2006b, 40-42). The idea of an underground water network existed up until the mid-19th century (subaerial river model), and it was not until the beginning of the 20th century ~~before~~that the present-day ~~perception~~conception was established. In colloquial language, however, ~~the~~ millennia-old metaphors ~~remain, irrespective~~persist regardless of modern geological ~~expertise~~knowledge.

~~Mainstream~~These metaphors are reinforced by mainstream popular science television, literature, and ~~schoolbooks reinforce these metaphors. The authors, without reflecting~~textbooks. Without much reflection on the consequences, some authors display an aquifer in the geologic tradition as a homogenous blue area, which is then interpreted by ~~the layman~~laypeople in the sense of the ~~described~~above-mentioned misconceptions (Schwartz et al., 2011). Inadequate or incorrect ~~depictions~~visual representations of groundwater in ~~schoolbooks~~textbooks further impede the development of scientifically accurate concepts. Shepardson et al. (2009) criticize the prevailing ~~depictions~~misrepresentations of the water cycle in American ~~school books that display~~textbooks, where water is displayed a stylized landscape with mountains and coastlines ~~which the~~. As many pupils are unable to relate these images to their actual surroundings ~~and that~~, such representations are ~~not practical~~impractical for ~~communicating~~conveying a deeper understanding of the water cycle and the role of groundwater. Reinfried (2006a) also sees ~~schoolbook figures~~pictures in textbooks as a source of misunderstandings. ~~The arrows that depict~~Arrows depicting the groundwater movement from land to ~~the~~ sea ~~could~~, for example, could be interpreted by ~~the~~ pupils to represent rivers or water veins. Wampler (1998, 2000), Dickerson et al. (2007~~) und~~), and Duffy (2012) also ~~report on~~have identified illustrations ~~that~~which are either too simplified or ~~simply~~downright negligent. ~~All these points of criticism are also relevant for Austrian schoolbooks as~~As a recent analysis of 23 ~~schoolbooks~~textbooks confirms, all of these criticisms can also be applied to Austrian textbooks (Unterbruner, Hilberg & Vago, in preparation).

Teachers are not always capable of compensating for the shortcomings of ~~the school books due to the fact that~~ textbooks as their own conception of groundwater is often ~~does not differ from~~similar to the preconceptions of their pupils (Dickerson & Dawkin, 2004; Duffy 2012). ~~Schwartz et al. (2011), in~~ In their study conducted as part of the Arizona Water Festival ~~2009 with~~within the scope of a school program~~,~~, in 2009, Schwartz et al. (2011) discovered that pupils performed better when their ~~teacher~~teachers had taken part in ~~an accompanying~~a training workshop on the subject.

How can Conceptual Change Theory ~~foster~~benefit 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 & Gropengießer (2014) or glacier by Felzmann (2014).~~

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~~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 & Posner (1992) postulate that ~~conceptual change can only take place under~~ certain circumstances~~.~~ must be given in order for conceptual change to be able to take place. The first prerequisite is ~~that~~ the existence of a cognitive conflict~~ arises. The students~~. Students must become dissatisfied with their own (inadequate) conception and must realize that they ~~cannot sufficiently~~ are unable to explain ~~the respective~~a specific phenomenon~~.~~ with sufficient accuracy. Furthermore, ~~the~~ new concepts offered ~~concepts~~to students must ~~seem~~be intelligible and plausible~~ to the students, as well as being effective in regard to explaining~~, and effectively explain the various phenomena. In accordance with Strike & Posner, Sinatra (2005) also identifies message characteristics that can foster or hinder conceptual change: ~~The learners~~Learners must find the message comprehensible, coherent, plausible~~,~~ and rhetorically compelling.

However, the implementation of research findings in ~~the~~ classroom ~~contexts~~settings often ~~lags behind the~~fails to meet expectations (Limón, 2001; Chan et al., 1997; Duffy, 2012). This is partly ~~explained by~~due to the fact that, in addition to guidance and support from teachers, 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~~ from students than “normal” classroom instruction, because a cognitive conflict in the absence of knowledge-building activity will not produce conceptual change.

