
Volume 25, Issue 4, July 2009
ISSN 0747-5632
ELSEVIER
COMPUTERS IN HUMAN BEHAVIOR
Robert D. Tennyson, Editor
Paul Kirschner, Associate Editor
Jen-Her Wu, Associate Editor
Including the Special Issue
The Use of Support Devices in Electronic Learning Environments
Guest Editors
Geraldine Clarebout, Holger Horz and Jan Elen

Computers in Human Behavior 25 (2009) 811–817

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

The role of graphical and text based argumentation tools in hypermedia learning

Joerg Zumbach *

University of Salzburg, Hellbrunner Strasse 34, 5020 Salzburg, Austria

ARTICLE INFO

Article history:
Available online 6 August 2008

ABSTRACT

In this study, the effects of visualization tools on argumentation skills, knowledge acquisition, and motivation during learning with a hypermedia learning environment were examined. Participants in this experiment had to complete an argumentation task on environmental issues by using a hypermedia learning environment as resource. In one condition, participants were provided with a graphical mind mapping tool in order to complete an argumentation task. In a second condition, a two-columned text editor has been given. A control group received no argumentation task and no corresponding support device. Results suggest that a graphical argumentation support device can enhance learners' motivation, but has no influence on knowledge acquisition or quality of arguments, whereas both argumentation support devices led to superior results compared to the control group. Overall, results reveal that the assignment of an argumentation task to hypermedia learning environments was an effective instructional strategy that led to enhanced knowledge acquisition compared to learning without an argumentation task.

1. Introduction

In hypermedia learning environments, the use of external representations is an established way to support learners in self-regulated learning with digital information media (e.g., Jonassen, 1996; Jonassen, Beissner, & Yacci, 1993). There are several functions these support devices address, like providing overviews, restructuring content or fostering of elaboration processes in order to enhance knowledge acquisition. In this research, we examine the role of external representations as support devices for argumentation tasks as a way to enhance and deepen learning with non-linear information media, and to avoid learners to conduct a rather shallow information processing. Providing an argumentation task is one possible strategy for enhancing reflection processes and Critical Thinking (Ennis, 1987; Voss & Means, 1991). For visualization of arguments within computer-based learning environments, the use of graphic tools or concept mapping software is very common (for an overview see Jonassen et al., 1993). Possible functions of these tools may be to create overviews, to restructure content or to reorganize, deepen or elaborate a subject's knowledge.

Meanwhile, several software tools within the area of concept mapping (or very often synonymously used "mind mapping") have spread over the market. A major problem from a scientific perspective seems to be a theoretical rationale for the use of such approaches. The mentioned synonymous use of mind mapping and concept mapping (cf. Mietzel, 2001) is one indicator for a rather evidence-based instead of a theory-based approach to the use of graphical tools for externalizing knowledge structures and ideas. Another indicator for missing theoretical considerations is the degree of freedom learners are confronted with. While some approaches provide ontologies and methods for structuring nodes and labeling edges other ones just provide customizable nodes and edges (e.g., Gaines & Shaw, 1995; Jonassen et al., 1993; Tan, 2000). Due to this heterogeneity, it is difficult to provide a concise definition of "mind mapping". Tan (2000) defines such approaches as two dimensional external representations of learners' mental concepts. Learners reveal these concepts as well as relationships amongst them by illustrating the cognitive structure of a person's domain knowledge. Mind maps are meanwhile used in a variety of disciplines to support learners in constructing, as well as reflecting, their knowledge (Gaines & Shaw, 1995). A more restricted method seems to be represented by the term "concept mapping" which is mostly traced back to Ausubel's theory of the mind (e.g., Ausubel, 1963; Tergan, 1986). Under this perspective, concept mapping represents a hierarchical clustering of super and under ordinate central concepts within a certain domain. Nevertheless, in educational practice concept and mind mapping are commonly used synonymously (cf. Åhlberg, 2004). While concept mapping has, in its origins, a theoretical foundation, the broader field of mind mapping approaches somehow misses these considerations.

In the following, an analysis of cognitive relevant theories for mind mapping approaches is provided. Thereby, some basic concepts as well as some basic misconceptions about human information processing are explained providing evidence that mental structures cannot be simply externalized by graphical representation. In addition, following an applied approach, a study is conduced showing the benefits of external tool support by using

* Corresponding author. Tel.: +43 (0) 662 8044 5801.
E-mail address: joerg.zumbach@sbg.ac.at.

0747-5632/$ - see front matter
doi:10.1016/j.chb.2008.07.005

an argumentation task for fostering learning with a hypermedia learning environment.

2. Theoretical background of mind mapping approaches

Mind mapping as a kind of *Cognitive Tool* are mainly designed in order to fulfill several functions and tasks. Mandl and Fischer (2000) differentiate between a psychometric perspective (e.g., in order to assess a person's knowledge structure) from a cognitive and applied educational point of view (e.g., in order to support learning processes). Under this educational perspective, such mapping techniques can contribute to fostering and monitoring metacognitive processes (Fischer, 1998) but also to visualize a person's knowledge structure with its underlying basic concepts and – if necessary – to indicate, initiate and support a conceptual change (cf. Bernd, Hippchen, Jüngst, & Strittmatter, 2000). Thus, functions of diagnosis and interventions merge.

