Concept Mapping as a Mindtool for Critical Thinking

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ABSTRACT

Concept mapping is a mindtool (cognitive tool) that can enhance the interdependence of declarative and procedural knowledge to produce yet another form of knowledge representation known as structural knowledge (Jonassen, 1996). Structural knowledge is best described as knowing *why* something is the case. It helps learners integrate and interrelate declarative and procedural knowledge by activating the perceived static nature of declarative knowledge and by increasing the awareness of why one knows how to do something. By using computer-based concept mapping tools as a cognitive or learning strategy, learners can sharpen inference-making and critical thinking skills and can avoid the acquisition and accumulation of inert (unusable) knowledge. This article discusses the use and application of two computer-based concept mapping tools, Inspiration® and Semnet®, in educational contexts to foster meaningful learning and understanding. Inspiration® and Semnet® are visual thinking environments that allow users to create concept maps, semantic networks, outlines, graphic organizers and other comprehension monitoring activities. The article addresses the use of computer-based concept mapping as a learning strategy, an instructional strategy, and as a collaborative thinking tool, offering guidelines for educators on how to implement these uses in the classroom.

Introduction

Knowledge representation refers to how we represent information in long-term and working memory (Gagne, Yekovich, & Yekovich, 1993). Knowledge representation can take many forms (mental representations) depending on the type of knowledge learned and the cognitive strategy used in acquiring that knowledge. For example, declarative knowledge—which is best described as knowing *that* something is the case—is represented in the form of propositions. Propositions are knowledge units often referred to as schema (Jonassen, 1988). These knowledge units form a *propositional network* and are comprised of arguments (topics and attributes) and relations that constrain those arguments (Gagne, Yekovich, & Yekovich, 1993). Our schema for "school" for example is comprised of arguments such as teachers, students, classes, grades, classrooms, and books, and relations that constrain those arguments such as "teachers teach students," "students learn from teachers," and "grades measure students' performance" (Figure 1).