In this sense, Sinatra & Pintrich (2003) and Sinatra (2005) go beyond Strike & Posner’s stringent focus on cognitive processes and depict conceptual change as a complex and dynamic interaction of affective, motivational, and contextual factors. ~~The~~Their focus is on 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~~, and engagement. Heddy & Sinatra (2013) point out that the potential for conceptual change increases with heightened student engagement. As an additional important detail, Sinatra (2005) defines three key aspects of a student’s existing background knowledge: (1) the strength of their preconceptions – the stronger the ideas ~~are~~, the more connected they are in their brain~~,~~ and the less ~~will~~likely they are to change~~,~~; (2) ~~the~~ coherence – less coherent ideas are more susceptible to change; and (3) ~~the~~ commitment – ideas ~~to which~~ an individual is strongly committed to are less likely to change.

~~Coming back~~Returning to the topic of groundwater, we can assume that a learning program ~~that~~which aims to give children, ~~youths~~adolescents, or adults a scientifically accurate understanding of groundwater must take ~~the~~into account existing preconceptions ~~into consideration. With reference to~~. In the words of Sinatra (2005), ~~the~~ students’ preconceptions of underground lakes, rivers, and water-filled caves are ~~expected~~likely to be “strong ideas” – not least because they have existed for centuries – while ~~the~~ coherence and ~~the~~ commitment ~~with~~to the topic of groundwater are probably ~~are at~~ relatively ~~low levels~~weak. In Austria, ~~the awareness for~~ groundwater awareness is not ~~very present in everyday life~~particularly widespread, and ~~not are probably~~ nor seem to be the motivation ~~and engagement for~~for and commitment to engaging with the topic. As groundwater~~, because of its permanent~~ availability ~~– independently of whether knowledge about groundwater~~ is ~~a crucial topic in~~

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~~education for sustainable development.~~ generally given, Austrian adolescents do not give much thought or attach great importance to it. Referring to Sinatra's categories, their commitment can be expected to be low. With the use of new media in hydrogeology education however, a higher level of motivation and engagement can be expected.

In the following~~,~~ sections, we present the underlying deliberations for the theory-guided design of the multimedia program.

Theory-guided designing of the multimedia ~~program will be presented.~~

3 ~~Theory guided designing of the multimedia~~ learning program

3.1. What ~~youths~~adolescents 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~~order to develop an adequate model of groundwater (cf. e.g. ~~, youths~~Hölting & Coldewey, 2013; Davis & de Wiest, 1966; Hilberg, 2015), adolescents 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~~,~~ its 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~~Below a certain depth, which can be a few decimeters or a few hundred meters ~~under~~below the surface, and depending on annual rainfall and ~~position~~the location of the surface water, the pores between the grains are entirely filled with water (aquifer).

~~(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 the influx into and discharge ~~into and~~ out of the aquifer.

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~~(5)-~~ Wells are used for ~~the extraction of~~extracting groundwater.

~~(6)-~~ Pollutants, e.g. from ~~e.g.~~ unsecured waste sites and agriculture, can contaminate groundwater.

~~(7)-~~ Groundwater needs to be protected from such ~~pollution~~contamination.

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

~~When designing the learning program, theories~~Theories of multimedia learning (Mayer, 2009; Moreno, 2006) constitute an important basis~~.~~ for designing such a learning program. One of ~~the main~~their key messages is that meaningful learning can be ~~fostered~~promoted by ~~considering~~taking into account the “architecture” of ~~humans’~~human information processing and the characteristics of the working memory. ~~When designing multimedia programs,~~ Mayer (2005, 2009) and Mayer & Moreno (2003) recommend several principles of multimedia learning, which we ~~paid attention to~~adopted when designing our multimedia learning program: 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~~according to Langer, Schultz von Thun & Tausch (2011) were taken into consideration in the text presentation. As ~~to the~~regards motivation, a geologist ~~takes~~guides 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~~on the test questions.

