Concept Mapping: Connecting Educators
Proc. of the Third Int. Conference on Concept Mapping
Tallinn, Estonia & Helsinki, Finland 2008

DIGITAL CONCEPT MAPS AS POWERFUL INTERFACES FOR ENHANCING INFORMATION SEARCH. AN EXPERIMENTAL STUDY ON THE EFFECTS OF SEMANTIC CUEING

Sigmar-Olaf Tergan, Tanja Engelmann & Friedrich W. Hesse
Institut für Wissensmedien – Knowledge Media Research Center, Tübingen (FRG)

Abstract. Research on the effectiveness of concept maps used as interfaces for knowledge-based information search has yielded inconsistent results. Simply representing content structures in a visual-spatial format has not resulted in higher performance or more positive usability ratings as compared to traditional interfaces. The assumption behind the study presented here is that the potential for semantic cueing of task-relevant information has not yet been fully exploited. An experiment was performed to study the effects of semantic cueing. Two types of interfaces, a digital concept map and a digital concept list, were compared. In the concept map condition, visual-spatial highlighting of category relations, as well as verbally labelled links for cueing semantic relations, were used for cueing correct decisions on the task-relevance of information resources. In the concept list condition only visual-spatial highlighting was used. The results showed that users of both interfaces showed no significant differences when resources had to be localized on the basis of category relationships. However, significant differences showed up when semantic (functional) relationships had to be taken into consideration. The results corresponded well with the usability ratings by the subjects. The overall conclusion is that digital concept maps may serve as powerful interfaces for enhancing information search if their inherent potential for semantic cueing of relevant resources is exploited in a task-appropriate manner.

1 Conceptual background

People seeking information need to make sense of the information and find what is relevant for a particular task. Thus it seems that the most effective communication not only provides the resources of task-appropriate information, but also the semantic relations between relevant topics of the resources. Orientation and navigation devices, for example hierarchical topic lists, site maps, structured lists of URLs, and concept maps, have been suggested as interfaces to help users make sense of a content domain and to provide users access to digital information resources (Rouet, Potelle, & Goumi, 2005). Whereas all these interfaces may reduce cognitive load by providing a structure that helps users decide upon the task-relevance of a particular resource, there are some typical features that seem to render some of the devices more effective in fostering information search than others.

A central aspect is semantic cueing. Hierarchical topic lists, site maps, and structured lists of URLs provide basic, implicit semantic cues concerning the hierarchical structure of the represented content domain. Outlining the hierarchical structure of a content domain in a visual-spatial format may help users to orient themselves. They can then navigate and infer super-ordinate and sub-ordinate relationships between topics (concepts), like category relations (is part of), and concept-example relations (is an example of). This is advantageous for making sense of the structure of the overall domain. A visual-spatial outline may also help users acquire knowledge and form a coherent mental representation of the knowledge domain (Kintsch & van Dijk, 1978). However, although many content structures may be represented adequately by using hierarchical outlines, a hybrid format using both hierarchical and web-like structures may be more appropriate for representing the interrelatedness of concepts in complex knowledge structures.

Concept maps have been suggested as an appropriate tool for representing knowledge structures (Novak & Gowin, 1984**;** Tergan, 2005; Novak & Cañas, 2006). A concept map according to Novak & Gowin is a visual-spatial array that represents elements of knowledge by means of nodes and directed labelled links. The nodes in a concept map represent ideas, concepts and beliefs, and the links show the relations among the concepts. Although concept maps are considered to be a hierarchical representation tool, a network structure for representing semantic interrelations can easily be implemented by using cross-links.

Since the implementation of digital concept mapping tools (e.g. Inspiration™, http://www.inspiration.com/; CmapTools™, http://cmap.ihmc.us/; SMART Ideas™, http://www2.smarttech.com/st/en-US/Products/SMART+Ideas/), concept maps have not only been used for the representation of conceptual knowledge but also for a comprehensive representation of content knowledge and resource knowledge (Tergan, 2005). They are used for representing and communicating information and information resources, and, used as an interface, for fostering orientation, navigation, and information access (e.g. Hoffman, Cañas, & Ford, 2000; Coffey & Cañas, 2006). Used as interfaces, concept maps are appreciated for their explicitness in representing the semantics of a domain, for offering visual search, and for providing a knowledge-based visual access to information resources. Semantic cues indicating the relevance of an information resource can appear in several explicit forms. They may be the labels of concepts, aspects of the graphical representation itself, like the distance between represented resources indicating a thematic or contextual relationship between contents. Semantic cues might