Procedural knowledge, on the other hand, is knowing *how* to do something and

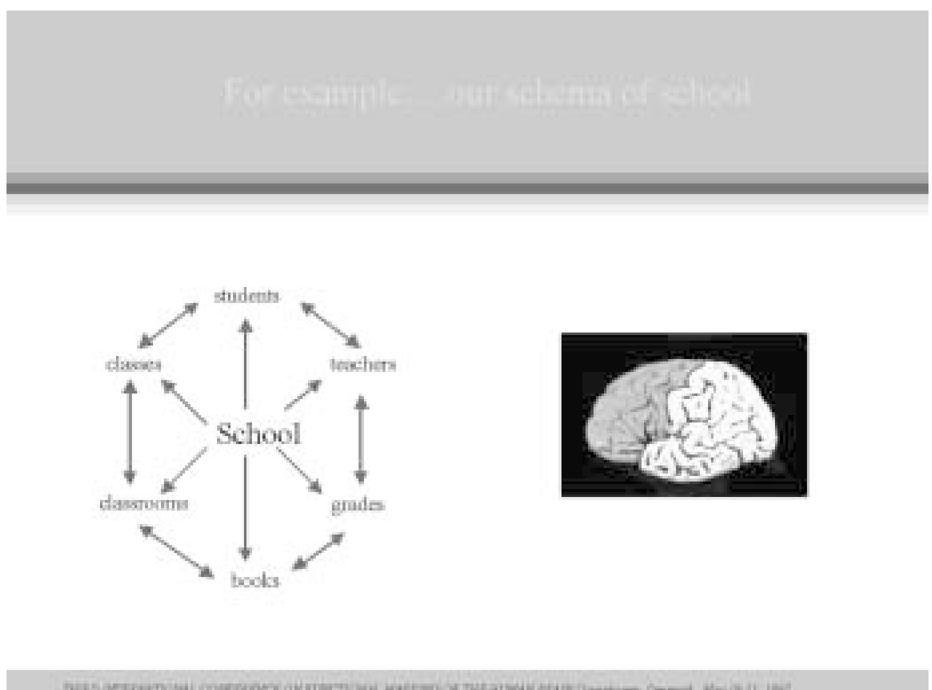

Figure 1: A propositional network of a school schema

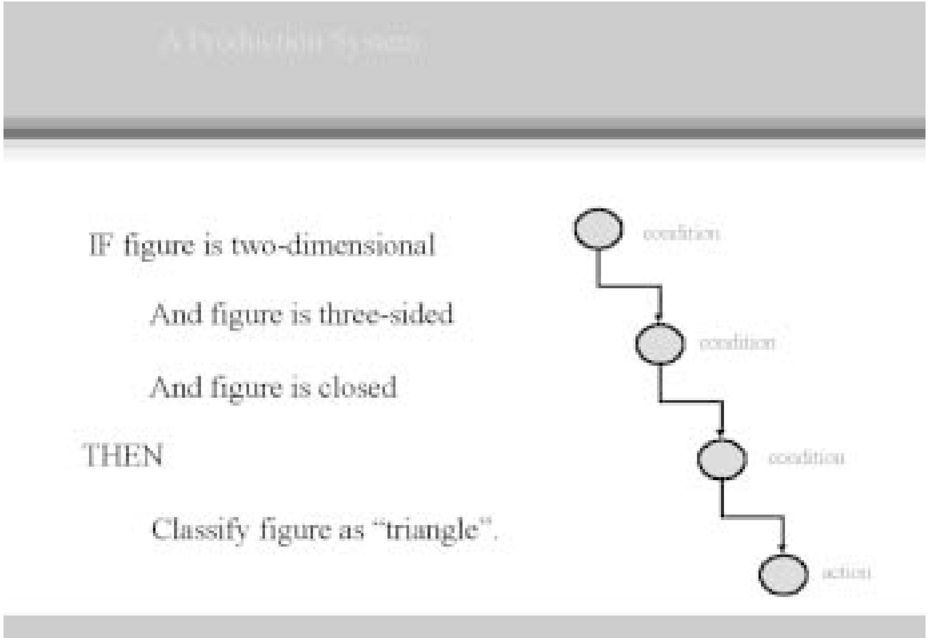

Figure 2: A production sequence based on contingency statements

is represented in the form of productions or if-then contingency statements (Figure 2). Productions are condition–action rules that enable people to solve problems, make decisions, and develop plans (Gagne et al., 1993; Jonassen, 1988). In other words, they "produce" an action or a mental or physical behavior.

Productions can be interrelated to form a production system which can lead to a complex behavior. Developing production systems for different types of knowledge enhances inference-making and critical-thinking skills.

Declarative knowledge and procedural knowledge are interdependent (Jonassen, 1996). Although one might think that acquiring propositional knowledge is a prerequisite for forming productions, in some cases forming procedural knowledge can lead to the acquisition of declarative knowledge, and *applying* declarative knowledge can lead to the acquisition of production systems. The interdependence of these two types of knowledge is largely dependent on the cognitive (or metacognitive) strategy that the learner is using while acquiring the knowledge. At the lower end of the spectrum, rehearsal strategies involving oral repetition of content, copying, and underlining will most likely result in a learner's ability to recall and state facts as is, and elaboration strategies such as paraphrasing and summarizing content will most likely result in concept learning. On the higher end of the spectrum, comprehension monitoring strategies involving self-questioning (a form of reflection) and using advance organizers to guide one's learning will most likely result in analysis, synthesis, and evaluation processes that are higher-order learning outcomes (Bloom, 1956). The above discussion indicates that learning strategies can affect the encoding process and hence the learning outcome and associated performance (Weinstein & Mayer, 1986).

Concept mapping is a mindtool (a cognitive tool) that can enhance the interdependence of declarative and procedural knowledge to produce yet another form of knowledge representation known as *structural knowledge* (Jonassen, 1996). Structural knowledge is best described as knowing *why* something is the case. It helps learners integrate and interrelate declarative and procedural knowledge by activating the perceived static nature of declarative knowledge and by increasing the awareness of *why* one knows *how* to do something. It is reflected in richer propositional networks known as semantic networks that communicate more knowledge about the interrelatedness of concepts articulated by the learner, revealing a deeper form of knowledge representation known as mental models (Jonassen & Tessmer, 1997). Concept mapping can lead to the development of rich mental models in learners requiring them to think about a knowledge domain in meaningful ways. By using this mindtool as a cognitive or learning strategy, learners can sharpen inference-making and critical-thinking skills and can avoid the acquisition and accumulation of inert (unusable) knowledge (Hannafin, 1992).

Studies about the effectiveness of concept mapping as a cognitive tool date back to the early 1980s, when a group of researchers at Cornell University became interested in studying changes in students' understandings of science concepts over a 12-year span of schooling (Novak, 1990). A need for developing a tool to represent students' understanding of concepts and more importantly *changes* in students' understanding over time, led to the creation of a cognitive map (later known as a concept map) as a graphical organizing structure for concepts. Several studies later emerged employing the use of this new visual tool or spatial representation of knowledge, some challenging Piaget's developmental theory in asserting that primary-grade children are capable of understanding abstract concepts by developing very thoughtful concept maps which they can explain intelligently to others (Symington & Novak, 1982). Other studies by Novak et al. demonstrated that graduate students found that concept maps helped them *learn how to learn* and were useful as a tool to represent changes in their knowledge structures over time. These same graduate students also indicated that concept maps were useful for representing knowledge in any discipline and that concept maps were helpful in organizing and understanding new subject matter (Novak, 1990). Another study conducted by Dagher and Cossman (1990) aimed at analyzing science teaching in schools found that verbal explanations of science concepts are not well-suited for helping students construct concept maps. The study suggested that some categories of propositions that are analogical, functional, and mechanical in nature would be more appropriate for developing concept maps. Such categories would enable more *conceptually transparent* concept maps (Wandersee, 1990) making it possible to better evaluate students' understandings, changes in understandings and misconceptions in understandings of science concepts. Concept mapping techniques began as paper-based and evolved to computer-based tools with the innovation of visual design software. This article discusses the use of two computer-based concept mapping tools, Inspiration® and Semnet®, in an educational setting to foster meaningful learning and understanding.

