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Media-assisted Learning in Science Education: An Interdisciplinary Approach to Hibernation and Energy Transfer

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ABSTRACT *A hypermedia learning environment for science education was developed to teach subject-integrative concepts of physics and biology. The program deals with "Life in winter," focussing on physical contexts and mammals' strategies for successful hibernation. In an attempt to support effective learning in such a complex knowledge domain, a variety of representations, such as, texts, pictures, films, animations or simulations, is used. Special guidelines for multimedia design were applied to take into account limitations of human mental processing capacities, to offer a high level of interactivity, and to stimulate relevant mental activities for learning by using a special workbook. In addition, the hypermedia environment was structured to combine concepts of physics and biology. The learning environment was implemented in ninth-grade classes. A significant increase in cognitive achievement was found with regard to both subject-specific and subject-integrative aspects. Questions related to retention and reasoning based on the material revealed significant gains in both categories. Relevant for inter-individual differences in learning outcomes were: general scientific expertise, and active and successful use of the workbook. Learners with lower scientific abilities were able to a certain extent, to compensate their shortcomings in scientific thinking by a conscientious use of the workbook. This finding supports arguments for adapting a guiding workbook to individual needs.*

KEY WORDS: *ICT, interdisciplinary learning, hypermedia learning, active learning, prior knowledge, achievement in science.*

Introduction

Many phenomena in nature are complex and require explanations using multiple perspectives. The acquisition of adequate concepts about nature requires the interconnection of several scientific disciplines. Such interdisciplinary learning requires the integration of multiple perspectives and information. Ballstaedt (1995) regarded this as the promotion of cross-linked thinking abilities. Bünder (2003) pointed to a series of reasoning and complex thinking abilities within problem-solving activities and inquiry tasks, when pupils were enrolled in interdisciplinary courses. Flexible and individual learning paths have to be encouraged, and tailored to individual needs and to prior knowledge. Interdisciplinary instruction and subject-integrated approaches always have to cope with complex matter or objectives. For instance, learners need to handle subject-specific aspects and procedures and to relate these to their existing knowledge. This may explain why only the more capable pupils are able to cope with so high demands.

Empirical data about pupils' achievement in interdisciplinary learning is scarce. Stevens, Wineburg, Herrenkohl, and Bell (2005) concluded that little is known about the effects of integrated school curricula, and even less about how "children across different grade levels and subject areas make sense of their teachers' attempts to merge different subjects and curricula" (p. 14).

Girwidz, Rubitzko, Schaal, and Bogner (2006, see present issue) described various multimedia features enabling a theory-guided development of multimedia application. The present study follows this approach by using multiple representations and interactivity as well as taking into consideration other psychological aspects, such as cognitive load. We briefly summarize the main ideas and outline several approaches dealing with multiple interconnections using a computer application. Hypermedia learning environments can be used as helpful tools for learning within complex domains (Spiro, Feltovich, Jacobson, & Coulson, 1992). Kerres (2000) and Weidenmann (2001) pointed to the importance of adequately structured learning material for facilitating knowledge construction. With self-directed access to multiple information units, pupils can arrange their own learning paths according to their individual needs.

However, self-directed learning process involving hypermedia may face the problem of disorientation: learners may be "lost in hyperspace." Tergan (2003) and Bannert (2003) referred to the potential benefits of spatial maps. Firstly, learners may effectively be supported by hierarchical maps, providing an overview of a learning environment; secondly, a graphical map can serve as a navigation tool, and, as an additional aid, indicate one's current location within the learning environment.