also be the explicit labelling of the kind of relationships between contents. It has been suggested that concept maps support external cognition, since their semantic explicitness facilitates inferences and decisions about the relevance of represented knowledge elements for coping with a particular task (Scaife & Rogers, 1996; Tergan, 2005). Because concept maps may represent the meaning inherent in information visualization, they could provide a bridging technology that might integrate aspects of knowledge and information visualization approaches (Keller & Tergan, 2005).

As an interface to information resources, digital concept maps may function as a vehicle to communicate the semantic interrelation between topics of resources of a digital content domain. In this way, they could foster information search processes better than other structural orientation, navigation, and information access tools. Basic assumptions underlying the use of concept maps as interfaces are: (1) Because concept maps are explicit and problem-centred in representing semantic relations between concepts of a domain, they may be more effective as an interface with respect to information search efficacy than other tools. The explicit labelling of relations between concepts may provide information seekers an advantage in searching for hyperlinked information resources and in deciding on whether the resources may contain information relevant for coping with a particular task. A semantic understanding of the task-relevance of content topics and related information resources enhances information search. (2) Because of the visual-spatial layout of the concepts, the topic structure of a knowledge domain can be represented more clearly with concept maps. Thus concept maps may be evaluated by information seekers more positively than other interfaces with respect to perceived cognitive load.

This paper presents an experimental study that intends to cross-validate the results of a previous study of Goumi, Rouet, & Aubert (2003) which seems to contradict any advantages of concept maps. It further intends to shed more light on the reasons why and the conditions when concept maps as interfaces may foster information search.

2 Research background

Research on the effectiveness of concept maps used as interfaces for information search has yielded inconsistent results (Carnot, Dunn, Cañas, Gram, & Muldoon, 2001; Weideman & Kritzinger, 2003; Goumi, Rouet, & Aubert, 2003; see Rouet, Potelle, & Goumi, 2005 for a recent review of research on the role of content representations in search tasks). Carnot et al. and Weideman & Kritzinger found that a hierarchical concept map used as interface proved to be more effective in search performance, easier to handle and more popular than a Web page-based interface. It could be suggested that in these studies, concept maps were more effective because the content structure of the hypertext was highlighted in a visual-spatial representation. Thus, when node labels and visual-spatial semantic cues were used in a concept map interface, Web pages could be searched visually on the basis of knowledge about the inherent content structure. In contrast, in the Web page-based interface the structure remained implicit and could not be used for deciding about the relevance of a Web page.

Goumi et al. (2003) compared a concept map interface with an alphabetic index and a hybrid interface, composed of an alphabetic index and a hierarchical content list. In this comparison, they found no advantages of the concept map interface. The concept map used in their study had two layers of representations. The top level layer consisted of an interwoven puzzle-like assembly of concept nodes. The second level layer was a web-like node-link map with non-labelled associative non-directed links. In the study of Goumi et al. students had to search for articles in a CD-ROM multimedia database on “Electronics”, containing about 90 articles. They then had to answer questions by using more detailed information contained in the articles. The number of clicks to find a task-relevant article by using the allocated interface was assessed. It turned out that for less knowledgeable students the alphabetic index was the most effective interface. Advanced students performed more effectively with the hybrid interface. They profited most by using the hierarchical content list of this interface to pre-select relevant areas of knowledge. The hybrid interface required fewer clicks than the two other interfaces, even though the difference between the “hybrid” and “index” interface was not significant. All in all, the concept map interface was evaluated by searchers as less suitable, and less popular.

In order to make sense of the results of Goumi et al. it is helpful to analyse the conditions of the study, particularly the task situation. The task was to answer topic related questions by using information contained in an article. However, the concept map used in this study does not seem to be appropriate for fostering information search. In the first place, the format of the map is not inherently hierarchical, which is normally a typical feature of most concept maps (Novak & Cañas, 2006). In the second place, semantic relations between nodes are not verbally labelled. In order to select a resource and study the respective article to answer a

question, the participant could only consider the meaning of the labels used for indicating content topics. A more detailed consideration of links that represented the topic structure of the domain was not possible and not intended by the authors.

