The Use of Digital Concept Maps as Cognitive Tools for Managing Knowledge and Knowledge Resources

Sigmar-Olaf Tergan

Knowledge Media Research Center (KMRC)
Konrad-Adenauer-Str. 40
D-72072 Tuebingen, Germany
s.tergan@iwm-kmrc.de

Abstract

Advanced computer-based concept-mapping tools are suggested to have the potential to foster spatial learning strategies and processes of individual knowledge management like the acquisition, organization, representation, (self-) evaluation, communication, localization and utilization of knowledge. In addition, they have the potential to represent not only conceptual knowledge, but also content knowledge about a domain, as well as knowledge resources. The aim of this paper is to analyze the potential of digital concept maps for supporting processes of individual knowledge management. Perspectives for application and research are outlined.

1. Introduction

In order to effectively cope with the growing amount and complexity of knowledge and knowledge resources in learning and problem solving, there is a need for effectively organizing, storing, and localizing knowledge and knowledge resources. Digital concept maps as external representations of individual knowledge may be used as cognitive tools for the management of knowledge and knowledge resources to assist students. Concept maps – sometimes called "knowledge maps" – are spatial arrays that represent elements of knowledge in a node-link-node diagram (Novak and Govin 1984; Dansereau in press). Like traditional paper & pencil concept maps, digital maps are grounded in the idea that humans may enhance cognitive processes and the structuring of knowledge if these processes and structures are exteriorized and visualized in a map (Jonassen 1992). Whereas traditional concept mapping tools only allow for two-dimensional representations, modern computer-based mapping tools (e.g. Knowledge Manager, (http://www.conceptmaps.it/default-eng.htm), Inspiration, (http://inspiration.com/productinfo/inspiration/), SMART Ideas, (http://www.smarttech.com/products/smart ideas/index.asp), Cmap Tools, http://cmap.ihmc.us/Documentation/)) also allow for hypertext-like representations, which include sub-maps, cross-links between knowledge elements, as well as links to knowledge resources. In addition, some tools provide functions for automatic restructuring of knowledge, full text knowledge retrieval and web-conferencing to support cooperative map-based work.

Concept maps have proven to be a valuable cognitive tool in a variety of learning and instructional settings (O'Donnell, Dansereau, and Hall 2002; Bruillard and Baron 2000). In the instructional context, they have been used primarily for purposes of knowledge diagnosis and fostering subject-matter comprehension and knowledge acquisition. Because of their potential to link concept nodes to files stored locally or on websites, these tools may be used in external diagrams to represent not only concept knowledge, but also subject-matter content knowledge (annotations, text, sketches, pictures, audio and video representations), and multimedia knowledge resources, e.g. located on web-sites, in PC files, web-logs, online learning environments. Concept maps may facilitate mental processing, because they allow for display-based reasoning (Larkin 1989; Cox 1999). In addition, they provide free interactive access to knowledge elements and resources represented by means of the diagram, and, thus, may enhance flexible knowledge use. It is, therefore, suggested that digital concept mapping may augment the capacity of the human brain in managing knowledge when coping in a self-regulated manner with complex cognitive processing tasks, e.g. resource-based learning, problem-based learning (Web-based studying, hypertext writing) (Savery and Duffy 1995; Rakes 1996; Bromme and Stahl 2005). In particular, advanced computer-based concept mapping tools may be a significant help for students studying in open e-learning scenarios based on a constructivist design rationale with a high amount of freedom for assembling ideas, generating and organizing knowledge, and use of knowledge for creative problem solutions. It is because of their dual potential for contributing to fostering processes of learning, as well as managing knowledge, that these tools are suggested to foster these same processes in e-learning scenarios (Tergan 2003; in press).

The goal of this paper is to outline the diverse potential of digital concept maps as a representational medium in supporting spatial semantic display processing for individual knowledge management in complex cognitive processing tasks. The analysis is based on a model of knowledge management processes as described by Probst, Raub, and Romhardt (1999). The processes focused on are cognitive, as well as meta-cognitive processes: knowledge identifica-

tion, knowledge evaluation, localization of knowledge resources, knowledge generation, knowledge representation/organization/, knowledge communication, and knowledge application.