An important aspect of learning with multimedia is the mental impact of multiple representations. Ainsworth (1999) described three main functions of multiple representations (i) They may complement each other, (ii) representations may constrain each other, or (iii) they may foster a deeper understanding of a topic. Spiro and colleagues (1992) emphasized the general importance of multiple representations in order to foster cognitive flexibility. Focussing on the limitations of human working memory, the Cognitive Load Theory (Chandler & Sweller, 1991; Sweller, Merrienboër, & Paas, 1998) provides an important theoretical background for multimedia environments. One central idea of the theory is the reduction of irrelevant mental activity, and the enhancement of mental activity relevant for information processing and knowledge construction, whereby abilities of learners and specific features of the learning objective have to be taken into account (see for example, Kalyuga, Ayres, Chandler, & Sweller, 2003). Interactivity, a special feature of multimedia, can also enhance active learning. Different levels of interactivity can foster cognitive engagement (Ohl, 2001). For instance, simulations can stimulate learners to reflect about a task, test hypotheses, verify or falsify them, or to analyse results. These are cognitive processes of a higher level (Stoney & Oliver, 1998). However, not only learning material, but also various methodological approaches can foster active mental processing. For example, discovery–oriented learning may promote active knowledge construction, but it needs further support (Mayer, 2004). Learning to use simulations needs support in defining hypotheses and in planning a research process (de Jong & van Joolingen, 1998). Self-directed learning can be realised by permitting individual learning paths. Learners can determine the sequencing of information units according to their own needs. Feedback is important in order to organize goal-directed learning. In the context of this study, several tasks were offered to the learners to explore situations by conducting experiments, manipulating objects, and dealing with questions and ambiguities.

The specific hypermedia-learning environment "Life in Winter" deals with thermodynamics and hibernation. The empirical evaluation focuses on different dependencies of learning outcomes. Pupils' activities during the learning process were assessed, and correlations with their prior knowledge and previous achievement scores in science education were examined. The aim was to find out more details about an implementation of the learning environment under real educational conditions. Specific objectives of this study were (i) to monitor learners' skills and abilities in constructing subject-specific concepts from both a biology and a physics perspective, and in coping with interdisciplinary ideas, (ii) to assess the influence of pupils' prior knowledge and general achievement in science education on the learning outcome, and (iii) to monitor the impact of the activities that students were involved in.

Design and Procedures

A specific goal of the hypermedia-learning environment "Life in Winter" was to initiate an interdisciplinary learning process, and to provide multiple perspectives to enhance understanding of the hibernation phenomenon. Energy transfer, including convection, heat conduction, and radiation are relevant for hibernation strategies and the adaptation of mammals. This interconnection between physic's concepts and biological aspects was implemented within a suitable hypertext structure. Cognitive demands were adapted to ninth graders, because a physics knowledge background is required for understanding various biological adaptations. For example, a polar bear's fur is a specific adaptation to cope with both convection and thermal radiation. The necessary knowledge is developed in a step-by-step process. To anchor interdisciplinary connections, animations help students to relate the new information to a realistic frame of reference. They also serve as advanced organizers at the beginning of a learning unit.

Learning units are presented in a non-linear hypermedia data base. To facilitate orientation in hypertext, navigation tools and support were provided. Figure 1 shows part of a graphical overview and helps to structure information. Figure 2 presents illustrated maps for subunits, using text and pictures that underline interdisciplinary connections.