According to Mandl and Fischer (2000), diagnosis and modeling of learners' knowledge structures are a basic application area of mapping techniques. The graphical representation of concepts and their relations help to conclude on underlying cognitive structures and their changes. Examples here are provided by Xiufeng (2004) who was able to show a conceptual change in basic chemistry using a concept mapping approach. Similarly, Farrell (2001) showed conceptual change related to basic mechanisms of teaching in pre service teacher education assessed by concept maps.

Basic theories that support the idea of knowledge structures are for example provided by Collins and Quillian (1969), Collins and Loftus (1975), and Norman and Rumelhart (1975) or Anderson (1983). More elaborated approaches on the structure of knowledge and diagnostic approaches are contributed for instance by Kintsch (1974), Graesser (1981), and Diekhoff, Brown, and Dansereau (1981).

All these approaches are based on a semantic network metaphor of our mind and conclude a storage metaphor based on propositions and their associations. Nevertheless, it remains more than questionable, if mind mapping is an adequate diagnostic approach to visualize such knowledge structures. First, the storage of knowledge is an implicit process while mind mapping is an explicit process that needs conscious information processing. Thus, the implicit knowledge structure might or cannot be externalized and remains hidden (cf. Berry, 1987). Second, the granularity of propositions is commonly neglected. Mind mapping nodes often contain more than one element of a proposition or might include several propositions. Third, the relationship between mind and concept mapping nodes do not reflect the relationship of propositions within a semantic network. Strength of associations and procedures can hardly, or not, be externalized within a mind mapping approach or tool.

Nevertheless, mind mapping seems to have some benefits on learning processes (e.g., Chularut & DeBacker, 2004; Okebukola, 1990) and outcomes, but why? A major rationale for the use of mapping techniques remains in the externalization process itself. By externalizing and restructuring of one's knowledge, a deeper elaboration of the content that has to be learned could be fostered. According to the levels of processing-approach (Craik & Lockhart, 1972) a deeper mental effort and, thus processing level could be initiated – especially when learning from text (cf. Schnotz, 1988). But does the more active involvement of learners justify the popularity of mind mapping (which is evident regarding the amount of software tools that is available; Google lists here over 3 million websites referring to mind mapping software), or is it equivalent with other methods like summarizing, draining notes or questioning in order to foster elaboration?

A possible benefit of mapping seems to be the structure representation that enables learners to draw inferences and to establish a semi-spatial information map. Thus, learners might be supported by navigating a kind of information space using their own mind maps as navigational tool (cf. Jonassen et al., 1993). No advantage of mapping could be expected from a dual coding perspective (cf. Paivio, 1978). As concept mapping does not contain visual information that interacts with verbal information or could be represented verbally and visually either (cf. Mayer, 2005), any advantage over text-based approaches seems not justifiable (but is still postulated, e.g., by Willis & Miertschin, 2006). Nevertheless, it is rather the active (and not passive and shallow way of) information processing a learner has to adopt by developing a concept or mind map that seems to drive the learning process. Following Mayer's SOI-model (2005) the semi-graphical representation might contribute to organization of a pictorial-spatial mental model and a verbal model of information that is currently externalized by a learner. In addition, mind mapping might here contribute to integrate new information into long-term memory. Thus, it is not astonishing that concept maps have become an important tool in order to support learning with printed text but also with digital information media (e.g., Jonassen & Reeves, 1996; Willis & Miertschin, 2006).

3. Mapping techniques as learning tool in digital learning environments and computer supported argumentation

Mapping techniques are not restricted to paper and pencil form. They are rather popular as software programs (e.g., Kozma, 1992; Tergan, 2006). Here, mind mapping software can be used as cognitive tools in order to enhance interactivity in computer-based learning environments. Cognitive tools can have different functions, not only to support learners but also to assess knowledge structures. The major rationale for using and implementing cognitive tools is providing the learner support throughout the learning process (Jonassen & Reeves, 1996). The major features of concept or mind mapping are here to support learners in knowledge acquisition, in use of learning strategies, as navigational aid in hypermedia learning environments and for support of information retrieval in hypermedia learning (e.g., Bruillard & Baron, 2000; Kommers & Lanzing, 1997; MacKinnon, 2006; Tergan, 2006). Within controlled experiments comparing hypermedia learning with and without support by concept mapping tasks the use of the cognitive tool or support device has been shown to lead to increased learning performance as compared to control groups without such a tool support (Tergan, 2006; note that the term "tool" is very broad and here used in sense of a supportive help device that enhances the learning process and, thus, its outcomes). Nevertheless, broader research on concept mapping use provides rather a heterogeneous picture: Some studies were able to show advantages of mind mapping approaches compared to control groups without a support device or other interventions (e.g., Chularut & DeBacker, 2004; Okebukola, 1990; Scandett, 2006; Uzuntiryaki & Geban, 2005). On contrary, some studies show no differences between the use of concept mapping and other meaningful instructional strategies (e.g., Heinze-Fry & Novak, 1990) or even disadvantages (Stensvold & Wilson, 1990). For example, in the study described by Stensvold and Wilson (1990), High school students in a science classroom were examined. While in an experimental condition, learners had to conduct concept mapping tasks, control group participants were not assigned to such tasks but had to perform the same learning tasks as students within the experimental group. In their analysis, Stensvold and Wilson found that the concept mapping task was rather unbeneficial related to learning outcomes. Possible explanation might here have been an inappropriate integration of the concept mapping task into the science lessons and, thus, rather an inhibiting effect of the additional task (learners might have been overstrained or – in terms of Cognitive

Load Theory – the Extraneous Cognitive Load might have been increased by providing a dual-task situation; e.g., Sweller, 2005). Nevertheless, a recent meta-analysis on the use of concept maps has shown evidence that in most studies using concept mapping as instructional strategy increased knowledge retention compared to control groups (Nesbit & Adesope, 2006). Nevertheless, Nesbit and Adesope (2006) also report that the heterogeneity of instructional conditions, settings, and applied methodology of what is regarded as mind or concept mapping is rather huge. Thus, interpretation from comparison of different studies has to be conducted with care.