Experiences and results of studies with other multimedia learning programs ~~about~~on biological topics were also taken into consideration (Unterbruner & 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 well they have grasped the learning contents, and to fuel their motivation. ~~The time required to work~~Working through a chapter ~~is~~takes between 15 and 20 minutes.

The program is interactive, cognitively activating, and devised to be worked through independently. Cognitive activation is ~~sought through the~~to be achieved by means of a problem-oriented approach on the one hand (e.g. Unterbruner & Pfligersdorffer, 2007; Zumbach et al., 2014), and through interactive elements on the other. Various interactive

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elements require the ~~user to actively participate~~user's active participation, for example by using a magnifying glass to enlarge smaller details.

3.3. The storyboard's dramaturgy of "Water in the Ground" ~~based on conceptual change~~

~~To avoid strengthening~~In accordance with the iterative approach of ~~existing incorrect~~ MER, we based our theoretical considerations regarding the design of the multimedia learning program on the investigations about students' pre~~-~~conceptions ~~(~~by Dickerson & Dawkins (2004), Dickerson et al., (2005, 2007), Ben-zvi-Assarf & Orion (2005), Reinfried (2005, 2006a, 2006b), Shepardson et al. (2009), Schultz (2006), and Schwartz et al. (2011) on the one hand, and on basic hydrogeological concepts on the other. In the latter case, we focused on the most relevant scientific aspects to our target group of young people who may never have dealt with the topic of groundwater before. Accordingly, results from conceptual change research by Strike & Posner, Vosniadou, and Sinatra, ~~2005),~~broadly influenced our storyboard design. The dramaturgy of the multimedia program/storyboard will be described in detail below (see Table 1).

First of all, we decided not to start our program by activating preconceptions and previous knowledge ~~We identify the fact~~in order to avoid reinforcing existing misconceptions (cf. Sinatra, 2005). As a primary problem, we identified that most people have no concrete notion~~,~~ or, at best, a very vague ~~one~~idea of the structure and composition of the ground ~~as a primary problem~~ (= weak coherence, cf. Sinatra, 2005). Groundwater may be an abstract phenomenon, ~~yet,~~but contrary to the issue of climate change, it can sometimes become quite tangible~~, for example in~~ (e.g. when building trenches~~.~~). However, we assume that most people ~~don't~~do not make the connection between the observation of these phenomena and groundwater. Our primary aim, i.e. to convey an accurate understanding of groundwater, ~~therefore initially~~thus requires the best possible visualization of the composition of the "ground beneath our feet". Therefore, ~~this~~the program begins with conveying said knowledge ~~is conveyed at the beginning of the program, initially~~, but without making any direct reference to groundwater~~, and on this basis the~~ at first. The subject of groundwater is subsequently developed~~.~~ based on that knowledge. We accordingly developed a dramaturgy for the storyboard based on the following central questions~~:~~ (cf. Hilberg, 2015):

~~(1)~~1) What makes up the ground beneath our feet?

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~~(2)~~2) What causes the layers in the ground?

~~(3)~~3) How can I envision groundwater?

~~(4)~~4) How does rain become groundwater?

~~(5)~~5) Why do I need ~~knowledge~~to know about groundwater?

……………………………………………

Table 1: Key questions in the designing process in regards to students‘ groundwater preconceptions (as far as reported in literature), scientific conceptions and multimedia implementation

…………………………………………..

Ad 1)

The challenge-oriented question of what ~~in fact~~ makes up the ground beneath our feet is intended to ~~make~~arouse the ~~user curios. While showing~~user's curiosity. Showing a picture of people standing in the pouring rain, the ~~Geologist~~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~~on a virtual elevator ride into the ground.