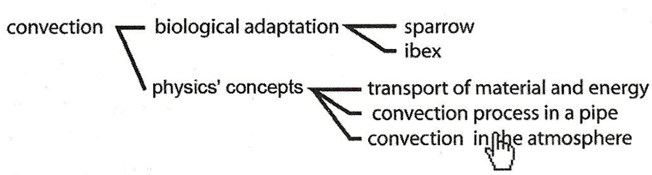


Figure 1. Part of the Structured Map

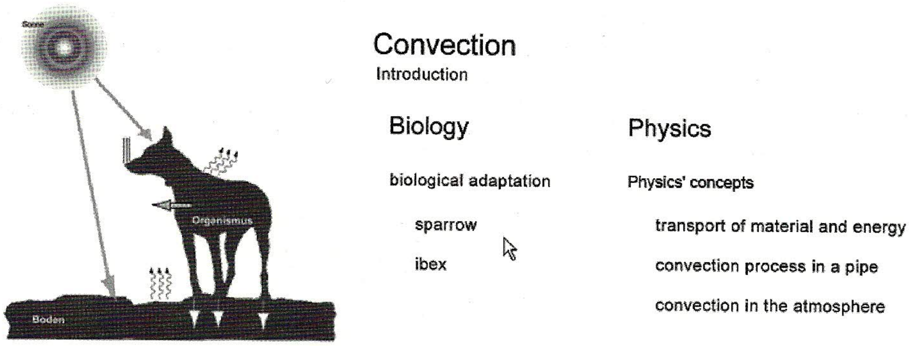


Figure 2. Starting Screen for a Sub-unit (Indicating the Interdisciplinary Structure)

Another specific strength of multimedia is the provision of several representations in combination. For example, video clips were combined with animations, as shown in Figure 3. On the left, a frame from a movie shows a real experiment, while simultaneously on the right an animation illustrates the relevant thermodynamics. Both presentations deal with thermodynamic convection, but employ different symbols. Structure and position help to identify corresponding elements. Additionally, various reference marks, like the burners, have a very similar appearance. While the video clip makes the streaming fluid visible (by using aluminium glitter as an indicator), the animation illustrates the corresponding invisible processes, such as, heat transmission and increase of volume, that cause the water to flow through the tube. This approach is intended to link realistic processes to models and more abstract concepts.

Figure 3. Representations Can Complement Each Other or Foster a Deeper Understanding

However, any processing of multiple representations requires mental resources. Therefore, we implemented some findings from cognitive load theory to take into account the scarcity of mental resources. For example, the information was divided into small sequences. Units were placed on the screen without a scrollbar, consistently presenting together what belongs together. The concept of contiguity was applied both to written text and pictures, and to animations with verbal text. Applications with strong interactivity were integrated in order to stimulate the mental activities necessary for learning. Figure 4 presents an example from the work with a simulated virtual mammal. A learner has to adapt parameters like habitat, fur, and body size, in order to prepare the "mammal" for successful hibernation. These three important variables for successful hibernation can be varied and as a consequence allow the animal to survive in winter.

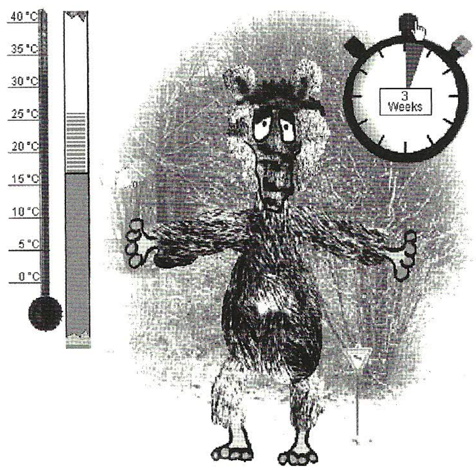


Figure 4. The Simulation of a Mammal that Has to Survive During Winter

To support goal-oriented active learning, an additional external workbook was used to provide appropriate guidance through the learning environment. Questions helped pupils to extract specific information from the hypermedia learning environment. For instance, animals had to be observed in films, or parameters had to be varied in simulations to find particular values for spread sheets or charts.

Empirical Methodology

Participants in this study were ninth graders at junior high school of intermediate abilities (Realschule). Altogether, 116 pupils with an age between 15 and 16 years participated in the study. The time line of the study and the measurement of pupils' learning are detailed in Figure 5.