4. How to support learning with concept mapping? open research questions and hypotheses

While common concept mapping has various degrees of freedom in use of concept node types or labeling of edges, there are several approaches of using ontologies in order to script and, thus, support learners (e.g., the IBIS-notation, Conklin & Begemann, 1989; see also Buckingham Shum, 1996). Especially the provision of an argumentation task conducted by means of mind mapping software seems to support learners' critical thinking abilities (cf. Ennis, 1987) and informal reasoning (King, 1995; Voss & Means, 1991). Although the use of mind mapping as cognitive tool for enhancing learning seems to be obviously advantageous, the role of the interface remains unclear. In order to support learners and to reduce extraneous cognitive load (Sweller, 2005) it might be useful to reduce the degrees of freedom in designing concept maps. Especially in argumentation tasks it could be beneficial to provide simpler but task adequate devices (e.g. text-based tools instead of semi-graphical structures) in order to reduce learners' extraneous cognitive load but to maintain Germane cognitive load as supported by the argumentation task.

Besides cognitive issues, concept or mind mapping tools might have a positive impact on motivation. They provide a relevant and meaningful learning task and – in case of a successful progress, can satisfy learners by feeding back their learning progress, make the learning process become more interesting and, thus, might involve learners into a flow experience (following the terminology of Csíkszentmihályi, 1990). Thus, intrinsic learning motivation could be fostered (cf. Keller, 1983; Rheinberg, Vollmeyer, & Engeser, 2003). Based upon these considerations, the following hypotheses can be deducted:

Hypothesis 1. A text-based argumentation editor is better task-suited than a mind mapping argumentation approach. The text-based tool should lead to decreased extraneous cognitive load and, thus, to increased learning and task performance. Both argumentation tasks should be advantageous compared to a control group by supporting Germane cognitive load. The semi-graphical tool should be more complex in handling and, thus, lead to a higher level of extraneous cognitive load than a simpler text-based tool. Thus, learning outcomes should be highest with a text-based tool, followed by a semi-graphical mind mapping tool and lowest within the control group.

Hypothesis 2. A mind mapping approach should be perceived more demanding but likewise also more motivating in conducting an argumentation task and, thus, should increase learners' intrinsic motivation. Nevertheless, to high task requirements leading to cognitive overload might also lead to decreased motivation. In general, a curvilinear relationship could be assumed while here only a bipolar relationship between task requirements and motivation is examined.

5. Method

In order to test the hypothesis we used a one factor design with three conditions of the independent variable. In one condition, participants were assigned to conduct an argumentation task during information retrieval within a hypermedia learning environment with a graphical mind mapping tool. In a second condition, participants had to conduct the same argumentation task within a two-columned text editor. A control group had no argumentation task during hypermedia navigation. Participants in control group condition were requested to learn the material without a text-based or concept mapping based argumentation task in order to master the post test as good as possible.

5.1. Participants

Sixty university students (43 women and 17 men, mean age = 26.4 years, SD = 5.34) that were randomly assigned to one of the three treatment conditions volunteered to participate. Volunteers either were paid for their participation or received a study related certificate.

5.2. Materials

The learning material for all participants was a hypermedia learning program on "Marine pollution by oil" (in German). The program consisted out of 172 associatively linked nodes. The topic was chosen, because it allows multiple perspective views on environmental issues related to human and natural pollution of the sea. Thus, it provides an ill-structured basis for argumentation processes that consider several aspects of environmental issues. At the beginning of each experiment, participants were randomly assigned to one of the three conditions and introduced to the program, followed by a pre-test. In the pre-test a motivational questionnaire and a concept-mapping knowledge test were conducted. The motivational questionnaire was a five item Likert scale (with values from a minimum of 1 to a maximum of 5) designed to assess learners' intrinsic motivation. It was developed based on the concept of interest (items 1, 2 and 4) and the state experience of flow (items 3 and 5; cf. Rheinberg et al., 2003) assuming that both experiences would represent intrinsic motivation as a state representation in its most direct manner. The questions (translated) applied here were (1) How interesting is the program and its topic? (2) How fascinating is the program/topic? (3) How boring is the program and its topic? (4) How much fun does the task/program make? (5) How much would you like to continue with the program/task? The scale had (after recoding inverted items) an internal consistency of Cronbach's Alpha = 0.87.