There may be other reasons why the concept map condition did not show benefit: The concept map used by Goumi et al. had two layers of representation, and each was presented in a different window at the screen. Clicking on a label at the top level representation opened up the second level. An article could only be accessed at the second level of representation. It has been shown that too complex, less structured, and layered concept maps were too difficult to handle for many users (Wiegmann, Dansereau, McCagg, Rewey, & Pitre, 1992). It may be assumed that the concept map's lack of clarity and usability was detrimental to effective use in the search process. Because of these impediments, it is not surprising that the results showed no advantage in information search for subjects in the concept map condition. If the map had been more clearly arranged so that the students could capitalize on the potential of its use, the students' evaluation of the suitability of concept maps might have been more positive.

In the Goumi et al. (2003) experiment it seems to have been easier for information seekers to infer the task-relevance of the corresponding articles from the label of a node representing a content domain. The prominent feature of concept maps of using directed and labelled links to semantically cue the relevance of a topic was not capitalized on. It may be concluded that the map used in the experiment lacked central features for fostering information search and was suboptimal for many users to cope effectively with the experimental tasks. Therefore, no benefit was shown as compared to the alphabetical index and the hybrid interface conditions. Empirical data as well as theoretical reflections support the assumption that a concept map will only be effective as an interface for fostering information search if it is directly relevant to the task, if it is clearly designed, and if it can be handled easily without imposing additional cognitive load to the users. In order to study the potential and advantages of a concept map as an interface, care has to be taken to fulfil these conditions. To elaborate on these three essential conditions: (1) Concept maps' potential for fostering information search can only be realized if their prominent feature, namely labelled and directed semantic links for semantically cueing the relevance of content topics, is capitalized upon in the design of the map so that users can decide if the topics match the demands of the task. (2) Concept maps as compared to other interfaces can only be more effective if users recognize an additional value in considering labelled and directed semantic links when searching for information resources. Otherwise alphabetic or hierarchically structured representations will do. (3) Concept maps must not impose additional cognitive load on users. They must be clearly designed. A manageable number of nodes and a clear structuring of the nodes are essential.

The basic assumption is: Concept maps will only fulfil their potential as an interface if the search conditions match the conditions for optimal use. If a concept map fulfils these conditions it will be an inherently more effective interface for supporting decisions about the task-relevance of content topics and related information resources. It will also be more effective than a simply alphabetic and hierarchical tool that leaves the semantic relations between content topics implicit, so that the users themselves have to infer any relation of information resources from studying the corresponding contents.

3 Experimental approach

An experiment was performed to analyse the effects of two types of interfaces: a concept map interface, and a concept list interface. These two interfaces differed in the explicitness of semantic cueing of category and functional relations indicating the task-relevance of information resources: We used the following dependent variables:

- Search time (time needed for deciding on the task-appropriateness of a resource)
- Correctness of a decision
- Estimated cognitive load (as measured with a 7 point-rating scale on the mental effort needed for coping with a task)

Four central hypotheses were tested:

1. If a task requires the consideration of category relations between concepts, search time and correctness of decisions of information seekers using a concept map interface or a concept list interface will not differ. In both interfaces the category relations can be inferred from the existing visual-spatial cues by using hierarchical structuring of concepts.

2. If a task requires the consideration of functional relations between concepts, the search performance of information seekers using a concept map interface as compared to a concept list interface will differ significantly: Using a concept map will be significantly more effective in reducing search time and fostering correct decisions about the task-relevance of an information resource under conditions of considering one, two or three and more relations.
3. The perceived cognitive load among subjects using the concept map and the concept list will differ depending on the type of relation and the number of functional relations which have to be considered in order to decide about the task-relevance of an information resource. If only category relations have to be considered, the evaluation of the perceived cognitive load of the concept map will not differ significantly from the evaluation of the concept list.
4. If a task requires the consideration of one, two, or three and more functional relations, the perceived cognitive load will differ significantly among subjects using the two different interfaces. Subjects working with the concept map will evaluate the perceived cognitive load as lower compared to subjects working with the concept list interface, under conditions of considering one, two or three and more relations.