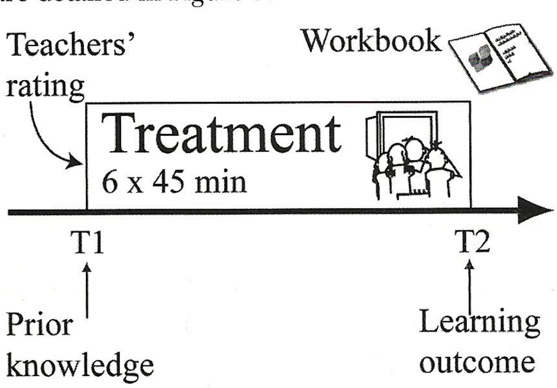


Figure 5. Study Design and Time Line

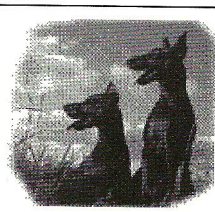
Before instruction, pupils' general achievement in science education was assessed by the teacher. The intervention started with a pre-test (T-1) measuring domain-specific prior knowledge. Pupils worked in pairs (dyads) with one notebook for each team and were guided through the learning environment by tasks in the workbook. Each dyad could follow its own pacing. The learning unit was completed within three days and consisted of six lessons. No further instruction or teacher support was provided. Immediately after the instruction, the pupils were administered a post-test (T_2). Identical questionnaires, consisting of 28 items with a maximum score of 36 in total were used to measure prior knowledge (T_1) and the learning outcomes (T_2). These questionnaires used a class test format familiar to pupils. Dichotomous and non-ambiguous item formats were employed to quantify the learning outcomes (see Table 1 for an example). Additionally, semi-open questions were applied to measure the interdisciplinary subject-integrated learning outcomes and reasoning with the material (Table 2). All semi-open items were analysed using "Qualitative Content Analysis" (Mayring, 2003). Data analysis comprised two main aspects: (i) A subject-specific classification and (ii) a classification according to the qualitative aspects of learning.

The subject-specific classification involved three sets of items, one quantifying specific knowledge in Biology, one in physics, and one for interdisciplinary integration (see Table 1 and 2). Each sub-domain yielded 12 points at most (a maximum of 36 points was possible). Qualitative aspects of multimedia learning were categorized with regard both to retention of information and to reasoning with the material (see also Mayer, 1997). Thirteen items were used for measuring retention and twenty three for reasoning with the material.

Table 1
An Example for Multiple-choice Item Focussing on Physics Learning

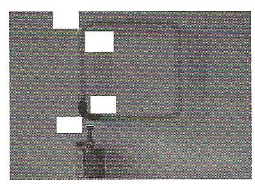
	What is the heat flow through a slab of granite?	6 J/s	☐
		12 J/s	☐
	The heat conductivity of granite is $2 \frac{J}{m.K.s.}$	3 J/s	☐
	The area is 1 m^2.	1,33 J/s	☐
	The layer thickness is 2 m.	0,75 J/s	☐
	The temperature difference is 3 K.		

Table 2
An Example for Semi-open Item focussing on Interdisciplinary Learning

	
Homoiothermic animals emit energy. When both animals were photographed in a cold environment with a thermo-sensitive camera, which animal will be better identified by a thermal image – the polar bear or the dog? Explain.	

Additionally, pupils' general achievement in science education (*pase*) was monitored, as well as the quality and intensity of the working process (*wp*). The first included pupils' previous achievement in written tests, oral skills, and general engagement in biology and physics (*pase:* pupils' general achievement in science education). According to the German grading system, "1" represented high achievement and "5" low achievement. We applied a median split in order to survey two sub-samples: High (*pase+*) and low achievers (*pase-*). The variable *wp* arose from the assessment of a pupil's workbook (quality and an intensity of the individual working process). A variety of multiple-choice tests, fill-in-texts, and allocation tasks were used, as shown in Table 3. Additionally, semi-open formats were used. In total, 18 items (maximum score 30) were analysed. Again, a median split provided two sub samples, that is, pupils with high quality and intensity of the working process (*wp+*), and the ones with low quality and intensity of the working process (*wp-*).