2. What Can Digital Concept Maps Offer Knowledge Management?

Based on the model by Probst, Raub, and Romhardt (1999), certain interacting process categories of knowledge management may be identified, which are relevant for students coping with knowledge-rich task situations in a self-regulated manner. The categories are: identification and evaluation of knowledge, locating information and knowledge resources, knowledge generation, knowledge representation (organization, storage), knowledge use, knowledge communication. How can digital concept mapping contribute to fostering processes of individual knowledge management? Some potential roles and functions of mapping tools for fostering processes of knowledge management are outlined in the following paragraphs:

Knowledge Identification. Knowledge identification is a meta-cognitive activity. The focus is on checking the availability of knowledge in one's mind that is deemed relevant for effectively coping with the affordances of a particular cognitive task, e.g. attaining a particular instructional goal, solving a complex problem, acquiring expert knowledge. The affordances may either be implicit to learning goals or cognitive tasks or may have been analyzed and made explicit during a process of task analysis. Knowledge identification may be fostered with a mapping tool if, during the process of studying or problem solving, learners have constructed their own knowledge map for representing externally what they did not risk storing in short-term memory due to its limited capacity. Such mapped knowledge may be visually searched, analyzed and identified as relevant or irrelevant for coping effectively with a particular task.

Knowledge Evaluation. Identified knowledge may be evaluated. Knowledge evaluation in individual knowledge management is a meta-cognitive process. An individual concept map, which has been constructed by a student to represent their own individual domain knowledge, may be used by her or him, both for checking the adequacy of the knowledge with respect to the task requirements and for identifying knowledge gaps. For example, if the task is to acquire expert knowledge, the structure of an individual's knowledge as represented in a concept map may be compared with the knowledge structure of an expert as represented in an expert map. The learners themselves use their mapped knowledge, compare it with the affordances of a task (in terms of the knowledge, which is necessary to cope with it effectively), or with an expert's knowledge structure used as a criterion for successful learning. The process of knowledge evaluation is a higher-level meta-cognitive process, which may be performed effectively by advanced learners, but will probably have to be scaffolded by novice learners.

Localization of Knowledge and Knowledge Resources. When individual knowledge has been evaluated as inappropriate for effectively coping with a cognitive task situation and knowledge gaps have been identified, it is necessary to look for task-relevant content and resource knowledge to fill the gaps and acquire appropriate knowledge. Digital concept maps are well-suited for fostering the localization of missing elements of knowledge and task-relevant knowledge resources. Concept maps may be used as tools to help individuals navigating and visually searching knowledge and knowledge resources in knowledge repositories (Scott 1993; Carvalho, Hewett, and Cañas 2001; Weideman and Kritzinger 2003).

Knowledge Generation. Central to individual learning in instructional scenarios are cognitive processes aimed at both making sense of information presented by instruction or localized in a self-regulated learning mode in some knowledge resource, as well as at generating new knowledge on the basis of existing knowledge. New knowledge is generated by constructive cognitive processes like integrating, elaborating, reorganizing, reformatting existing knowledge structures and linking knowledge elements (concept knowledge, content knowledge, resource knowledge) with contexts and situations to which they may be applied. Concept mapping has been used effectively in instructional settings to foster processes of knowledge generation (e.g. Wallace et al. 1998; Dansereau in press). For example, Norrie and Gaines (1995) and Gaines and Shaw (1995) describe the rationale of a prototype Learning Web implementation, as well as tools, such as concept maps and repertory grids used within the web for knowledge generation. Concept-Mapping tools provide functions for externalized cognition (Cox 1999). They make knowledge explicit, facilitate knowledge elaboration, and may foster tuning and restructuring existing knowledge structures (Rumelhart and Norman 1978).

Knowledge Representation / Organization. The process of knowledge representation is closely related to the processes mentioned above. In order to make generated knowledge accessible for future use, it must be mentally represented and organized according to some semantic or pragmatic rationale, in a format, which mirrors the cognitive affordances for coping with a particular task situation. The representation must be dynamically adaptable according to changes in personal interests and task affordances. In complex and knowledge-rich cognitive processing tasks, it is necessary not only to represent the abstracted conceptual knowledge of a domain, but also content knowledge and task-relevant knowledge resources, which are associated with the conceptual knowledge in a coherent representational format. Digital concept mapping tools provide functions for externalizing mental representations of knowledge in arbitrary formats. Digital maps allow for mapping in a hypertext-like format by using sub-maps and hyperlinks. The problem with concept maps as external representations of knowledge is that the maps must make sense to the user in order to be used effectively. They need to be externalizations of knowledge in a literal sense. After some time,

maps often no longer make sense to the users. For a different user, it is even more difficult to make sense of a map without a common understanding of the semantic or pragmatic rationale behind a representation (Marshall 2001).

