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Knowledge Maps as Scaffolds for Cognitive Processing

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Knowledge maps are node-link representations in which ideas are located in nodes and connected to other related ideas through a series of labeled links. The research on knowledge mapping in the last 12 years has produced a number of consistent findings. Students recall more central ideas when they learn from a knowledge map than when they learn from text and those with low verbal ability or low prior knowledge often benefit the most. The use of knowledge maps also appears to amplify the benefits associated with scripted cooperation. Learning from maps is enhanced by active processing strategies such as summarization or annotation and by designing maps according to gestalt principles of organization. Fruitful areas for future research on knowledge mapping include examining whether knowledge maps reduce cognitive load, how map learning is influenced by the structure of the information to be learned, and the possibilities for transfer. Implications for practice are briefly delineated.

KEY WORDS: knowledge maps; scaffolding; active learning; individual difference.

The purpose of this article is to provide a review of the research on a particular form of knowledge representation, the knowledge map, and to point to areas of future research with this tool and to some of the practical implications of the work related to it. Other forms of graphical representation such as concept mapping (Novak, 1990, 1998; Novak and Musonda, 1991) have

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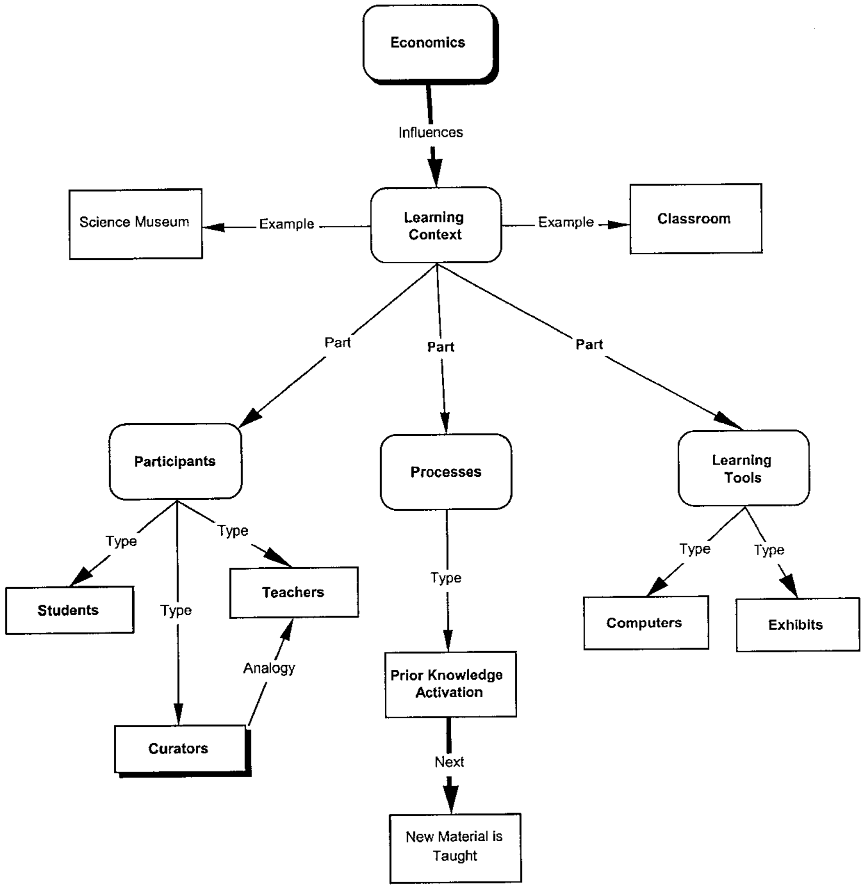

Fig. 1. An example of a partial knowledge map describing learning contexts.

been widely used in science education research but a complete review of the various forms of graphical representation is beyond the scope of this paper.

Knowledge maps are node-link representations in which ideas are located in nodes and connected to other related ideas through a series of labeled links (see Fig. 1). They differ from other similar representations such as mind maps, concept maps, and graphic organizers in the deliberate use of a common set of labeled links that connect ideas. Some links are domain specific (e.g., *function* is very useful for some topic domains but not others) whereas other links (e.g., *part*) are more broadly used. Links have arrowheads to indicate the direction of the relationship between ideas. Three main categories of links can be used (McCagg and Dansereau, 1991): dynamic links that denote a changing relationship between the linked