The concept-mapping pre-test was designed to assess participants' structural knowledge using a software program (developed with ToolBook; see Fig. 1 for an example screen; cf. Bonato, 1990; Dansereau et al., 1979; Scheele & Groeben, 1984). Subjects were given twenty central concepts out of the learning program, which they had to relate to each other by means of links. Each link was depicting one of the following semantic relationships: (1) is an example for (hierarchical structure); (2) Results in (chain structure); (3) Help through (cluster), and (4) In contradiction to (cluster). In order to evaluate the concept-maps (following Bonato, 1990), an expert concept map was constructed, capturing all important relations between the twenty concepts. Then for each subjects' concept map an overlay index was calculated by coding each exact match between the relations of the subjects' and the experts' map with a value of one, and each acceptable, but not quite correct match with a value of 0.5. No penalty was administered for false relations.

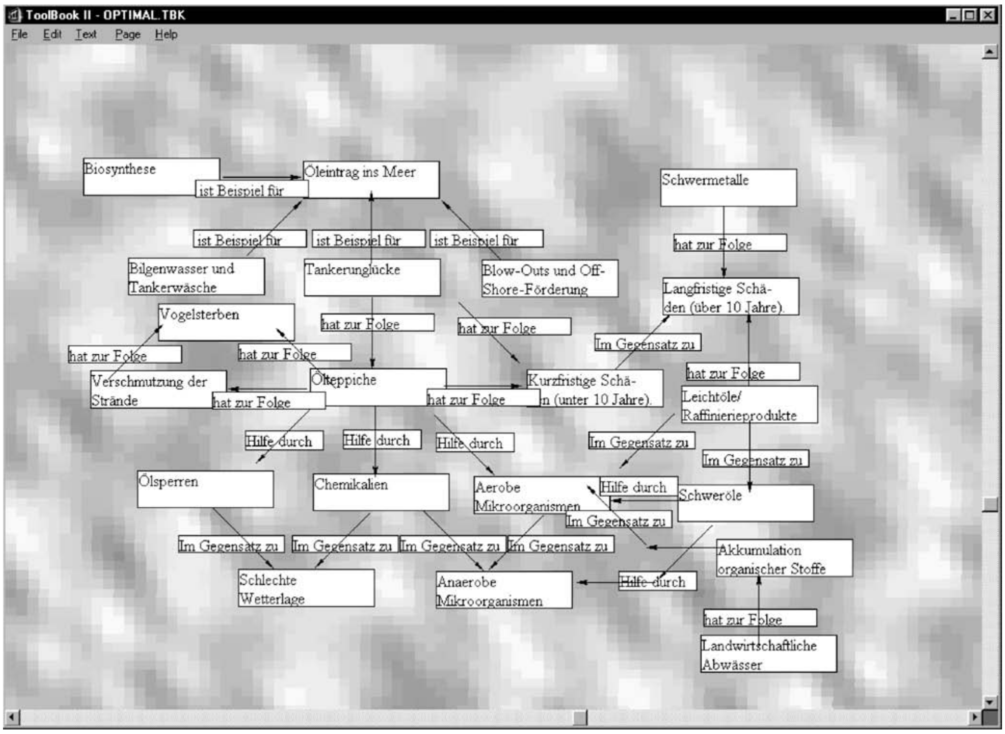

Fig. 1. Example for an expert map assessing structural knowledge.

The actual experimental task in the two argumentation conditions was the argumentative analysis of the following statement: "Oil pollution is no danger to marine ecosystems in the long run. After decades of intensive research there were no obvious cues for long term damage to flora and fauna caused by oil pollution." Subjects were asked to look for relevant information in the underlying hypertext system and to use the given argumentation editors. Participants in the control group were confronted with the task to inform themselves about marine pollution by means of the hypermedia program.

In the text-editor condition a tool using an input formula with two columns, one for pro and one for contra arguments (see Fig. 2, left) was given to the learners. The complementary graphic based mind mapping tool was commercial software that allowed participants to draw notes and to connect them with arrows. Participants were required to mark cards with a "+" or a "−" in order to mark a pro or a contra statement (see Fig. 2, right).

In both argumentation conditions, participants' statements were analyzed quantitatively (number of statements), but also regarding their quality, their content and their relationship to other arguments. For the analysis of arguments, categories developed in problem solving research considering informal reasoning by focusing on enthymemes were used (i.e., incomplete arguments; Voss, Blais, Means, Greene, & Ahwesh, 1989; Voss & Means, 1991). Each single statement was rated on each of the categories Acceptability, Relevance, Emotionality and Distinctiveness (from a minimum of 1 to a maximum of 5). Inter-rater agreement among two raters was computed for 36 randomly chosen arguments from both argumentation conditions showing a satisfying mean intra-class-correlation-coefficient of $r_k = 0.84$.

The experiment ended with the post-test where the same instruments as in the pre-test were administered (motivational questionnaire and the concept mapping task for assessing structural knowledge). Time on task was constant for all three conditions with one hour and thirty-five minutes.