Computer-Based Concept Mapping Tools

Inspiration® and Semnet® are computer-based visual thinking environments that allow users to create concept maps (also known as semantic networks or nets), webs, outlines, and graphic organizers. They are easy-to-use, multiplatform, and Web-enabled (can be ported to the Web). The basic elements of concept mapping software are *nodes* and *links.* Learners use nodes to represent ideas and links to represent relationships that connect ideas. Applying these elements to our earlier example of the schema for the concept "school," *students* and *teachers* would each be a node in the concept map and *students learn from teachers* would be a link. As the nodes and links become interrelated, a structural knowledge representation emerges paving the way for a meaningful understanding of the knowledge domain depicted. In order to build a concept map, the learner must "transform the knowledge to be mapped from its current linear form to a context-dependent form" (Wandersee, 1990, p. 927). This process forces the learner to interact with the knowledge domain, identify the key concepts, and relate them to each other in a meaningful way. Prior knowledge and personal experience play an important role in this learning task ultimately creating a reorganization of existing schemata into a new knowledge structure that is useful and pertinent.

The main advantage to the utilization of computer-based concept mapping tools such as Inspiration® and Semnet® is that they remove the drudgery and mess of revising paper-based concept maps (Anderson-Inman & Zeitz, 1993). Computer-based concept maps can be modified dynamically making it possible for learners to reflect their improved understanding of a content domain over time by revising their concept maps quickly and easily. Revisions can also be initiated or guided by teachers, which makes concept mapping effective as a means of assessing student learning (McClure, Sonak, & Suen, 1999). Computer-based concept maps can also be used as planning tools to organize a project or a learning activity. In essence, concept mapping can be used as a learning strategy, an instructional strategy, a strategy for planning a curriculum, and a means of assessing students' understanding of abstract concepts (Novak, 1990). Although the focus of this article is primarily on the use of computer-based concept mapping as a learning strategy, other uses will be briefly explored.

Concept Mapping as a Learning Strategy

Inspiration® supports the following learning strategies that according to Weinstein and Mayer (1986) fall under four categories: organizational strategies for basic learning tasks, organizational strategies for complex learning tasks, elaboration strategies for complex learning tasks, and comprehension monitoring skills. Table 1 displays the strategies, the associated category, and an educational context.

It is evident from the above associations that Inspiration® can have extensive classroom uses that support students in *learning how to learn*. Students can use

LEARNING STRATEGY	CATEGORY	EDUCATIONAL EXAMPLE
Planning	Organization strategy for basic learning tasks	Preparing advance organizers for learning
Organizing	Organizational strategy for basic learning tasks	Grouping or ordering to-be-learned items from a list or a section of prose
Outlining	Organizational strategy for complex tasks	Outlining a passage or creating a hierarchy
Webbing	Organizational strategy for complex tasks	Creating a diagram to show the relationship among facts and concepts
Writing	Elaboration strategies for complex tasks	Paraphrasing, summarizing, or describing how new information relates to existing knowledge
Knowledge mapping Brainstorming Concept mapping	Elaboration strategies for complex tasks	Creating analogies, metaphors, and other structures that describe how new or more complex information relates to existing information
Reflection Exploration	Comprehension monitoring strategies	Checking for comprehension failures using self-questioning and other methods that help students find the main ideas and elaborate on important information