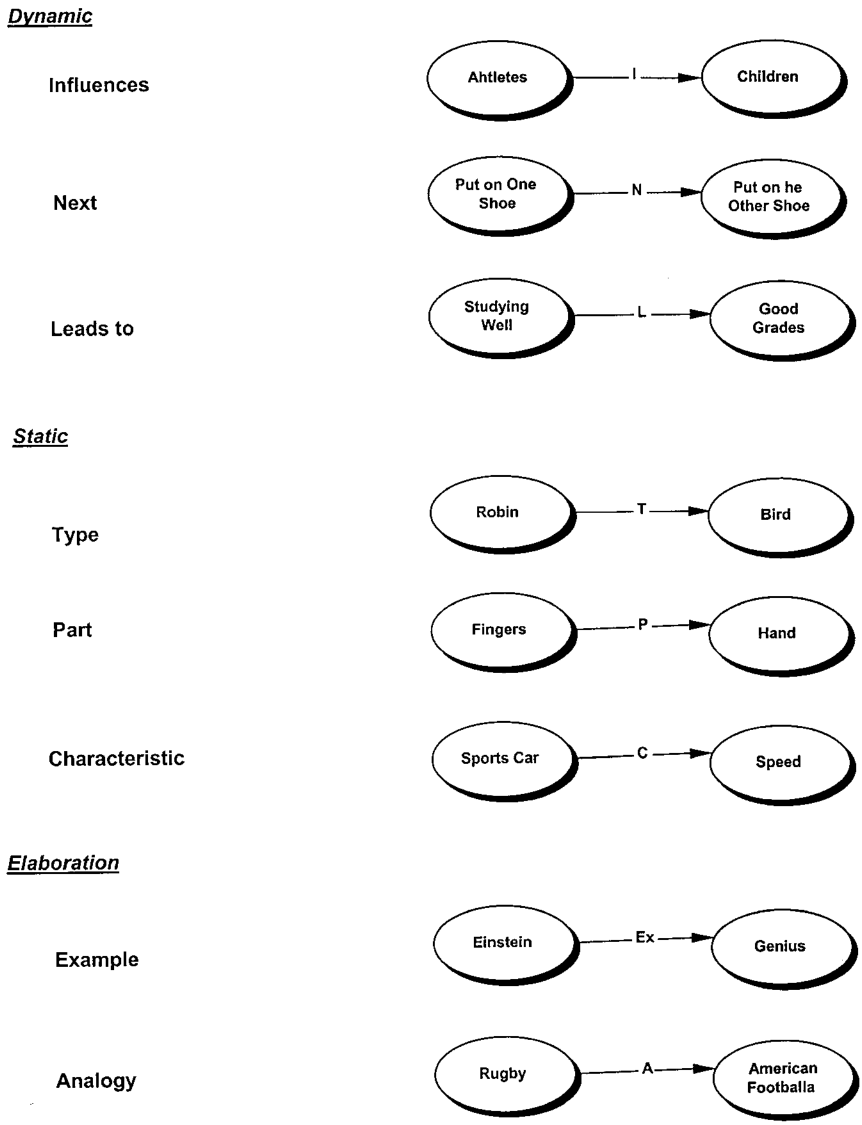

Fig. 2. Examples of link types.

ideas (e.g., a cause and effect relationship such as "Heavy rain *caused* a flash flood"); static links that describe structural relationships between ideas (e.g., an arm is a *part* of a human body), and elaborative links that extend information (e.g., Einstein is an example of a genius). Examples of these links are found in Fig. 2. In the TCU knowledge mapping system (Lambiotte *et al.*,

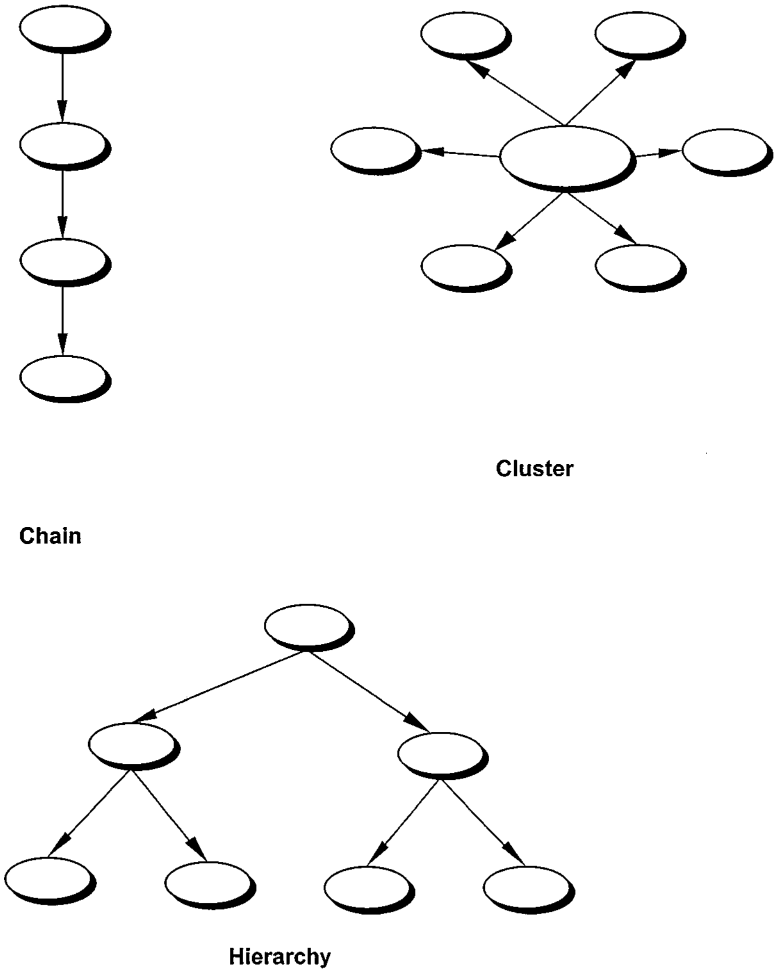

Fig. 3. Examples of knowledge prototypes.