3.1 Method

3.1.1 Subjects

Subjects of the study were 44 paid students (31 female, 13 male) at the University of Tuebingen, Germany. The average age was 23,59 (*SD* = 4,04). The students were randomly assigned to the experimental condition or to the control condition.

3.1.2 Materials

A pre-selected set of 34 Web pages of the internet portal e-teaching.org (www.e-teaching.org) was used. The portal consists of about 2000 Web pages on E-Teaching. The selection of Web pages covered the topic "Technologies of Web-based Communication in Online Teaching Scenarios". The labels of the Web pages were represented as concepts. The concepts were hyperlinked to corresponding Web pages. Both a concept map (Fig. 1) and a concept list (Fig. 2) were generated. Both interfaces equally represent content structures visual-spatially by means of hierarchical structuring. However, they differ in the explicitness of semantic cueing of task-relevant information resources. Two types of semantic relations were used: category relations (e.g. "is an example of") for representing content structures; and functional relations (e.g. "is used by") for representing task-relevant relations among topics of the knowledge domain, displayed as concept nodes. Both types of relations were represented implicitly in the concept list interface but explicitly in the concept map interface. The explicit representation in the concept map interface was carried out by means of explicit verbal labelling of the links between content topics and related information resources. Category relations in both interfaces were represented visual-spatially. In the concept map interface all relations were also labelled verbally. Functional relations in the concept list condition were not represented visual-spatially. They had to be inferred by first selecting a task-relevant Web site and then extracting the relation from the content. For reasons of search economy the task-relevant contents of an information resource were highlighted by using red coloured characters.

3.1.3 Task

The task was to answer questions that required decisions concerning the relevance of information resources. Each of the questions induced the information seeker to consider relations between represented topics, as a prerequisite for deciding about the relevance of an information resource linked to a particular topic. Several types of questions had to be answered. The questions were multiple choice questions with a varying number of alternatives, of which up to three could be correct. Answering the questions required the participant to consider whether there was either a category relation between topics (concepts) of Web pages, or whether there were one or more functional relations between topics. The primary task was to try to answer the questions on the basis of the concept map and concept list interface respectively. However, subjects were Also free to seek information in the contents of task-relevant resources.

Examples

Example of a task requiring consideration of 1 category relationship
You want to find more detailed information about Learning Management Systems. You are looking for one or more resources which may contain more detailed information. Which of the following resources of the internet-portal e-teaching.org may be of relevance? (1) Bubble Sort, (2) E-Chalk, (3) ILIAS, (4) CLIX.