Table 1

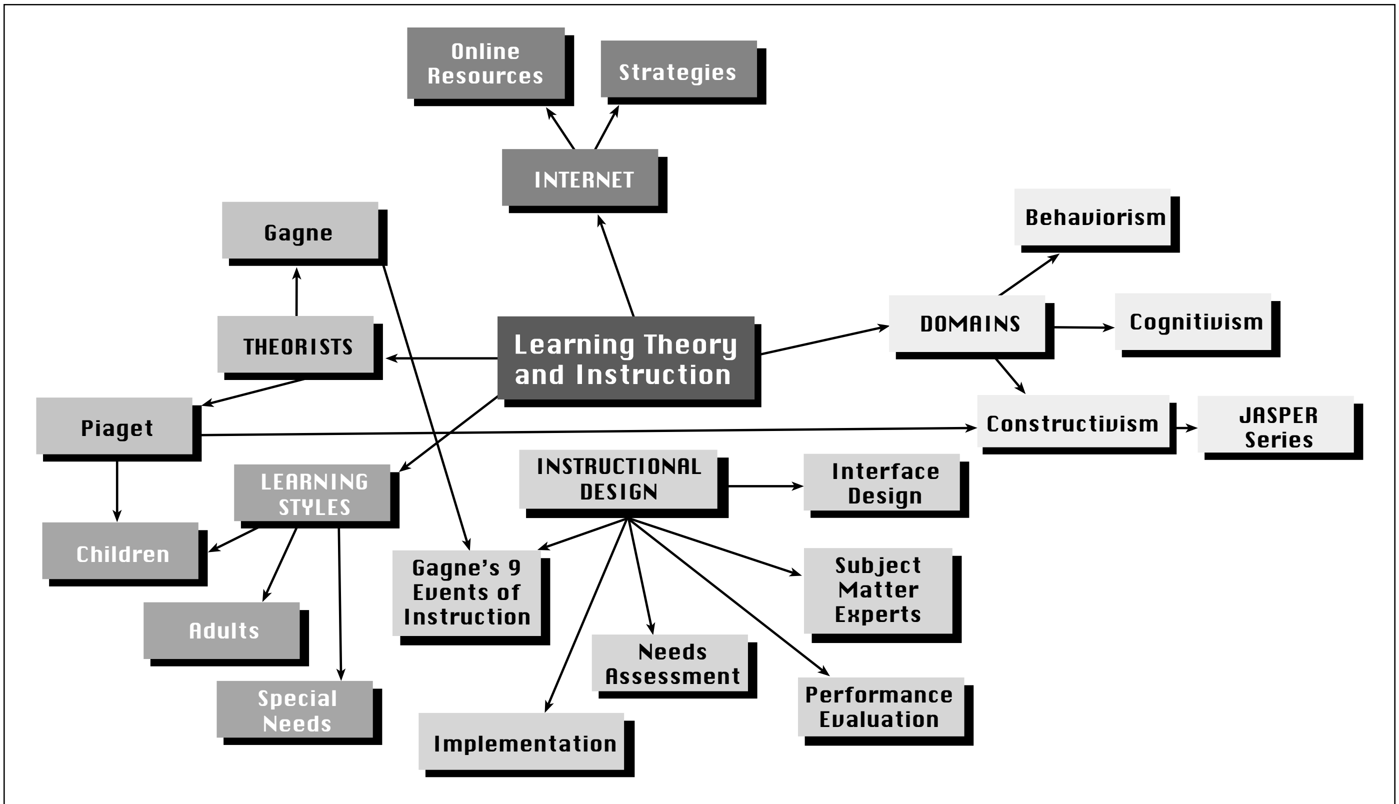

Figure 3: First iteration of a concept map

this mindtool as an organizational strategy to identify important concepts of a content domain and the interrelationships between them. This process serves the same purpose as outlining a chapter but requires a more thorough analysis of the content (Jonassen, 1996). Students are engaged in generating a semantic network that mirrors their understanding of the content under study. This spatial representation of ideas and relationships becomes a scaffold for acquiring new knowledge (Spoehr, 1994). As students progress in the learning process, they can revisit their concept maps and modify the content by adding new ideas, formalizing undeveloped ideas and reorganizing relationships between ideas based on new understandings. This exploratory and reflective process serves as a comprehension monitoring strategy that helps students move through the three stages of knowledge acquisition proposed by schema theorists (e.g., accretion, restructuring, and tuning) proposed by Norman (1978). The following is an example to illustrate the above.

In EDIT 704, a graduate course at George Mason University that addresses learning theory and instructional technology, students used Inspiration® to construct concept maps to represent their understanding of the various learning theories and their relationship to instruction in preparation for a research paper on learning theory. Beginning with propositional networks that largely depicted the acquisition of declarative knowledge, students revised their concept maps every couple of weeks ending with elaborate semantic networks that reflected a deeper and more meaningful understanding of the content (structural knowledge), based on new readings and instructional activities conducted throughout the course. The semantic network provided a rich information base guiding students in their end semester writing task. In this example, students used concept mapping both as an organizing tool and a comprehension monitoring tool. Below is an example of a student's propositional network (first iteration) and its evolution into a semantic network (fourth iteration). The first iteration (Figure 3) supports the organizational strategy for basic learning tasks and the knowledge acquisition phase of accretion. The learner is organizing concepts in clusters based on the readings and prior knowledge. The structure is incomplete; however, it acts as a prototype module for the construction of a new knowledge module (Norman, 1978). The concept map relates the following five concepts to the main concept of learning theory and instructional design: theorists, the Internet, domains, instructional design, and learning styles. The learner has provided further groupings for each of these concepts however no relationships or elaborations have yet been identified.

The fourth iteration (Figure 4, p. 20) supports the organizational strategy for complex learning tasks (webbing) and the knowledge-acquisition phase of restructuring. The learner has achieved new insight into the structure of the topic and is making elaborations by creating relationships between the concepts in the diagram. The concept map shows evidence in "jumps in understanding" specifically as it relates to the concept of "theorists."