6. Results

6.1. Motivation

An ANOVA with repeated measurement between pre- and post-test revealed a significant main effect for the time of measurement, $F(1, 57) = 12.71$, $p = 0.001$; $\eta^2 = 0.18$, as well as a significant interaction between time of measurement and the independent variable, $F(1, 57) = 5.76$, $p = 0.005$; $\eta^2 = 0.17$. While participants' motivation decreased in the text editor condition and more in the control

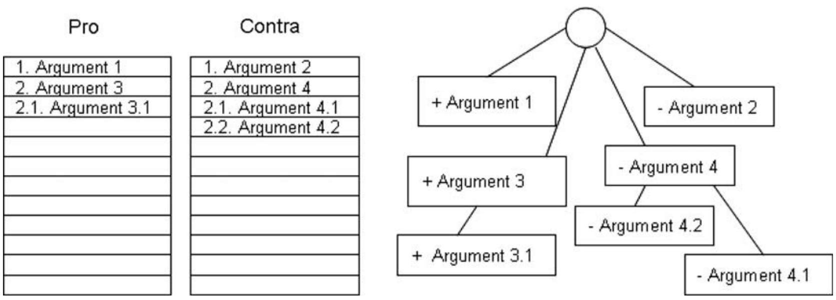

Fig. 2. Argumentation editors.

group, the motivation within the graphic editor group increased during the treatment (see Fig. 3 and Table 1). Concerning the post-test a Scheffe test computes only a significant difference between control group and graphic editor ($p < 0.05$).

6.2. Structural knowledge

An ANOVA with repeated measurement between pre- and post-test revealed a significant main effect for the time of measurement, $F(1, 57) = 104.88$, $p < 0.001$; $\eta^2 = 0.65$, as well as a significant interaction between time of measurement and the independent variable, $F(1, 57) = 3.97$, $p = 0.024$; $\eta^2 = 0.12$. All three groups had a significant increase in test performance but do not differ significantly in post-test. An ANCOVA using pre test performance as covariate and post test performance as dependant variable reveals a significant influence of prior knowledge, $F(1, 56) = 88.58$, $p < 0.001$; $\eta^2 = 0.61$, and a significant difference between the groups, $F(2, 56) = 4.10$, $p = 0.02$; $\eta^2 = 0.13$. A LSD-test reveals that both experimental groups led to better post test performance than the control group ($p < 0.05$) (see Fig. 4 and Table 1).

6.3. Quantity and quality of argumentation

A MANOVA was computed on the number of arguments, acceptability, relevance emotionality, distinctiveness as well the balance between pro and contra arguments (as computed from Formula 1). There was a significant main effect, $F(6, 33) = 2.11$, $p = 0.04$ (one-sided, Wilk's Lambda); $\eta^2 = 0.28$. A test for between-subjects effects revealed a significant difference in balance between pro and contra arguments, $F(1, 38) = 6.91$, $p = 0.012$; $\eta^2 = 0.15$, with the text editor leading to a better balance (i.e., here: lower scores; see Table 1 for means and standard deviations of all dependent measures).

Formula 1. Balance-Index

$$B_{i,j} = \Sigma_{j=1}^{n} \frac{P_j - A_j}{P_j + A_j}$$

The Balance-index $B_{i,t}$ is the sum of the number of supporting statements related to a base statement P and rejecting nodes A, with i being the person-index, j the level-index, n the number of levels and t the time. The values of the Balance-Index represent the tendency of a Participant's argumentation. It reaches values between "−1" (extremely one-sided, e.g. only negative statements) and "+1" (extremely one-sided, e.g. only positive statements; see Zumbach, Reimann, & Koch, 2001). Here the absolute value is used for inference statistical testing.

7. Discussion

In this study, the influences of two different tools for visualization of argumentation structures during hypertext-based learning on knowledge acquisition, motivation, and argumentation quality were examined. A graphical mind mapping tool and a two-columned text-based argumentation tool have been provided and compared with a control group that had no argumentation task. While mind mapping tools often are preferred due to their semi-graphical representation of information, this possible advantage is more than questionable from a cognitive science point of view. It was argued here, that it may rather increase Extraneous Cognitive Load as indirectly measured by learning outcomes compared with basic text-based argumentation tools although the graphical organization might support organization of one's argumentation structure.

In this experiment, we found no single advantage or disadvantage of one tool compared to the other within effects on knowledge acquisition. But both argumentation tasks led to superior results within the assessment of structural knowledge than learning without such a given task as realized in the control group. Thus, the argumentation task seemed to be successful in fostering a deeper elaboration of the content provided by the hypermedia information system.

A major advantage of the graphical editor was found in motivation. While the decrease in learners' intrinsic motivation was largest in the control group, there was also a decrease of motivation during the treatment within the text editor condition. On the contrary, intrinsic learner motivation increased within the group that had the graphical argument editor. It remains unclear, whether this effect can be attributed to kind of "game like" interface and handling of the software, the possibility of the interface design or other reasons. Our hypothesis was here, that this kind of developing and