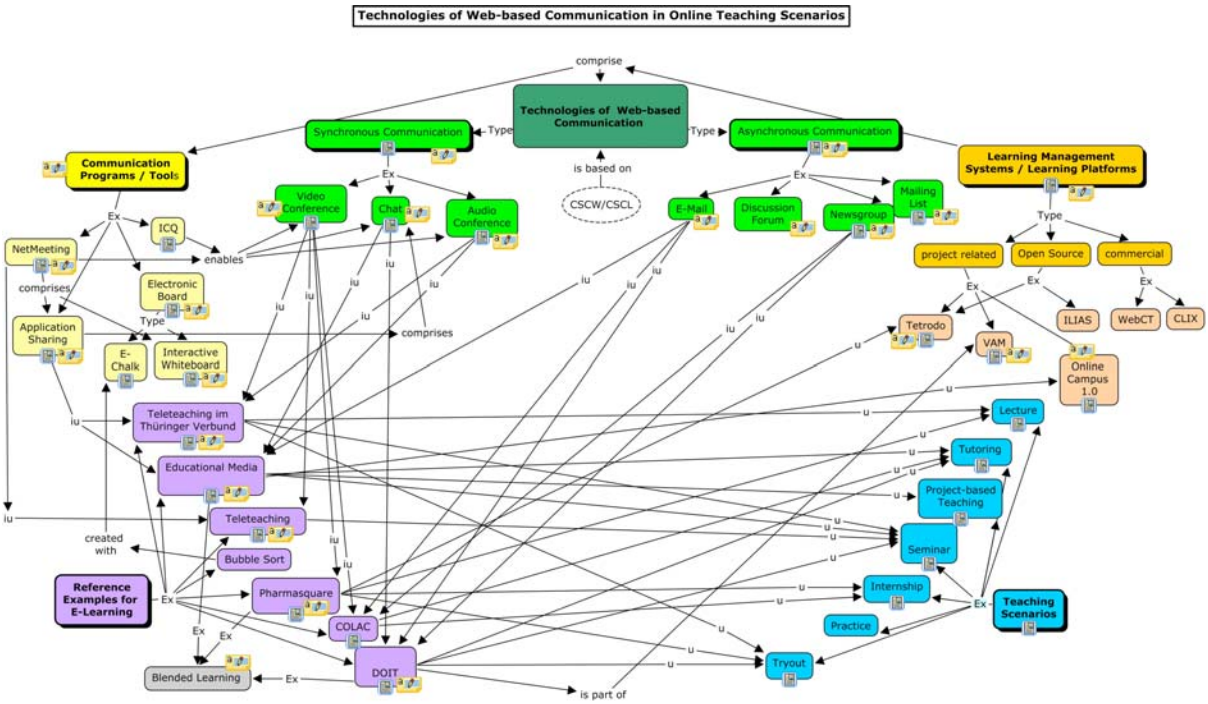

Figure 1: Concept map interface with a hybrid representation of concepts and labelled and directed semantic relations. Concepts belonging to the same category are represented visual-spatially, same-colour and structured hierarchically. Abbreviations of labels for relations are used for assuring clarity (Ex: example; iu: is used; u: uses).

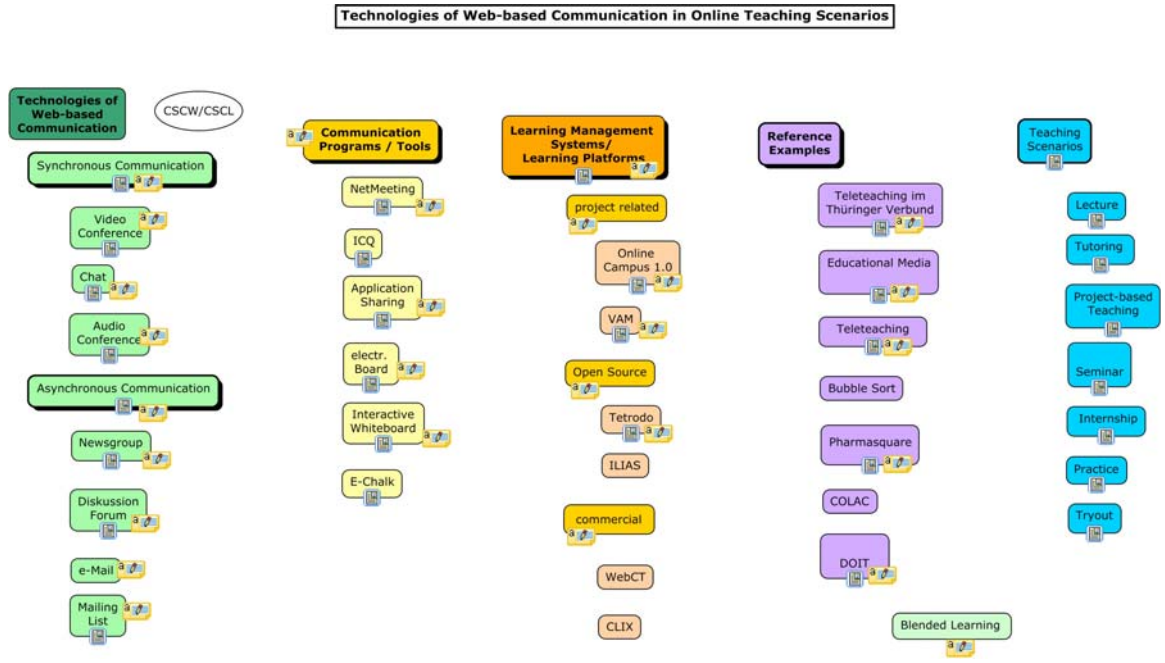

Figure 2: Concept list interface with a hierarchical representation of concepts. Concepts belonging to the same category are represented visual-spatially, same-colour and structured hierarchically.