The learner is recognizing deficiencies in previous concept maps and restructuring the knowledge base by making inferences and adding analogies (Norman,

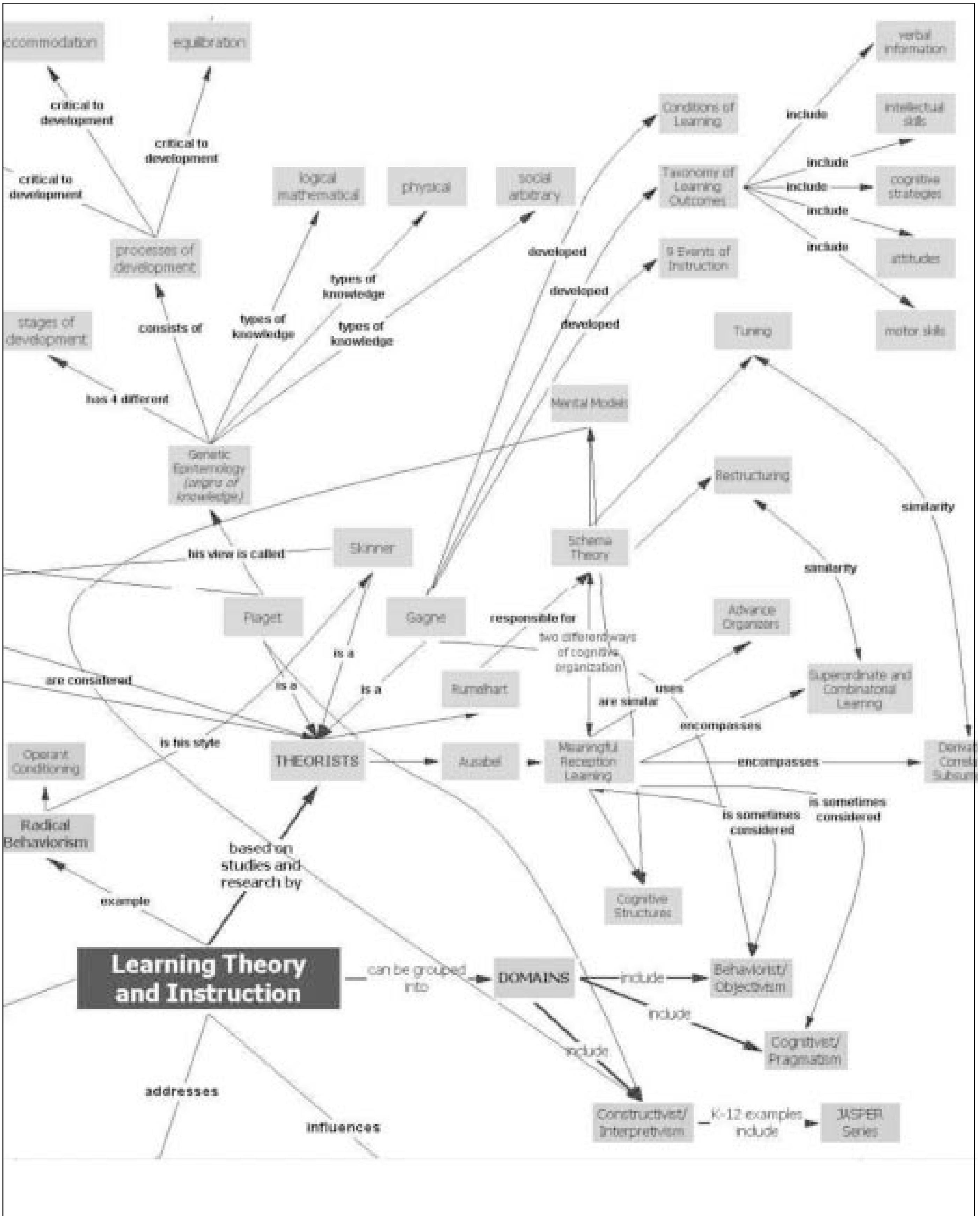

Figure 4: A section of the fourth iteration of a concept map

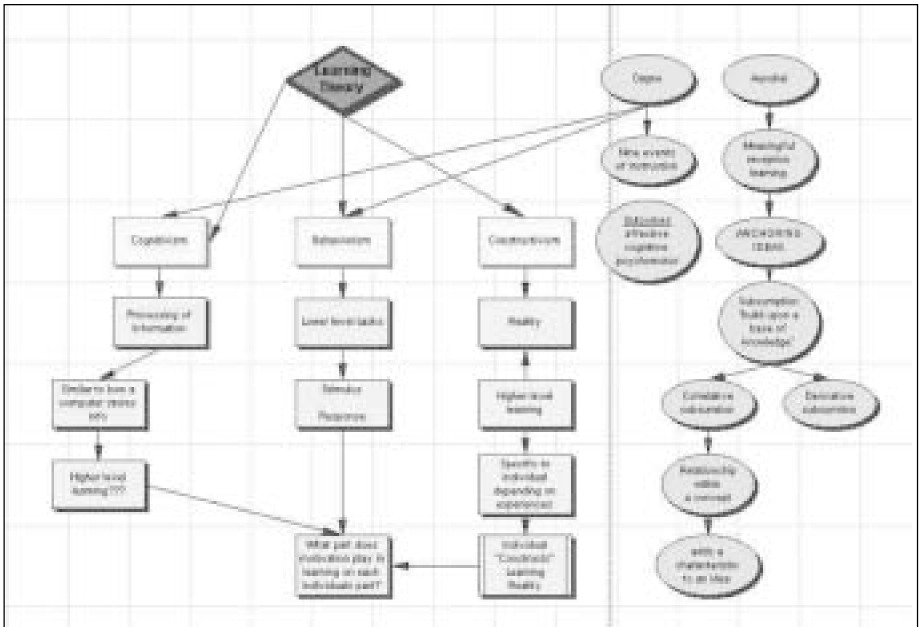

Figure 5: A first iteration concept map in spatial form

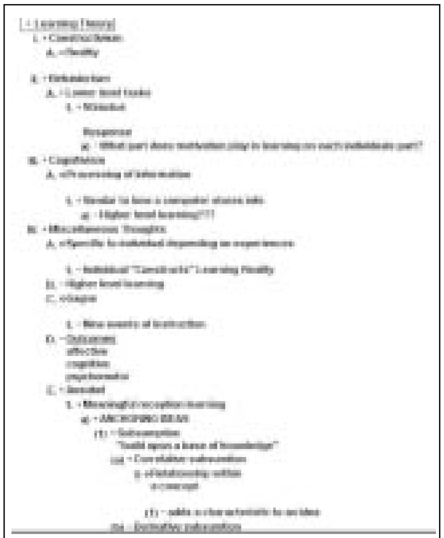

Figure 6: The same concept map in outline form

1978). A noticeable inference in this concept map is the finding of similarities between Ausubel's meaningful reception learning and schema theory.

Inspiration® also supports nonvisual thinkers by allowing users to toggle between the diagram view (the visual representation of the concept map) and an outline view. At any time during the creation of a concept map, a user can toggle to the outline view to view the concept map in an outline form. The outline view provides a hierarchical structure of the concept map based on the links between nodes. Users can use this view to add new topics, insert subtopics, and rearrange the organizational structure of the concept map. Users can also type notes in outline view under each topic or subtopic to help convert the concept map into a document in preparation of a writing assignment. All changes performed in the *outline view* are reflected in the *diagram view* and vice versa. Figure 5, p. 21, shows a diagram view of a concept map on learning theory created in Inspiration® in EDIT 704, and Figure 6, p. 21, shows the corresponding outline view. The intuitiveness of the software in converting the concepts and links to an outline view (and vice versa) makes it easier for the linear thinker (or the visual thinker) to fine tune the structure when viewing it in a more familiar form.

Concept Mapping as an Instructional Strategy

Inspiration® also has a *rapid fire* feature that allows users to get down their ideas as fast as they can think of them without having to create new symbols each time. This feature can support brainstorming as a learning strategy and can be used by teachers as a tool to generate an organized structure for new or complex content, based on