Table 3
Selected Examples of Workbook Items

Allocate the letters to the blank squares in the picture. a) Water emits energy b) Energy is transmitted to the water. c) Temperature of the water decreases. d) Temperature of the water increases.	
Adaptation to cold habitats Mark in the drawing the polar bear's adaptations to his habitat. Describe the physical background in short words.	

Results

Interdisciplinary Learning and Subject-specific Learning

Pupils in general improved their cognitive achievement both in subject-specific and in subject-integrative learning. Figures 6 and 7 indicate higher achievement scores after instruction. The total achievement scores were normally distributed. However, some subscales were not; hence, for reasons of consistency non-parametric statistics were applied for identifying differences between pre- and post-test achievement. Individual achievement scores shifted towards higher scores from pre- to post-test. Achievement scores for biology, physics, and subject-integrative ideas (see Figure 7). Wilcoxon-Tests for paired-samples were used for data analyses of the three sub-scores. The results are listed in Table 4.

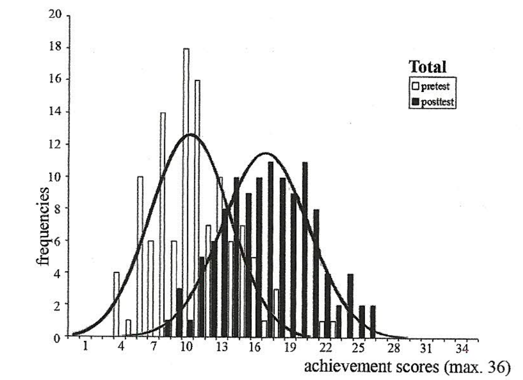


Figure 6. Distribution of Achievement Scores (responses to all items)

a)

b)

c)

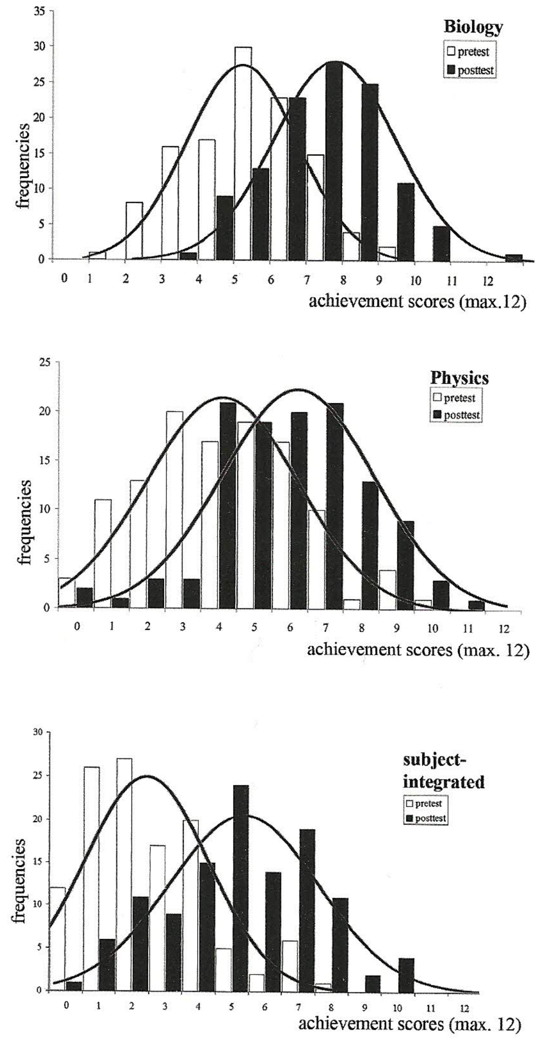


Figure 7. Distribution of Achievement Scores in a) Biology, b) Physics, and c) Interdisciplinary Items.

Table 4
Paired-samples Wilcoxon-Test Learning Outcomes in Biology , Physics and Interdisciplinary Contents (N = 116).