Example of a task requiring consideration of 1 functional relationship

You are searching for e-learning reference systems to find more detailed information about the online use of teaching methods. Please decide on which of the teaching methods is/are used by a particular reference system. The reference system „Educational Media“ uses as a teaching method … (a) lecture, (b) tutoring, (3) project-based teaching, (4) seminar, (5) internship, (6) tryout, (7) practice.

Example of a task requiring consideration of 2 functional relationships
You are searching for an e-learning reference system where the teaching method „Lecture“, and the communication technology „Video conference“ are applied in conjunction. Which of the following information resources may contain relevant information? (1) Teleteaching im Thüringer Verbund, (2) Educational Media, (3) Teleteaching, (4) Bubble Sort, (5) Pharmasquare, (6) COLAC, (7) DOIT.

Example of a task requiring consideration of 3 and more functional relationships
You intend to offer a “blended learning” seminar. As communication tools you want to use a cooperation tool for Web-based cooperative text design as well as audio conferences and e-mail. You are searching for an appropriate reference example to learn more about how to use these technologies. Which of the following resources would you choose get more information? (1) Teleteaching im Thüringer Verbund, (2) Educational Media, (3) Teleteaching, (4) Bubble Sort, (5) DOIT, (6) COLAG, (7) Pharmasquare.

The concept list and the concept map interface were developed by using the CmapTools concept mapping software (http://cmap.ihmc.us/). They both represented categorical relations between concepts visual-spatially in a tree-like hierarchical structure. However, in contrast to the concept list; the concept map also represented functional relations by means of labelled and directed links. That is, in the concept map hierarchical relations between concepts are represented in a visual-spatial mode as well as in a verbal mode by using link labels like “is a type of” or “is an example of”. In the case of the concept map the subjects could directly infer the relevance of an information resource by considering the category and the functional relations represented in the map. If desired, they could, however, also access the task-relevant resources and search for information relevant for coping with a task. In the case of the concept list inferring a relation was only possible for questions requiring consideration of a category relation. If a question which required the consideration of one or more functional relations had to be answered, information seekers using a concept list first had to search the relevant information by accessing potentially relevant Web pages and looking up the information in the text. Subjects in both experimental conditions could access an information resource by clicking at a corresponding concept node in the provided interface.

3.1.4 Procedure

In a first phase all subjects were administered two questionnaires. The first one was for assessing demographic data, and the second one was for assessing user prerequisites, such as computer- and mapping-experience, preferences for processing textual or graphical information, or prior knowledge on e-learning technologies (5 test-items). In the second phase, after brief instruction about the information seeking scenario, the users were presented a questionnaire with multiple choice questions. Each question was asking for a decision on which of the information resources listed would possibly contain relevant information to enable the participant to answer the question. In order to assess the effectiveness of the two interfaces, two basic dependent variables were used: time needed for answering questions of a particular question type *and* number of correct answers. Time for answering each question was recorded automatically by the mapping tool. In phase three, a short questionnaire was administered to assess perceived cognitive load.

3.2 Results

An analysis of the statistical premises showed that ANOVAS could be used for hypothesis testing. The results are as follows:

Hypothesis 1 was confirmed: Search time and correctness of decisions using a concept map interface or a concept list interface did not differ for answering questions requiring the consideration of category relations. In this condition, for deciding about the task-adequateness of a particular information resource, there were no statistical differences at a level of $p<0.05$ between subjects working with either the concept map or the concept list with respect to time for search and number of correct answers (search time: M_{CM} = 3:24:38; M_{CL} = 5:04:36; $F(3,629)$; $p<0.07$; number of correct answers: M_{CM} = 14.39; M_{CL} = 14.48; $F(0,021)$; $p<0.89$)).

Hypothesis 2 was partly confirmed: In order to answer questions requiring the consideration of one, two or three functional relations between concepts for deciding about the task-adequateness of a particular information resource, there were varying statistical differences between subjects working with the concept map as compared to subjects working with the concept list with respect to time for search and correctness of search results. The results were as follows: Search time, one relation: M_{CM} =3:06:00; M_{CL} = 7:06:36; $F(57,96)$; $p<0.001$ (s); search time, two relations: M_{CM} =3:36:49; M_{CL} = 5:56:00; $F(35,00)$; $p<0.001$ (s); search time, three and more relations: M_{CM} = 10:02:20; M_{CL} =11:09:03; $F(0,26)$; $p>0.05$ (ns); number of correct answers, one relation: M_{CM} = 21,09;