student input. For example, teachers can pose questions during class that encourage students to generate analogies and metaphors to help them relate new content to existing knowledge, and they can capture student responses by entering them instantaneously into Inspiration® using the rapid fire feature. At the end of such a brainstorming session, a student-generated concept map emerges that can serve as an advance organizer for future class discussions. This example can also be perceived as a preinstruction or assessment exercise, allowing teachers to inspect students' existing knowledge structures to identify misconceptions and adapt instruction to facilitate new learning (McClure, Sonak, & Suen, 1999). Other features of Inspiration® include a library of symbols that range from pictures of animals to geometric shapes allowing users to contextualize their concept maps. Users can also create their own symbols to illustrate concepts and use colors and other drawing tools to highlight and accentuate the main ideas and interrelationships.

It is not difficult from the above discussion to visualize the effectiveness of this computer-based concept mapping tool in facilitating student learning. Students can use it as a study aid to organize thoughts, create outlines, plan research papers, and examine content domains by extracting main concepts and ideas and realizing the interconnectedness of those ideas. Teachers can use this tool as a planning aid to actively generate graphic organizers for content, create lesson plans, and adapt instruction to students' needs by monitoring students' use of concept mapping to develop key concepts of a content domain.

Concept Mapping as a Collaborative Thinking Tool

The other visual learning tool discussed in this paper is Semnet®. SemNet® software can be used to represent knowledge domains much in the same way Inspiration® does. It allows users to organize ideas about any topic in the form of a semantic network linked by named relations. However, the main difference between Semnet® and Inspiration® is that Semnet® creates a hypertext environment that allows the user to navigate between concepts through the