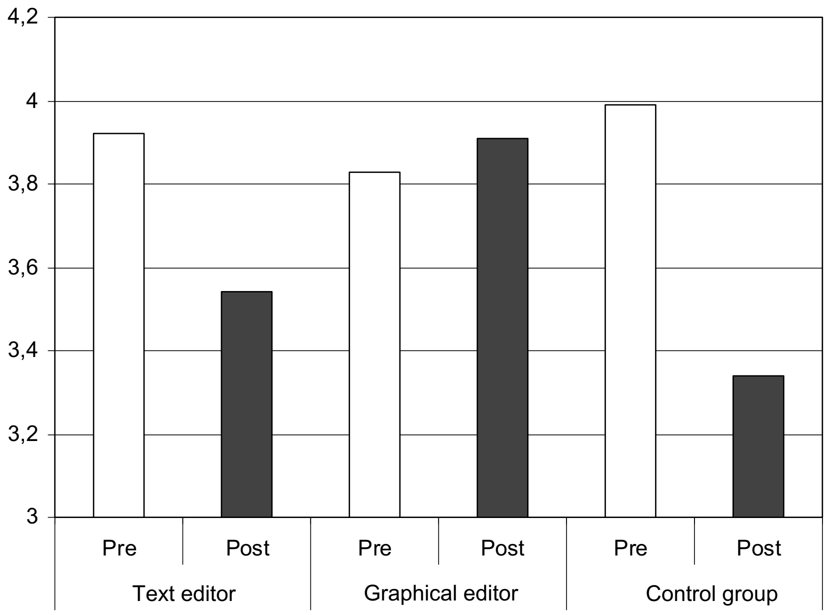

Fig. 3. Motivation.

Table 1
Means and standard deviations of dependent variables

Dependent variables	Text editor		Graphical editor		Control group	
	Mean	SD	Mean	SD	Mean	SD
Motivation pre test	3.92	0.66	3.83	0.51	3.99	0.4
Motivation post test	3.12	0.89	3.59	0.68	3.34	0.72
Knowledge pre test	5.83	2.01	5.85	1.6	5.8	2.36
Knowledge post test	8.15	2.75	7.98	1.57	6.95	2.18
Number of arguments	9.2	3.72	8.85	3.98	N/A	N/A
Acceptability	3.51	1.25	3.11	1.97	N/A	N/A
Relevance	3.06	1.22	2.88	1.89	N/A	N/A
Emotionality	1.55	0.81	1.11	0.77	N/A	N/A
Distinctiveness	2.82	1.15	2.79	1.76	N/A	N/A
Balance	0.28	0.3	0.55	0.33	N/A	N/A

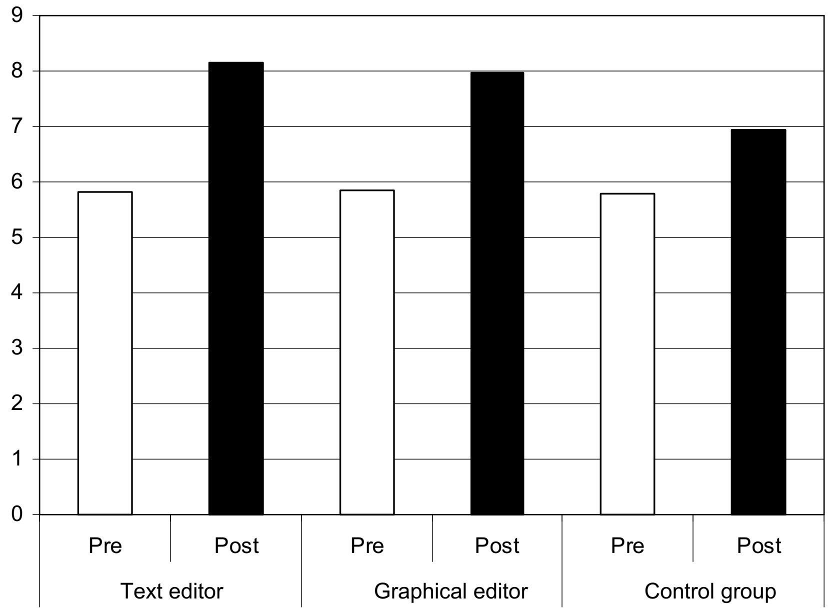

Fig. 4. Structural knowledge.

restructuring should foster learners' intrinsic motivation operationalized here by assessing participants' state of interest and flow. Results reveal here that within the control group and the text editor condition this motivational state decreased more significantly than in the graphical tool condition. These finding might be explained by a curiosity or novelty effect of the graphical interface (cf. Clark & Sugrue, 1990). It might be possible that in repeated use or long term studies this effect might vanish.

A comparison between the qualitative (acceptability, relevance, emotionality, distinctiveness) and quantitative (number of arguments) aspects of learners' argumentation between both experimental groups revealed no clear advantage of a specific tool. Nevertheless, the balance between pro and contra arguments as another indicator for a sound argumentation (cf. Voss & Means, 1991) was better supported by the interface design of the text based argumentation editor. Due to the demand characteristics of the interface with its two columns, the affordance to provide not only pro arguments (or contra arguments) was higher and, thus, might have resulted in a more balanced relation between pro and contra arguments.

All in all the study suggests that the combination of argumentation tasks and learning with hypertext is an effective approach for knowledge acquisition. Both tools of external representation of arguments revealed advantages regarding knowledge acquisition compared to the control group. While there were minor advantages of the graphical argumentation in maintaining learners' intrinsic motivation, there were also some minor advantages of the text-based argumentation editor regarding the balance between pro and contra arguments. These findings might be a result of this short time intervention and, thus, vanish in applied and everyday use of such tools. The presumably most important finding from this study is, that by providing external supportive tools in combination with a cognitive demanding task (here: the argumentation task) might be able to foster deepened information processing and, thus, enhanced knowledge acquisition.

Further research on mind mapping and external learning tools in sense of support devices in hypermedia learning environments should foster and establish the relationship between basic and applied cognitive issues. Mind mapping approaches might be helpful in order to enhance deepened information processing and knowledge acquisition. Nevertheless, the design of such an external tool has to meet the needs resulting from a learning task's requirements. Especially when integrating information represented in different code systems, two dimensional learner generated semantic maps combining representation of images and text might be superior to simple text based tools by using multi-codal information processing, but here are separate and future analyses necessary.