A virtual elevator (Screenshot 1) then takes the ~~users~~user 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~~different depths in the ground: At 2 meters, we see the pipelines of the sewerage system ~~are shown, at~~. At 3 meters, there is coarse gravel~~, at~~. At 10 meters ~~the users~~, we find ~~themselves~~ourselves in an underground train station~~, at~~. At 11 meters below the surface, the ~~lift~~elevator passes through fine-grained gravel~~, at~~. At 14 meters ~~it encounters~~, we encounter sand and, finally, at 18 meters below the surface ~~the~~ , we arrive at groundwater ~~is reached~~level. Further down, at 25 meters, the elevator passes through fine-grained wet gravel and at 30 meters the elevator ride ends in dry clay.

How geologists ~~attain~~obtain 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~~The geologist then presents a scientific model developed by ~~the company~~ *Ecovia* for the procurement of hydrogeological data. Gravel, sand, and clay are layered between ~~Plexiglas~~ acrylic glass panes. The water level, the flow of the groundwater, and the ~~input~~ingress of pollutants can be ~~varied at~~

~~will~~freely adjusted and monitored at ~~the glass~~transparent 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~~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 subsurface layers displayed~~ in the subsurface~~, and ~~then~~ the distance travelled by the virtual elevator~~ travelled~~ is also indicated (see red figure in Screenshot 2).

Ad 2)

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

Ad 3)

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

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’~~their own pre-~~concepts~~conceptions and the before presented content (cf. cognitive conflict). This ~~further clarifies~~seeks to emphasize that there are various notions ~~as~~related to ~~what~~concept of groundwater~~ is~~ and that not all of them are technically correct. But ~~as not~~in order to ~~reinforce any preexisting~~avoid reinforcing pre-existing misconceptions, ~~these~~the options presented are briefly commented on ~~briefly~~ (e.g. “an underground lake does not exist”). In accordance with Sinatra (2005), who ~~said~~holds that strong ideas ~~will~~are rather ~~resist~~resistant to change, we ~~tried~~aimed 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~~geologist asks how the pore space between the grains ~~come to be~~becomes filled with water.

Ad 4)

How rain ~~becomes~~turns into groundwater is illustrated ~~through a~~by means of an experimental demonstration ~~experiment~~ showing the permeability of gravel, sand, and clay (~~screenshot~~Screenshot 3). The user is ~~required~~prompted to ~~estimate~~guess through which of the three sediments the water will percolate the fastest. In order to ~~foster~~promote cognitive activation, ~~their chosen~~the answer they choose is not commented ~~upon~~on immediately, but ~~rather the demonstration begins and~~ the correct answer is ~~only~~ given ~~thereafter~~ in the form of individual feedback~~.~~ following the demonstration.

In the next part, the hydrogeological terms of "pore space" and "aquiclude" are explained. We ~~see~~consider 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~~, which can be ~~replayed repeatedly~~played on repeat, shows a raindrop on its way through the layers of the model ~~— in~~. In the first run-~~-~~through ~~concretely and subsequently~~, the user is given a concrete demonstration. Subsequently, they are provided with explanations regarding the flow rate ~~in~~through each of the different substrates (~~screenshot~~Screenshot 4).

~~After~~Following this detailed ~~view~~presentation, the ~~whole~~overall model is shown ~~once~~ again and the ~~Geologist~~geologist simulates rain using blue-colored water. Subsequently, the flow of groundwater, the interaction between rivers and ~~the~~ groundwater, and the terms of "groundwater table" and "aquifer" are exemplified ~~with the help~~by means of the *Ecovia*-model.

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

Ad ~~(~~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~~groundwater is ~~subjected~~exposed to, and the protection and conservation of groundwater.

~~Once again based on~~Referring back to the model once again, 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~~Theuser is then confronted with a case study in which the mayor of a town receives a proposal to use a plot of land ~~for the deposition of~~as a refuse~~.~~ disposal site. An animation shows the path ~~which~~ hazardous substances would take ~~in~~through the ground in red ~~color~~, illustrating whether they would potentially pose a threat to the quality of an existing well (~~screenshot~~Screenshot 5). Finally, the threat ~~to~~of groundwater ~~through~~ pollution ~~resulting from agriculture~~by the agricultural sector is addressed.