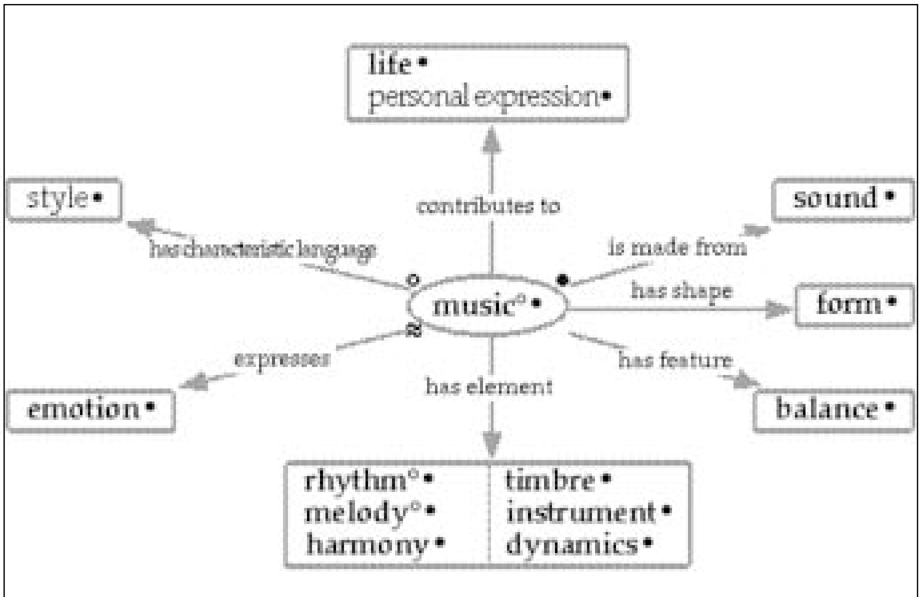

Figure 7: Courtesy http://trumpet.sdsu.edu/SemNet_Study_Tool.html, Semnet Research Group

named relations by emphasizing the concept-relation-concept in the construction of the knowledge map. This is based on the principle that concepts are ideas that can usually be described by a word or a phrase and that concepts can be understood through their relations to other concepts. Thus Semnet® "preserves the subject-verb-object relationship between two concepts to show the core concept, relationship, and related concepts as a 'web' of knowledge to which other illustrative material may be linked and attached" (Semnet Research Group, 1991). For example, the concept music can be understood through the word "music" and also through its relations to other concepts (Figure 7, p. 22).

Those relations are elaborated using the subject-verb-object, which is the basis for normal sentence construction, as can be seen in Figure 7. A concept-relation-concept is known as an instance. In Figure 7, there are seven instances. By providing this structure, Semnet® forces students to elaborate on the linkages between nodes (concepts) in a concept map promoting the interdependence between declarative and procedural knowledge right from the start and eliminating the propositional stage. While students are constructing semantic networks or knowledge maps, they are actively seeking information to describe concepts by naming them and naming relationships that link two or more concepts together. In the process, they are creating an information map of their knowledge structure and this is much more useful than rote memorization. According to Weinstein and Mayer (1986), this supports elaboration strategies of complex tasks. The dots appearing next to the related concepts—emotion, balance, life, style, form, rhythm, melody, harmony, and so on—imply that the user has created an individual net or knowledge structure for each of those concepts. By clicking on a related concept, Semnet® will show the user the individual net in which the related concept becomes the central or core concept.

This cascading metaphor of connecting *instances* through active links to other instances is a unique feature of Semnet® software that makes it ideal for use as a collaborative thinking tool. Different users can create individual concept maps (or nets) that can be merged together to create a larger and more encompassing net through a social knowledge construction process that involves collaboration. Collaboration in this context implies the clarification of ideas through the use of concept maps. According to the Semnet® Research Group (1991), Semnet® software "can support collaborative endeavors such as curriculum development by teams of professionals." Curriculum developers can form a community of practice and communicate their expertise by constructing individual concept maps to represent a model curriculum and then use these maps as a shared resource to initiate a discussion aimed at synthesizing ideas. Novak (1990) emphasized how this process can facilitate building a science curriculum, for example, around the *major conceptual schemes* of science (reflecting the psychological structure of knowledge) instead of the traditional topical (logical) arrangement of the science curriculum currently in place. He further elaborates (referencing Wandersee, 1990) by stating that "concept maps can be used to present both a global view of a K–12 science curriculum built around basic science concepts, and varying degrees of magnification to the level of a specific science lesson with each map showing key concepts and concept relationships necessary to understand the larger or the more explicit domain of science" (p. 944). Semnet® software provides the technological potential of dynamically linking individual maps to construct a larger map, making it possible to "telescope from a macro to a microscopic concept map for the domain to be studied" (Novak, 1990, p. 944). Using Semnet® software as a tool to engage in curriculum building supports the process of social negotiation that is a fundamental principle of communities of practice and what makes this exercise truly collaborative. This process can have major implications for classroom use. Teachers can engage students in collaborative activities that require the construction of individual computer-based concept maps to be used as blueprints for the realization of a larger task (project) that requires the integration of these maps into a single comprehensive structure.

To summarize, Table 2 outlines the three concept mapping strategies discussed above (concept mapping as a learning strategy, concept mapping as an instructional strategy, and concept mapping as a collaborative thinking tool) and their implications for instruction and classroom use.