N = 116	R+	R-	z	sig. (2-tailed)
Biology	54.5	29.2	7.7	< .001
Physics	54.6	33.3	6.9	< .001
Subject-integrative	59.2	26.0	7.9	< .001
Total	59.6	10.1	8.9	< .001

Retention and Reasoning with the Material

The quality of learning and the applicability of knowledge were examined by comparing the retention and reasoning sub-scores of the pre- and post-tests. Wilcoxon-Tests for paired-samples were used for data analyses of the two sub-scores. The results are listed in Table 5. Learners yielded significant learning gains with regard to both retention and reasoning (p. < 0.001) (see Figure 8 and Table 5).

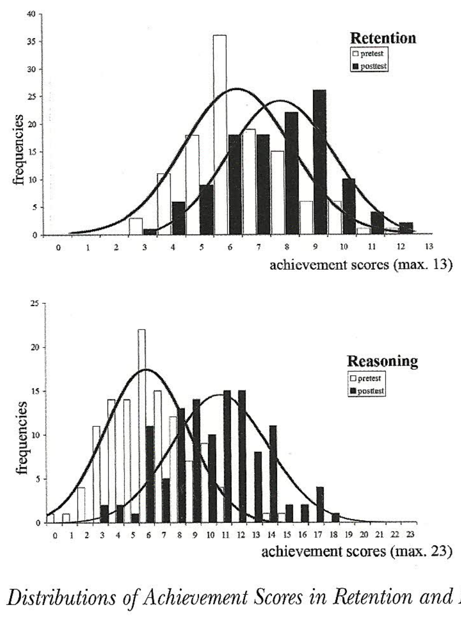


Figure 8. Distributions of Achievement Scores in Retention and Reasoning

Table 5
Paired-samples Wilcoxon-Test: Learning Outcome Retention and Reasoning.

N = 116	R+	R-	z	(2-tailed)
Retention	59.2	26.4	8.0	< .001
Reasoning	58.3	18.5	8.5	< .001

We also examined whether the data showed evidence of the influence of pupils' achievement and working. In detail, three hypotheses were tested: (i) Pupils' general achievement in science education (variable *pase*) has an influence on learning. Better general achievement in science education leads to improved learning. (ii) Quality and intensity of the working process (variable *wp*) are relevant factors. A more effective working on the tasks of the workbook leads to greater improvement of knowledge. (iii) An interaction effect between *pase* and *wp* can be assumed, meaning that pupils with better achievement in science education are also more effective in their work, thus, not just increasing but multiplying their learning outcome. Prior knowledge was treated as a covariate for analysis of variance (see Table 6).

Table 6
ANCOVA with Prior Knowledge as the Covariate and Quality of Working (wp) and Pupils' General Achievement in Science Education (pase) as Factors, with Learning Gain (T2-T1) as the Dependent Variable.

Source	Square-sum (Typ III)	df	Mean of Squares	F	α
Corrected Model	498 *	4	124	10.4	< .001
Constant Term	1550	1	1550	129	< .001
Prior knowledge	467	1	467	39.0	< .001
Quality of working (*wp*)	53.4	1	53.4	4.46	.037
Pupils achievement in science education (*pase*)	107	1	107	8.89	< .001
Interaction *pase - wp*	11.9	1	11.9	.993	.321
Total	6333	116			
Correct. Total Variance	1840	115			

* *R*-square = .311 (corrected *R*-square = .286)

The variables "pase" and "*wp*" appeared to be significant factors for the learning results. The main effects confirmed hypotheses (i) and (ii) This means, that strong learners in science education ($pase^{+}$) achieved significant better learning results than weak learners ($\underline{p}$. < .005). Furthermore, learners of the wp^{+} -group achieved significantly better compared to the wp^{-} group ($\underline{p}$. < .05), independent of their *pase* scores. Hypothesis (iii) was rejected. There was no statistically significant interaction effect between *pase* and *wp* ($\underline{p}$. > .32).