M_{CL} = 19,29; F(9,71); p<0.003 (s); number of correct answers, two relations: M_{CM} = 41,00; M_{CL} = 40,57; F(0,54); p>0.05 (ns); number of correct answers, three and more relations: M_{CM} = 20,74; M_{CL} = 19,52; F(10,37); p<0.01 (s). Subjects working with the concept maps had a significantly lower *search time* when they had to consider one or two functional relations, as compared to subjects working with the concept list. However, when three and more functional relations had to be considered, there was no significant difference in search time between users of the concept map and users of the concept list. As to the number of *correct answers*, only when one or three and more relations had to be considered the concept map was more effective than a concept list. When two conditions had to be considered, subjects working with the concept map interface did not significantly differ from subjects working with a concept list interface.

Hypothesis 3 was confirmed. When category relations had to be considered, the evaluation of the perceived cognitive load of users working with the concept map did not differ significantly from the evaluation of concept list users (M_{CM} = 2,13; M_{CL} = 2,19; F(0,02); p>0.05 (ns)).

Hypothesis 4 was partly confirmed: When functional relations were in focus, subjects using the concept map reported significantly less cognitive load when one or three and more functional relations had to be considered (one relation: M_{CM} = 2,09; M_{CL} = 3,00; F(6,42); p<0.05 (s); three and more relations: M_{CM} = 3,65; M_{CL} = 4,76; F(8,47); p<0.01 (s)). However, when two functional relations had to be considered, there was no statistical difference between subjects using the concept map as compared to subjects using the concept list (M_{CM} = 3,30; M_{CL} = 3,90; F(2,17); p>0.05 (ns)).

4 Discussion

The goal of the experiment was to study the effectiveness of a concept map as opposed to a concept list as an interface for fostering information search performance. Earlier studies (Weideman & Kritzinger, 2003; Goumi et al., 2003) had yielded contradictory results. It was criticized that in the study of Goumi et al. crucial features of a concept map as an interface for fostering information search had not been adequately used so that the potential of concept maps did not come to bear. It was assumed that the strength of concept maps lay in the explicit verbal cueing of semantic relations. If a concept map capitalized on semantic relations between concepts (topics) for cueing the task-relevance of information resources, performance in both information search and usability ratings would be enhanced.

In the present study, the effectiveness of a concept map and a concept list was studied. Both interfaces represented category relations quite similarly visual-spatially in a hierarchical structure. However, in the concept map interface functional relations between information resources were additionally represented explicitly in a verbal and visual-spatial mode and could be “read off”, whereas in the concept list interface the relations between information resources had to be inferred from the text contained in the information resources. The results of the reported experiment show that, contrary to suggestions of Goumi et al. (2003), concept maps can be used successfully as interfaces for helping in the search for information resources if certain conditions are right: if the knowledge about semantic relations between the topics of the resources is relevant for information search, if the semantic relations are represented explicitly in a visual and verbal mode, if the concept map is comprehensible and easily usable. The results indicate that if only category relations are relevant for making decisions on the task-relevance of information resources, then a hierarchically structured concept list may be equally effective as a hierarchically structured concept map. Apparently the verbal labelling of relations in the concept map interface has no added value for category relations. If, however, functional relations are the primary focus, concept map users in most cases outperform concept list users.

Further research has to study in more detail why subjects using the concept map interface had a lower search time and more correct answers in some conditions but not in others. As to the perceived cognitive load, the results indicate that cognitive load is the same when using a concept map or a concept list, if category relations have to be considered. In this case, cueing the task-relevance of resources in a visual-spatial mode seems to be sufficient for fostering information search. However, if functional relations between concept nodes have to be considered for deciding on the task-relevance of information resources, the concept map users reported less cognitive load. A plausible explanation is that the combination of verbal and visual-spatial semantic cueing of the task-relevance of resources helps users to make sense of external representations, in turn making possible a knowledge-based information search. This seems to foster processes of external cognition (Scaife & Rogers, 1996) and, hence, to contribute to reducing cognitive load - provided that basic design criteria for clarity and comprehensibility of concept maps are met (Wiegmann et al., 1992).