Conclusion

Concept mapping is a powerful and effective cognitive tool that encourages students

CONCEPT MAPPING CAN BE USED AS A:	SPECIFIC ACTIVITIES INCLUDE:	THESE ACTIVITIES CAN FACILITATE THE FOLLOWING CLASSROOM APPLICATION:
Learning strategy or a study tool	Planning, organizing, outlining, webbing, knowledge mapping, reflection, exploration	Writing a paper Conducting research Designing a science experiment Outlining a chapter Creating story Webs
Instructional strategy or a teaching tool	Planning, organizing, brainstorming, pre-instruction assessment exercise	Preparing an advance organizer Preparing a lesson plan Organizing assessment Supporting generative learning activities
Collaborative thinking tool	Curriculum planning, project planning, collaboration, exploration, reflection, knowledge building	Creating communities of practice Facilitating interdisciplinary projects Collecting and organizing information and resources

Table 2

to organize their knowledge about a content domain and to be explicit about the nature of relationships between ideas (Spoehr, 1994). Concept mapping forces students to think meaningfully about the content domain in order to identify and verify important concepts, classify concepts, describe the relationship between concepts and assess its meaning, analyze the nature of the relationship, and form the link or connection which engages the most critical thinking (Jonassen, 1996). Depending on how concept mapping is utilized in an instructional context, it can alter the encoding process that in turn affects the learning outcome and performance of students. As a learning strategy, concept mapping can support organizational strategies, elaboration strategies, and comprehension monitoring strategies in varying degrees of complexity. Computer-based concept mapping tools such as Inspiration® and Semnet® can facilitate these learning strategies by helping students create propositional and semantic networks to articulate and communicate their meaningful understanding and hence structural representation of a knowledge domain and by providing rich information structures that can function as advance organizers and schemas for analysis, synthesis, and evaluation of knowledge.

As an instructional strategy, teachers can use computer-based concept mapping to engage students in a generative, pre-instructional dialogue about concepts and principles of a knowledge domain and subsequently capture this dialogue in a concept map to create an advance organizer of the content to be studied based on students' input. Teachers can also use this advance organizer as a diagnostic tool to create appropriate lesson plans aimed at clarifying misconceptions that students may have about the knowledge domain under study. Finally, computer-based concept mapping can be used as a collaborative tool to foster teamwork and facilitate project-based activities by encouraging the sharing, discussion, and integration of spatial representations of content in order to construct a more cohesive and comprehensive knowledge structure.

REFERENCES

Anderson-Inman, L., & Zeitz, L. (1993). Computer-based concept mapping: Active studying for active learners. *The Computer Teacher, 21*(1), 6–8, 10–11.

Dagher, Z., & Crossman, G. W. (1990, April). *The nature of verbal explanations given by science teachers.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Gagne, E. D., Yekovich, C. W., & Yekovich, F. R. (1993). *The cognitive psychology of school learning*. New York: HarperCollins College Publishers.

Hannafin, M. J. (1992). Emerging technologies, ISD, and learning environments: Critical perspectives. *Educational Technology Research & Development, 40*(1), 49–63.

Inspiration® Software, Inc. www.inspiration.com.

Jonassen, D. H. & Tessmer, M. (1997). An outcomes-based taxonomy for instructional systems design, evaluation, and research. *Training Research Journal, 2*, 11–46.

Jonassen, D. H. (1996). *Computers in the Classroom: Mindtools for Critical Thinking.* Englewood Cliffs, NJ: Prentice Hall Inc.

Jonassen, D. H. (1988). Designing structured hypertext and structuring access to hypertext. *Educational Technology, 28*(11), 13–16.

Norman, D. (1978). Notes toward a theory of complex learning. In A. M. Lesgold, J. W. Pelligrino, S. D. Fokkema, & R. Glaser (Eds.), *Cognitive psychology and education.* Norwell, MA: Plenum Publishers.

Novak, J. D. (1990). Concept mapping: A useful tool for science education. *Journal of Research in Science Teaching, 27*(10), 937–949.

Parsons, J. J., & Oja, D. (1996). *Computer concepts.* CTI, Cambridge, MA.

Semnet Research Group, Inc. (1991). *Semnet study tool.* http://trumpet.sdsu.edu/semnet.html

McClure J., Sonak, B., & Suen H. (1995). Concept map assessment of classroom learning: Reliability, validity, and logistical practicality. *Journal of Research in Science Teaching, 36*(4), 475–492.

Spoehr, K. T. (1994). Enhancing the acquisition of conceptual structures through hypermedia. In K. McGilly (Ed.), *Classroom lessons: Integrating* *cognitive theory and classroom practice.* Cambridge, MA: MIT Press.

Symington, D. & Novak, J. D. (1982). Teaching children how to learn. *Educational magazine, 39*(5), 13–16.

Wandersee, J. H. (1990). Concept Mapping and the Cartography of Cognition. *Journal of Research in Science Teaching, 27*(10), 923–936.

Weinstein, C. E. & Mayer, R. E. (1986). The Teaching of Learning Strategies. In Wittrock (Ed.), *Handbook of research on teaching.* New York: Macmillan Publishing.

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