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

……………………………..

Screenshots from the multimedia learning program: 1 – 6

Table 1: Key questions in the design process regarding students’ preconceptions of groundwater (to the extent described in the literature), scientific conceptions, and multimedia implementation

……………………………..

4. Research questions

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

- 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?

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5. Sample

Pupils/School:

This sample consisted of 237 Austrian 7th grade pupils (n_{female} = 99, n_{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~~from 9 of ~~the~~those classes were assigned to 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~~on the topic of groundwater ~~can be considered~~ as provided for by the Austrian curriculum is limited.

Students/University:

This sample consisted of 115 Austrian teacher training students in the ~~first stage of their degree, in the~~ subjects of “Biology & Environmental Education” and “Geography & Economics” in the first stage of their degree at the University of Salzburg. 73 students were assigned to the experimental~~-~~ group and 42 students to the control group. The percentage of female students (70%) was considerably higher than ~~the percentage~~that of male students, which ~~corresponds to~~is consistent with 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 to be marginal. Based on their choice of further ~~studies~~education, however, it can be assumed that this group possesses a particular interest in ~~Biology~~biology and/or ~~Geoscience~~geoscience.

6. ~~-~~Methodology

The quasi-experimental design of ~~the~~our research regarding the effectiveness of the multimedia learning program ~~was made up~~consisted of a pre-test and a post-test to evaluate preconceptions, knowledge, and attitudes regarding groundwater, as well as ~~the~~ individual ~~process~~processes of working through the program, and a questionnaire for its formative

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evaluation. In order to control ~~repeated~~repeat measurement effects and to prevent random events (e.g. TV documentaries) from impacting our results, participants ~~of~~from each sample ~~group~~ (pupils and students) were randomly assigned to an experimental or control group (see ~~tab.1).~~Table 2). The control group did not work on groundwater, because we did not intend to compare different teaching methods or media with the multimedia learning program, but to investigate the program's learning efficacy.

The teaching staff of the schools and university provided ~~the~~ time for the participants to ~~take~~complete the pre- and post-tests (T1 and T3~~)~~), and to work through the program (incl. T2) (see ~~tab. 1~~Table 2). The participating pupils and students were thus in their familiar educational environment, ~~but~~and 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~~By 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~~), in which case the pupils/students ~~would individually~~ could have been expected to engage with the topic individually 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.

…………………………

~~Tab. 1:~~Table 2. Research plan

……………………

…………………………..….

6.1. Instruments

Pre-~~/Post~~- and 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~~issues.

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

Since drawing is an effective method to capture mental representations (~~see~~cf. Schwartz et al., 2011, ~~Sp~~p. 148; Dove, Everett & Preece, 1999; White & 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 wording of the question and instructions for the drawing ~~were worded~~was kept very ~~broadly~~broad in order to avoid influencing the ~~content as far as~~outcome to the greatest possible~~.~~ extent.

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~~ (Cohen's kappa for students: k = .91, for pupils: k = .86~~,~~; cf. Fleiss & Cohen, 1973) based on the following categories:

Hydrogeologically correct conception:

- water in porous and permeable rocks (~~fig.~~Figure 2)
- ~~partly~~partially correct: water in porous and permeable rocks, but with an important detail, e.g. the aquiclude, ~~is~~ missing (~~fig.~~Figure 3)

Hydrogeologically inadequate conceptions:

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

The answers to the open question regarding the participants' conceptions of groundwater were analyzed ~~in terms of~~for 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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Figures 2 – 6: Examples for the categories of analysis

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Ad (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 the 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~~answers given were merely a guess (low ~~value~~score) or whether, according to the participants' subjective ~~rating~~opinion, 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 had increased significantly.

Questionnaire for formative evaluation

The participants were given a questionnaire (T2) and asked to evaluate the program ~~straight~~immediately after ~~having worked~~working through it. They were ~~asked~~instructed to rate it ~~using~~on an 18~~ items on a~~-item Likert~~-~~ scale~~. The~~ to evaluate the degree of usability, the subjective success rate, the enjoyment of the user experience, as well as how understandable and interesting they perceived 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 $\alpha = .81$ (pupils) ~~und~~and $\alpha = .74$ (students).