Knowledge Communication. Knowledge communication, as a knowledge management process, may serve different purposes, for example, to disseminate knowledge from a tutor to students, between students, and from a student to a tutor. Students working together in a cooperative instructional setting construct and communicate knowledge in order to construct a shared understanding or contribute to the design and development of a common cognitive artifact. Computer-based mapping tools may contribute to foster processes of knowledge communication in several ways. They may, for example, be used to communicate the concept structure of a subject matter and enhance knowledge acquisition. They may also be used as a basis for fostering cooperative work. Mapping tools may be particularly useful in fostering coping strategies in a task situation that requires knowledge, which is too comprehensive, and conceptual views, which are too diverse, for a single person to manage successfully. If a map is generated and owned by different users, the map can take over functions in communicating, and making explicit a particular knowledge representation of concepts, contents and resources, as well as different personal views of individual users for enhancing cross-community sharing of knowledge (Novak and Wurst in press). It may serve as a shared knowledge space for making argumentation more coherent, as well as contributing to enhance the quality of a cognitive artifact. Different students obtain access to the same structure of knowledge elements, annotate and re-annotate it, and thereby contribute to a commonly understood subject-matter content or to a commonly edited document. Tools that support cooperative work by means of map-conferencing via Internet are, for example, Cmap Tools, Inspiration, and SMART Ideas.

Knowledge Use. The ultimate ambition of knowledge management is to enhance the efficiency of knowledge use when coping with cognitive tasks. In order to facilitate knowledge use, the external representations of knowledge have to be structured and represented task-appropriately. Knowledge representations must be easily restructured and adapted to different situations, tasks, individual interests and contexts of use (Spiro et al. 1991). It has been suggested that concept mapping may enhance the processing capacities of the human brain. A necessary precondition for this enhancement is that the knowledge must be represented explicitly and knowledge elements must be accessed freely and tracked easily. Concept map-based visualizations of ideas and individual knowledge representations fulfill this prerequisite.

3. Perspectives for Application and Research

Concept mapping has proven to be a valuable technique for enhancing aspects of cognitive processing of conceptual knowledge. Whereas traditional techniques fail to meet the demands of coping effectively with managing concept, content and resource knowledge with one coherent external representation, digital concept mapping has great potential to support learners in self-regulated learning and knowledge management. However, representing, making accessible and localizing knowledge elements with the help of digital concept maps is not enough to make a learner-centered conception/concept of knowledge management become true. Considering empirical evidence of research in cognition, it may be predicted that it is the constructive cognitive activity of the users of the concept mapping tools aimed at generating, integrating and organizing domain knowledge and knowledge about resources that will give digital mapping tools an additional value for managing knowledge in contexts of resource-based learning and problem solving. It is important to develop conceptions/concepts of how to integrate ideas of knowledge and information visualization and how to use visualization strategies and tools more effectively (Tergan in press).

Research on the effective use of mapping tools for supporting the management of conceptual, content and resource knowledge in e-learning scenarios has to be initiated. This research has to focus on the individual and situational conditions for the effective use of concept maps for knowledge management and on how management processes may be fostered by technical features, instructional measures, and AI facilities. Questions of interest are a.o.: How do mental representations and concept maps, as external representations of individual knowledge, influence each other while solving spatial problems? How does the integration of content and resource knowledge in a spatial-semantic display, such as a concept map, contribute to the construction of a coherent, comprehensive mental representation of subject matter? How can AI techniques contribute to adapting digital concept mapping to the various prerequisites of users and task requirements?

A research program has been initiated to study the conditions of effective spatial-semantic processing of digital concept maps for managing knowledge. The conceptual rationale of the program, as well as results of first experimental and quasi-experimental studies, have been presented at a symposium at the 10th Biennial Conference of the European Association for Research on Learning and Instruction (EARLI) in Padova (Italy) August 26-30, 2003 (Tergan 2003). At the „International Workshop on Visual Artifacts for the Organization of Information and Knowledge“ (http://www.kmrc.de/workshops/visual_artifacts/?go=part) in Tuebingen (Germany), the role of diagrammatic representations of information and knowledge in supporting reasoning, problem solving, and knowledge use has been investigated from interdisciplinary perspectives (see Tergan and Keller in press). The topic will be further discussed with regard to concept map-based visualizations of knowledge and information at a follow-up symposium at the 11th Biennial Conference of the EARLI at Nicosia (Cyprus) August 23• 27, 2005.

References

Bromme, R., and Stahl, E. 2005. Is Hypertext a Book or a Space? The Impact of Different Introductory Metaphors on Hypertext Construction. *Computers & Education* 44(2):115-133.

Bruillard, E, and Baron, G.-L. 2000. Computer-Based Concept Mapping: A Review of a Cognitive Tool for Students. In *Proceedings of Conference on Educational Uses of Information and Communication Technologies (ICEUT 2000)*, eds. D. Benzie, and D. Passey, 331-38. Beijing: Publishing House of Electronics Industry (PHEI).

Carvalho, M.; Hewett, R.; and Cañas, A. J. 2001. Enhancing Web Searches from Concept-Map Based Knowledge Models. *Proceedings of the SCI. Fifth World Multi-Conference on Systems, Cybernetics and Informatics*. Orlando, FL. Available online November 10, 2004: http://www.ihmc.us/users/acanas/Publications/EnhancedWeb-Searches/Enhancing%20Web%20Searches%20from%20Concept%20Map-based%20Knowledge%20Models.pdf

Cox, R. 1999. Representation Construction, Externalized Cognition and Individual Differences. *Learning and Instruction* 9(4):343-363.