Discussion

Learners' abilities to construct subject-specific concepts and to integrate interdisciplinary ideas increased. The participants developed a consistent knowledge representation for Biology, Physics, and interdisciplinary contents, especially concepts about animals' adaptation and thermodynamic phenomena. In our approach, new knowledge was properly available both for retention and for reasoning tasks. In general, pupils profited from the hypermedia learning environment. This might be an indication for the adequate design of our learning environment. Learners were able to find relevant information in the database, to relate the different kinds of representation to each other and to cope with the non-linear hypermedia system. Altogether, sufficient mental resources were available to process actively the information presented in the learning environment.

Almost all students showed a clear shift in all subscales. Higher achievement was even attained by learners with higher grades in science education (*pase+*). Individual domain-specific prior knowledge was also a powerful factor for successful knowledge acquisition. This is quite in line with publications that have examined the influence of prior knowledge on the learning outcome (Dochy *et al.*, 1999; Weinert & Helmke, 1998). Concerning learning with digital media, Gerdes (1997), for instance, reported higher learning outcomes when non-linear hypertexts were provided to pupils with high prior knowledge compared to pupils with lower prior knowledge. Mayer and Moreno (2003) identified pre-training effects within learning processes with multimedia and reported a better transfer effect and a reduction of individual cognitive load effects when basic knowledge was well established.

Scientific literacy is a well-known important predictor for the success of instructional procedures in science education (Bybee, 1997). The learning environment "Life in Winter" copes with requirements for the training of basic skills in scientific thinking, such as raising questions, formulating hypotheses, predicting, controlling variables, and interpreting data. In addition to pupils' scientific skills and prior knowledge, both the quality and the intensity of the working process were identified as important factors for successful learning. There was no interaction effect between general achievement in science education, and quality and intensity of working. Provided that they worked adequately on the tasks given in the workbook, even not so gifted students achieved satisfactory learning results. Altogether 65 % of the tasks in the workbook were solved correctly. Pointing to the correlation "the better the activation, the better the result in learning outcome," Bünder (2003) successfully provided so-called *encouragement scripts* to motivate learners during the learning process. Altogether, providing specific support for an adequate working process seems to be very important. Taking these aspects into account, it can be assumed that adequate design of learning material is important and should be based on learners' abilities. Furthermore, educational hypermedia learning environments should follow criteria derived form theories of multi- and hyper-media (Girwidz et al., this issue).

Outlook

Although any enhancement of pupils' general achievement in science education is a long-term requirement, it might be helpful to employ a variety of teaching methods. Learning in "virtual" environments should be complemented with "real" experiments in order to promote pupils' abilities and skills in planning, realising and verifying the results. In addition, pupils may have to cope with measurement inaccuracies in hands-on lab work, while computer simulations reflect quite precise patterns. Enhancement of mental activities may support a learner in structuring the knowledge domain by him/herself. Tergan (2003) referred to the potential of concept mapping for supporting of individual knowledge management in e-learning scenarios. Further help could be the guidance provided by an external workbook.

The use of intelligent learning materials may be another promising approach. Based on users' expertise, information is presented in an adequate way. Leutner (2002) described various functions of such adaptive multimedia materials. Among them were learning materials taking into account individual preferences for learning.

Depending on prior knowledge, learning materials could be presented in a step-by-step fashion for novice learners, while a highly interconnected and interdisciplinary version may promote knowledge construction for learners with more expertise. In the present study, an experimental research design was used to gain information about the hypermedia learning environment "Life in Winter" and its impact on learning in science education. Pupils worked without any further educational support of the teacher. The next step should be the implementation of the hypermedia learning environment into a regular teaching unit by using additional real experiments, and other authentic and non-virtual methods of instruction. A question for forthcoming studies will be how such a combination can be implemented to provide further enrichment for learning.

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