All data were analyzed using IBM SPSS 22.0.

7. Results

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Pre-instructional conceptions of groundwater

~~According to~~In line with the international studies described above, the results of the drawing exercises ~~of~~from the pre-test showed that the dominating preconceptions of students and pupils were the academically incorrect ~~concepts~~conceptions 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 ~~tab.2~~Table 3).

~~The~~In their, verbal descriptions ~~of groundwater were conveyed correctly by~~, 60% of ~~the~~ pupils ~~and~~vs. 89% of ~~the~~ students~~.~~ described the concept correctly. This discrepancy ~~has its origin in the mostly~~ can be attributed to the fact that most of the verbal descriptions of groundwater provided were very short and ~~general verbal descriptions of groundwater~~generic (e.g., “water in the ground~~”)~~”), and did not express nor allow conclusions as to the underlying conceptions.

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~~Tab. 2~~…………………………

Table 3: Comparison of the conceptions of groundwater of pupils and students from the experimental group in the pre- and post-tests (in %)

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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~~produced by 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~~, although from a much higher baseline (~~fig.~~Figure 7, see also ~~tab. 2~~Table 3).

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~~Fig.~~Figure 7: ~~scientifically~~Scientifically accurate ~~concepts~~conceptions of pupils and students from the experimental group in the pre- and post-test

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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~~for both pupils and students (~~fig~~Figure 8).

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~~Fig.~~Figure 8: Comparison of the correct and most frequently mentioned incorrect groundwater conceptions of pupils and students from the experimental group in the pre- and post-tests

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The degree to which this effect can be attributed to the effectiveness of the multimedia learning program ~~is shown by the~~becomes evident in a comparison of the experimental- and control groups. 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~~ a significant improvement in the scores of 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.~~Figure 9).

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~~Fig.~~Figure 9: Comparison of the conception ~~score~~scores of the experimental- and control groups (n_{pupils} = 195; $n_{students}$ = 92; max. 4 points)

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Knowledge acquisition

In order to verify the overall increase in knowledge, all items testing knowledge ~~are~~were combined to a total knowledge score. Every correct answer ~~is~~was worth two points, ~~making~~resulting in 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~~was determined by the difference between the total knowledge ~~score of~~scores from 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, the scores of students from the experimental group increased ~~their scores~~ by 3.29 points while those students 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) =

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12.35; p ~~<.~~< .01; η^2 = .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 ~~<.~~< .05; η^2 = .05) in the control group.

The increase in knowledge regarding the fundamental geological concepts of 'porosity' and 'sediments' was shown to be ~~especially~~particularly high in both experimental groups. Pupils and students performed best ~~in the topics~~with regard to "sediments", "~~Flow~~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.

~~It was~~We also examined whether the increase in knowledge varied between participants with a higher level of prior knowledge compared to those with little or no prior knowledge. In ~~both~~ the ~~pupils' and the students'~~ experimental groups ~~it was~~of both pupils and students, we observed that participants with little prior knowledge achieved an increase in their knowledge ~~score~~scores in a significantly greater number of instances than those who possessed a higher level of prior knowledge to begin with.

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Acceptance of the learning program

The multimedia learning program was ~~judged~~evaluated very positively. From a maximum of 60 possible points (4 points per item) in the evaluation questionnaire, the average score given by pupils was 51.4 points (s = 5.47) while students gave an average of 55 points (s = 3.87).

The results of the individual scales related to interest, comprehensibility, enjoyment, subjective achievement, and usability are summarized in ~~table 3~~Table 4.

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~~Tab. 3~~……………………………..