Dansereau, D. F. in press. Node-Link Mapping Principles for Visualizing Information and Knowledge. In *Visualization of Information and Knowledge. Searching for Synergies*, eds. S.-O. Tergan, and T. Keller. Heidelberg/New York: Springer – Lecture Notes in Computer Science.

Gaines, B.-R., and Shaw, M. L. G. 1995. Concept Maps as Hypermedia Components. *International Journal of Human Computer Studies* 43(3):223-361.

Jonassen, D. H. 1992. Semantic Networking as Cognitive Tool. In *Cognitive Tools for Learning*, eds. P. A. M. Kommers, D. H. Jonassen, and J. M. Mayer, 12-22. Berlin: Springer.

Larkin, J. H. 1989. Display-Based Problem Solving. In *Complex Information Processing: The Impact of Herbert A. Simon*, eds. D. Klahr, and K. Kotovsky, 319-341. Hillsdale, NJ: Lawrence Erlbaum Associates.

Marshall, C. C. 2001. The Haunting Question of Intelligibility. Paper presented at the *Eleventh Hypertext '01* (Aarhus, Denmark, 2001) (http://www.csdl.tamu.edu/~shipman/SpatialHypertext/SH1/marshall.pdf).

Norrie, D. H., and Gaines, B. R. 1995. The Learning Web: A System View and an Agent-Oriented Model. *International Journal of Educational Telecommunications* 1(1):23-41.

Novak, J. D., and Gowin, D. B. 1984. *Learning how to Learn. Cambridge*: Cambridge University Press.

Novak, J., and Wurst, M. in press. Collaborative Knowledge Visualization for Cross-Community Learning. In *Visualization of Information and Knowledge. Searching for Synergies*, eds. S.-O. Tergan, and T. Keller. Heidelberg/New York: Springer – Lecture Notes in Computer Science.

O'Donnell, A. M., Dansereau, D. F., and Hall, R. H. 2002. Knowledge Maps as Scaffolds for Cognitive Processing. *Educational Psychology Review* 14(1):71-86.

Probst, G., Raub, S., and Romhardt, K. 1999. *Wissen managen. Wie Unternehmen ihre wertvollste Ressource optimal nutzen*. Frankfurt am Main; Wiesbaden: FAZ/ Gabler.

Rakes, G. C. 1996. Using the Internet as a Tool in a Resource-Based Learning Environment. *Educational Technology* 36(5):52-56.

Rumelhart, D. E., and Norman, D. A. 1978. Accretion, Tuning and Restructuring: Three Modes of Learning. In *Semantic Factors in Cognition*, eds. J. W. Cotton, and R. L. Klatzky, 37-53. Hillsdale, NJ: Lawrence Erlbaum Associates.

Savery, J. R., and Duffy, T. M. 1995. Problem Based Learning: An Instructional Model and Its Constructivist Framework. *Educational Technology* 35:31-38.

Scott, D. 1993. Visual Search in Modern Human-Computer Interfaces. *Behaviour & Information Technology* 12(3): 174-189.

Spiro, R. J.; Feltovich, P. J.; Jacobson, M. J.; and Coulson., R. L. 1991. Cognitive Flexibility, Constructivism, and Hypertext: Random Access Instruction for Advanced Knowledge Acquisition in Ill-Structured Domains. *Educational Technology* 31:24-33

Tergan, S.-O. 2003. Managing Knowledge with Computer-Based Mapping Tools. In *Proceedings of the ED-Media 2003 World Conference on Educational Multimedia, Hypermedia & Telecommunication*, eds. D. Lassner, and C. McNaugh, 2514-2517. University of Honolulu: Honolulu, Hawaii (USA), June 23-28, 2003.

Tergan, S.-O. in press. Concept Mapping for Managing Knowledge and Knowledge Resources. In *Visualization of Information and Knowledge. Searching for Synergies*, eds. S.-O. Tergan, and T. Keller. Heidelberg/New York: Springer – Lecture Notes in Computer Science.

Tergan, S.-O., and T. Keller, eds. in press. *Visualization of Information and Knowledge. Searching for Synergies.* Heidelberg/New York: Springer – Lecture Notes in Computer Science.

Wallace, D. S., West, S. W. C., Ware, A., and Dansereau, D. F. 1998. The Effect of Knowledge Maps that Incorporate Gestalt Principles on Learning. *Journal of Experimental Education* 67:5-16.

Weideman, M., and 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. Available online November 10th: http://www.uwc.ac.za/ems/is/hict