References

Âhlberg, M. (2004). Varieties of concept mapping. In A. J. Canas, J. D. Novak, & F. M. Gonzales (Eds.), *Concept maps: Theory, methodology, technology* (pp. 25–28). Pamplona, Spain: Universidad Publia de Navarra.

Anderson, J. R. (1983). *The architecture of cognition*. Cambridge: Harvard University Press.

Ausubel, D. P. (1963). *The psychology of meaningful learning*. New York: Grune & Stratton.

Bernd, H., Hippchen, T., Jüngst, K.-L., & Strittmatter, P. (2000). Durcharbeitung von Begriffsstrukturdarstellungen in unterrichtlichen und computerunterstützten Lernumgebungen [Working with structural representations in traditional and computer-supported learning environments]. In H. Mandl & F. Fischer (Eds.), *Wissen sichtbar machen [Making knowledge visible]* (pp. 15–36). Göttingen, DE: Hogrefe.

Berry, D. C. (1987). The problem of implicit knowledge. *Expert Systems, 4*(3), 144–151.

Bonato, M. (1990). *Wissensstrukturierung mittels Struktur-Lege-Techniken. Eine graphentheoretische Analyse von Wissensnetzen [Structuring knowledge with structural representation techniques. A graph-theoretical analysis of knowledge structures]. Frankfurt/M.* DE: Peter Lang.

Bruillard, E., & Baron, G.-L. (2000). Computer-based concept mapping: A review of a cognitive tool for students. In D. Benzie & D. Passey (Eds.), *Proceedings of the conference on educational uses of information and communication technologies* (pp. 331–338). Beijing: PHEI.

Buckingham Shum, S. (1996). Design argumentation as design rationale. *The Encyclopedia of Computer Science and Technology, 35*(Suppl. 20), 95–128.

Chularut, P., & DeBacker, T. K. (2004). The influence of concept mapping on achievement, self-regulation, and self-efficacy in students of English as a second language. *Contemporary Educational Psychology, 29*, 248–263.

Clark, R. E., & Sugrue, B. M. (1990). North American disputes about research on learning from media. *International Journal of Educational Research, 14*, 485–579.

Collins, A. M., & Loftus, E. F. (1975). A spreading activation theory of semantic processing. *Psychological Review, 82*, 407–428.

Collins, A. M., & Quillian, M. R. (1969). Retrieval time from semantic memory. *Journal of Verbal Learning and Verbal Behavior, 8*, 241–248.

Conklin, J., & Begemann, M. L. (1989). GIBIS: A tool for all reasons. *Journal of the American Society for Information Science, 5*, 200–213.

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing. A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11*, 671–684.

Csíkszentmihályi, M. (1990). *Flow: The psychology of optimal experience*. New York, NY: Harper and Row.

Dansereau, D. F., Collins, K. W., McDonald, B. A., Holley, C. F., Garland, J., Diekhoff, G., et al. (1979). Development and evaluation of a learning strategy program. *Journal of Educational Psychology, 71*, 64–73.

Diekhoff, G. M., Brown, P. J., & Dansereau, D. F. (1981). A prose learning strategy training program based on network and depth-of-processing models. *Journal of Experimental Education, 50*, 180–184.

Ennis, R. H. (1987). A taxonomy of critical thinking dispositions and abilities. In J. B. Baron & R. J. Sternberg (Eds.), *Teaching thinking skills: Theory and practice* (pp. 9–26). New York, NY: Freeman.

Farrell, T. (2001). Concept maps to trace conceptual change in pre service English teachers. *RELC Journal, 32*(2), 27–44.

Fischer, F. (1998). *Mappingverfahren als kognitive Werkzeuge für problemorientiertes Lernen [Mapping techniques as cognitive tools for problem-oriented learning]*. Frankfurt, DE: Peter Lang.

Gaines, B. R., & Shaw, M. L. G. (1995). Concept maps as hypermedia components. *International Journal of Human-Computer Studies, 43*, 323–361.

Graesser, A. C. (1981). *Prose comprehension beyond the world*. Berlin: Springer.

Heinze-Fry, J. A., & Novak, J. D. (1990). Concept mapping brings long-term movement toward meaningful learning. *Science Education, 74*, 461–472.

Jonassen, D. H. (1996). *Computers in the classroom: Mindtools for critical thinking*. Columbus, OH: Prentice Hall.

Jonassen, D. H., Beissner, K., & Yacci, M. (1993). *Structural knowledge: techniques for representing, conveying, and acquiring structural knowledge*. Hillsdale, NJ: Erlbaum.

Jonassen, D. H., & Reeves, T. C. (1996). Learning with technology using computers as cognitive tools. In D. H. Jonassen (Ed.), *Computers in the classroom: Mindtools for critical thinking* (pp. 693–719). Columbus, OH: Prentice Hall.

Keller, J. M. (1983). Motivational design of instruction. In C. M. Reigeluth (Ed.), *Instructional design, theories and models: An overview of their current status* (pp. 383–433). Hillsdale, NJ: Erlbaum.