Table 4: Results ~~of the~~from formative evaluation

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8. Discussion and ~~Conclusions~~conclusions

Even though the importance of groundwater to humans and nature cannot be overstated, the results of our studies show that ~~an~~young people often lack a correct understanding of this topic ~~is often only to a weak extent correctly represented in young people´s minds.~~. In ~~accordance~~alignment with international studies, most of the Austrian pupils and students ~~in the~~from our pre-test imagined groundwater ~~as~~to be a subterranean river or lake. Only 3% of the 13-year-olds and 11% of the university students tested produced drawings that could be considered an expression of a correct understanding of groundwater in porous and permeable rocks. These results ~~underline~~highlight the importance of teaching about groundwater within the scope of science education and education for sustainable development.

We have demonstrated that groundwater education can be significantly improved by using our multimedia learning program. Both pupils and students~~,~~ achieved a significant increase in correct groundwater conceptions and knowledge ~~achieved~~ during a ~~one-off~~single session with the multimedia program (15 to 20 minutes~~)~~), 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~~is useful in order to ~~foster~~promote learning about groundwater.

As an example of successful learning with the multimedia learning program, the results of a ~~12~~ 13-year-old boy regarding conceptual change and knowledge increase are shown in ~~figure~~Figure 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*".~~river. Two weeks after working with the multimedia learning program, his drawing looked quite different. He produced a hydrogeologically correct drawing of groundwater ~~and wrote: "*Groundwater is*~~ with porous and permeable sediment layers, clay as an aquiclude, and a correct water ~~*that runs through gravel and is gathered above clay.*"~~table, even including the profile of an aerial river. The considerable refinement in his understanding of the concept of groundwater was also obvious in his retention performance. In the pre-test, he had answered ~~7~~9 out of ~~the~~16 questions correctly, ~~9 incorrectly, and~~compared to 15 out of 16 in the ~~problem-solving transfer was missing. His~~ post-test~~ contained 14 correct and 2 incorrect answers and the problem-solving transfer was answered correctly.~~. His subjective confidence rating had increased significantly (mean values on a 10-point scale: pre-test 6.4 → post-test 9.8).

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Figure 10: Example ~~for~~of conceptual change ~~by~~ in a 13-year-old boy from learning with the multimedia program ~~from a 12 year old boy~~.

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In a similar way, 42% of pupils and 49% of students in the experimental group drew a correct or partially correct representation of 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, were observed between the experimental and control ~~group could be established~~groups. 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~~completing the questionnaire was significantly higher in the experimental group.

~~Members of the experimental groups, in~~In particular pupils with little or no prior knowledge about groundwater, mostly improved their performance by working with the program. Similar results have been reported from other studies on the efficiency of multimedia learning programs (Unterbruner & 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~~their own reading and listening competency. On the other hand, learning in class is often adjusted to the, skills of an average ~~pupil's skills~~pupil. In addition, the program's interestingness and comprehensibility were rated very highly by the participants. ~~Particularly~~Especially learners with little prior knowledge benefit from comprehensible, coherent, and well-arranged texts, pictures, and animations (cf. Mayer, 2005, 2009).

~~The fact~~Furthermore, there is strong evidence that our multimedia program was successful in fostering the motivation for engaging with the topic of groundwater and increasing the "commitment" factor (Sinatra, 2005). In addition to the above-mentioned interestingness, most of the participants really enjoyed working with the program (see Table 4). Apparently,

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the multimedia learning program was able to enhance motivation, a component which is argued to be a key factor in promoting conceptual change (Dole & Sinatra, 1998; Sinatra, 2005; Heddy & Sinatra, 2013).

Nevertheless, it is evident that the conception of groundwater as an underground river or lake is a very “strong idea~~” is obvious. In about~~”. Approximately half of our pupils and students proved to be resistant ~~towards~~to 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~~into a classroom-based learning environment ~~in class~~ might enhance its effectiveness.

The fact that there was a greater amount of unclear drawings in the post-test (see Table 3) may be interpreted as an intermediate step in the process of conceptual reconstruction. These unclear drawings can be understood as indicators for a learning process that had started by working with the program but had not been completed in the sense of conceptual reconstruction. New knowledge may have been gained but not deeply understood. As mentioned above, the program’s incorporation into a classroom setting might also reduce the number of unclear drawings as a result of an intensified engagement with the topic.