We suggest that research on concept maps used as interfaces should focus on explicit semantic cueing and knowledge-based information search. Visual-spatial semantic cueing of the category structure inherent in an information repository may not always be enough to foster information search. Information visualizations “need to be tailored and augmented to focus attention on the task-relevant information“ (Sebrechts, 2005). Keeping in mind this suggestion, digital concept maps used as interfaces for fostering information search should not merely represent category relations of a content structure, as in many approaches on information visualization. They should explicitly represent, in a combined verbal and visual-spatial representational mode, those relations between concepts which have been identified in a task analysis as relevant for coping with a particular task and which have been selected for visual-spatial representation. It is suggested that concept maps used as interfaces for information search may overcome some of the shortcomings of pure visual semantic cueing in the traditional information visualization approach (Tergan, Keller & Burkhard, 2006). They might therefore be used successfully in resource-based learning, problem solving and counselling scenarios.

For future research we suggest that the differential effects of the visual-spatial and the verbal mode for representing different kinds of semantic relations in concept maps be analysed in more detail as to information search efficacy. Digital concept maps have not been studied much as interfaces for information search. However, because coping effectively with information resources in a diversity of resource-based educational and workplace settings will become a more and more important competency, in future research and application concept maps as interfaces used for fostering information search should receive much more attention.

References

Carnot, M. J., Dunn, B. R., Cañas, A. J., Gram, P., & Muldoon, J. (2001). Concept Maps vs. Web Pages for Information Searching and Browsing. Retrieved March 13, 2008 from: http://itech.pjc.edu/pgram/pdfs/ConceptMapsPaper.pdf.

Coffey, J., Hoffman, R., & Cañas, A. (2006). Concept-map based knowledge modelling: perspectives from information and knowledge visualization. Information Visualization, 5(3), 192-201.

Hoffman, R. R., Coffey, J. W., & Ford, K. M. (2000). A case study in the research paradigm of human-centered computing: Local expertise in weather forecasting. Report on the contract "human-centered system prototype”. Washington, DC: National Technology Alliance.

Keller, T., & Tergan, S.-O. (2005). Visualizing Knowledge and Information: An Introduction. In S.-O. Tergan & T. Keller (Eds.), Knowledge and information visualization: Searching for synergies. LNCS 3426 (pp. 1-23). Heidelberg: Springer-Verlag.

Kintsch, W., & van Dijk, T.A. (1978). Toward a model of text comprehension and production. Psychological Review, 85, 363-394.

Novak, J. D., & Gowin, D. B. (1984). Learning how to learn. Cambridge: Cambridge University Press.

Novak, J. D., & Cañas, A. J. (2006). The origins of the concept mapping tool and the continuing evolution of the tool. Information Visualization, 5(3), 175-184.

Rouet, J.-F., Potelle, H., & Goumi, A. (2005). The role of content representations in hypermedia learning. Effects of task and learner variables. In S.-O. Tergan & T. Keller (Eds.), Knowledge and information visualization: Searching for synergies. LNCS 3426 (pp. 328-339). Heidelberg: Springer-Verlag.

Scaife, M., & Rogers, Y. (1996). External Cognition: how do Graphical Representations Work? International Journal of Human-Computer Studies, 45, 185-213.

Tergan, S.-O. (2005). Digital Concept Maps for Managing Knowledge and Knowledge Resources. In S.-O. Tergan & T. Keller (Eds.), Knowledge and information visualization: Searching for synergies. LNCS 3426 (pp. 185-204). Heidelberg: Springer-Verlag.

Tergan, S.-O., Keller, T., & Burkhard, R.A. (2006). Integrating knowledge and information: digital concept maps as a bridging technology. In S.-O. Tergan, T. Keller, & R.A. Burkhard, R. (Eds.). Concept Maps. A Special Issue of Information Visualization 5(3), 167-174.

Weideman, M., & Kritzinger, W. (2003). Concept Mapping - a proposed theoretical model for implementation as a knowledge repository. Working paper from the "ICT in Higher Education" research project. University of Western Cape - South Africa. Downloaded March 13, 2008: http://www.uwc.ac.za/ems/is/hicte/.

Wiegmann, D.A., Dansereau, D.F., McCagg, E.C., Rewey, K.L., & Pitre, U. (1992). Effects of knowledge map characteristics on information processing. Contemporary Educational Psychology, 17, 136-155.