King, A. (1995). Designing the instructional process to enhance Critical Thinking across the curriculum. *Teaching of Psychology, 22*(1), 13–17.

Kintsch, W. (1974). *The representation of meaning in memory*. Hillsdale, NJ: Erlbaum.

Kommers, P. A., & Lanzing, J. (1997). Students' concept mapping for hypermedia design. *Journal of Interactive Learning Research, 8*, 421–455.

Kozma, R. (1992). Construction knowledge with learning too. In P. A. M. Kommers, D. H. Jonassen, & J. T. Mayes (Eds.), *Cognitive tools for learning* (pp. 23–32). Berlin: Springer.

MacKinnon, G. R. (2006). Contentious issues in science education: Building critical thinking patterns through two dimensional concept mapping. *Journal of Educational Multimedia and Hypermedia, 15*, 433–445.

Mandl, H., & Fischer, F. (2000). Mapping-Techniken und Begriffsnetze in Lern- und Kooperationsprozessen [Mapping techniques and semantic nets in learning and cooperation processes]. In H. Mandl & F. Fischer (Eds.), *Wissen sichtbar machen [Making knowledge visible]* (pp. 3–14). Göttingen, DE: Hogrefe.

Mayer, R. E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31–48). Cambridge: University Press.

Mietzel, G. (2001). *Pädagogische Psychologie des Lernens und Lehrens [Educational Psychology of Learning and Teaching]*. Göttingen, DE: Hogrefe.

Nesbit, J. C., & Adesope, O. O. (2006). Learning with concept and knowledge maps: A Meta-Analysis. *Review of Educational Research, 76*, 413–448.

Norman, D. A., & Rumelhart, D. E. (Eds.). (1975). *Explorations in cognition*. San Francisco, CA: Freeman.

Okebukola, P. A. (1990). Attaining meaningful learning of concepts in genetics and ecology: An examination of the potency of the concept-mapping technique. *Journal of Research in Science Teaching, 27*(5), 493–504.

Paivio, A. (1978). A dual coding approach to perception and cognition. In H. L. Pick & E. Salzman (Eds.), *Modes of perceiving and processing information* (pp. 39–51). Hillsdale, NJ: Erlbaum.

Rheinberg, F., Vollmeyer, R., & Engeser, S. (2003). Die Erfassung des Flow-Erlebens [Assessment of the flow experience]. In J. Stiensmeier-Pelster & F. Rheinberg (Eds.), *Diagnostik von Motivation und Selbstkonzept [Diagnostics of motivation and self concept]* (pp. 261–279). Göttingen, DE: Hogrefe.

Scandett, J. F. (2006). The efficacy of concept mapping in aural skills training. *Dissertation Abstracts International Section A: Humanities and Social Sciences, 66*(9-A), 3202.

Scheele, B., & Groeben, N. (1984). *Die Heidelberger Struktur-Lege-Technik (SLT) [The Heidelberg structural representation approach]*. Weinheim: Beltz.

Schnotz, W. (1988). Textverstehen als Aufbau mentaler Modelle [Text comprehension as mental model development]. In H. Mandl & H. Spada (Eds.), *Wissenspsychologie [The psychology of knowing]* (pp. 299–332). Weinheim, DE: PVU.

Stensvold, M. S., & Wilson, J. T. (1990). The interaction of verbal ability with concept mapping in learning from a chemistry laboratory activity. *Science Education, 74*, 473–480.

Sweller, J. (2005). Implications of cognitive load theory for multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (pp. 19–30). New York, NY: Cambridge University Press.

Tan, S. C. (2000). The effects of incorporating concept mapping into computer assisted instruction. *Journal of Educational Computing Research, 23*, 113–131.

Tergan, S.-O. (1986). *Modelle der Wissensrepräsentation als Grundlage qualitativer Wissensdiagnostik [Models of knowledge representation as basis for qualitative knowledge assessment]*. Opladen, DE: Westdeutscher Verlag.

Tergan, S.-O. (2006). Individuelles Wissens- und Informationsmanagement mit Concept Maps beim netzbasierten Lernen [Individual knowledge and information management with concept maps in web-based learning]. In H. Mandl & H. F. Friedrich (Eds.), *Handbuch Lernstrategien [Handbook learning strategies]* (pp. 307–324). Göttingen, DE: Hogrefe.

Uzuntiryaki, E., & Geban, O. (2005). Effect of conceptual change approach accompanied with concept mapping on understanding of solution concepts. *Instructional Science, 33*, 311–339.

Voss, J. F., Blais, J., Means, M. L., Greene, T. R., & Ahwesh, E. (1989). Informal reasoning and subject matter knowledge in the solving of economics problems by naive and novice individuals. *Cognition and Instruction, 3*, 269–302.

Voss, J. F., & Means, M. L. (1991). Learning to reason via instruction in argumentation. *Learning and Instruction, 1*, 337–350.

Willis, C. L., & Miertschin, S. L. (2006). Mind maps as active learning tools. *Journal of Computing Sciences in Colleges, 21*, 266–272.

Xiufeng, L. (2004). Using concept mapping for assessing and promoting relational conceptual change in science. *Science Education, 88*, 373–396.

Zumbach, J., Reimann, P., & Koch, S. (2001). Influence of passive versus active information access to hypertextual information resources on cognitive and emotional parameters. *Journal of Educational Computing Research, 25*, 301–318.