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~~might 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~~drawings in assessments is a meaningful tool in order to ~~understand conceptions~~demonstrate an understanding of the conception of groundwater. The drawings ~~more often~~frequently revealed an incorrect or vague understanding of the groundwater system, and enabled a better understanding of the participants’ mental models of groundwater. Dickerson & Dawkins (2004) also found that students ~~could~~were able to state ideas about groundwater and the water cycle using correct terminology to describe incorrect thinking. Schwartz et al. (2011) ~~emphasize~~emphasized that students’ ability to conceptualize the groundwater system, as evidenced by ~~drawing~~their drawings, 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 a limiting factor, but rather a vague or missing conception of the ~~respective~~ topic. As many pupils' and students' drawings ~~show~~showed, 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.~~Figure 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~~Our data suggest that it is a powerful tool ~~to foster~~for promoting meaningful learning about groundwater in terms of both conceptual change and improved knowledge. ~~It~~The tool has proved to be ~~an~~ appropriate ~~tool~~ for pupils in class as well as students in teacher training.

Acknowledgements

The authors would like to express their gratitude to ~~the company~~ "*Ecovia – Landschaft, Wasser, Bildung*" for their permission to use their analog groundwater model "*Demokoffer Grundwasser*" for the visualization of groundwater dynamics in our multimedia learning program and in some of the screenshots presented here. We greatly appreciate the constructive suggestions made by two anonymous reviewers.

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Tab. 1

Table 1. Key questions in the designing process in regards to students' groundwater preconceptions (as far as reported in literature), scientific conceptions and multimedia implementation

Key questions	**Students' preconceptions**	**Scientific conceptions**	**Storyboard/multimedia designing**
What makes up the ground beneath our feet?	Not reported in literature	Layers consisting of rock material of various grain sizes (gravel, sand or clay) as result of erosion and sedimentation processes	Animation: virtual elevator Pictures of a drill hole; virtual examination of a drill core consisting of gravel, sand and clay Interactive Presentation: Soil profile Presentation and explanation of the scientific model (Ecovia)
What causes the layers in the ground?	Not reported in literature	Transport and sedimentation of rock material driven by surface runoff Flow velocity controls transport capacity and thus grain size distribution of the sediments	Interactive example of an alpine river
How can I envision groundwater?	GW as subterranean rivers, water veins or lakes, water stored in caves or cavities in the ground	GW fills and flows through pores between distinct grains of a coarse grained sedimentary layer (aquifer) Aquifer is limited by fine grained impermeable sediments or hard rocks (aquiclude)	Presentation of resp. confrontation with the scientifically correct conception of GW and the three most common misconceptions (subterranean rivers, lakes; caves)
How does rain become groundwater?	Vague notion of rainwater seeping into the ground Rainwater gathering in structures as can be seen on the earth's surface (see above)	Precipitation infiltrates into the soil, percolates through the pores of the permeable unsaturated zone and enters the aquifer – groundwater recharge	Demonstration experiment: permeability of gravel, sand and clay Interactive explanations of aquifer, aquiclude and pore space Animation: A raindrop on its way through the sediment layers
Why do I need to know about groundwater?	Not reported in literature	GW resources can be influenced by many activities of daily life. GW protection and the sustainable use requires founded understanding of hydrogeological processes	Application task: well drilling Case study about risks of contamination by deposition of refuse Animation: path of hazardous substances in the ground and consequences

Table 2: Research plan (EG = experimental group, CG = control group, T1 = pre-test, T2 = formative evaluation, T3 = post-test)

Group		Phase 1	Phase 2		Phase 3
		Start	3 weeks later	Immediately after learning program	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

Tab. ~~2~~3: 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

Tab. 34: Results of the formative evaluation (Likert-scale from 1= “strongly disagree” to 4 = “strongly agree”)

	Pupils		Students	
	x	sd	x	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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