1989), maps are based on knowledge prototypes (e.g., hierarchies, see Fig. 3) and are designed based on gestalt principles.

Knowledge maps can be used as primary sources for knowledge acquisition, adjunct aids to text processing, communication tools for organizing ideas, or retrieval cues. They serve as scaffolds or supports to cognitive processing because they can reduce cognitive load, enhance representation of relationships among complex constructs, provide multiple retrieval paths for accessing knowledge, provide support for students whose verbal skills are weak, and serve as important props for communicating shared knowledge.

Learning from expert maps has been the primary focus of the research on knowledge mapping. Although this emphasis is suggestive of a focus on reception learning, the learner must construct the relationships that link two or more nodes. One might view this as a form of exogenous constructivism as described by Moshman (1982). Some of the uses of expert maps by pairs of students involve a more socially constructivist element in that students must reconcile their interpretations of an expert map. Self-generated knowledge maps come closest to contemporary views of constructivism and these are used in some of the later work on the use of knowledge maps with clients in counseling for substance abuse. Thus, the various uses of knowledge maps reflect multiple views of the learning process. In over a decade of research, the focus has been on (a) the effects of using knowledge maps in contrast to text representations, (b) enhancing learning from maps by processing instructions and map design, and (c) the role of individual differences in the effective use of knowledge maps. A number of consistent findings have emerged from this research.

KNOWLEDGE MAPS VERSUS TEXTS

Knowledge maps make the macrostructure of a body of information more salient. Students who study from them subsequently recall more main ideas in comparison to students who study informationally isomorphic text representations (Hall *et al.*, 1992, 1999; Rewey *et al.*, 1989, 1991). There were no significant differences on the recall of microstructure (details). Rewey *et al.* (1989) contrasted the use of knowledge maps by individuals or dyads on an immediate acquisition of knowledge task or on a second task performed alone. For those who did the first task alone, the second task constituted additional practice. For those who studied the first task with a partner, the second task represented a transfer to individual study. The results of the study indicated that knowledge maps enhanced recall in comparison to texts, particularly the recall of main ideas. Maps also appear to improve the performance benefits of cooperative learning when students are provided with training on how to use maps (Patterson *et al.*, 1992). Patterson *et al.* showed that cooperating students using maps recalled more than those using text.

In addition to recall, the use of knowledge maps also enhances students' subjective reactions to studying and testing. Hall and O'Donnell (1996) compared students who studied either a knowledge map or textual representation of the same content. Participants completed a free recall test 2 days after studying the material. In both sessions of the experiment, they completed subjective graphs in which they rated their motivation, concentration, and anxiety over the duration of the settings. Map users reported significantly greater motivation and concentration than text users. As in other studies, map users recalled significantly more than text users. Recall of main ideas was again superior to the recall of subordinate ideas. The finding that the use of knowledge maps improves affective states while studying and testing is consistent with those of Reynolds *et al.* (1991) who found that students using a hypermap computer environment expressed less frustration than those using hypertext.

Research on knowledge maps has led to improved uses of maps to support transfer. Initial work by Rewey *et al.* (1989) showed no transfer effects from dyadic study to individual studying, a result that may have occurred because students were not sufficiently trained to manage the complexity of using a new format (knowledge maps) and working with a partner. Subsequent work by Patterson *et al.* (1992) indicates that training benefited students' performance with knowledge maps. Experiences with knowledge maps also appear to improve studying of text representations. Chmielewski and Dansereau (1998) trained a group of students in the use of knowledge maps by having them complete a series of workbook exercises related to mapping, develop a map of their own, and make judgments about a series of maps. During a second session, all participants, including those who did not receive map training, studied two sets of *text* materials (no maps were available). They took recall tests 5 days later. Students who received training in knowledge mapping recalled significantly more macro-level ideas than those who did not receive training. This finding of positive transfer from map training to text study was replicated in a second experiment. In summary, the research to date indicates that maps can enhance the acquisition of macro-level ideas, improve affective responses to studying and testing, enhance cooperative learning, and lead to positive transfer of text processing skills. A key factor in producing these positive outcomes lies in the training that is provided in the use of maps.

ENHANCING LEARNING FROM KNOWLEDGE MAPS

Two approaches to improving the usefulness of knowledge maps are instructing students on processing strategies and developing design principles for making better maps. In the first category, summarization (Hall *et al.*, 1999; Rewey *et al.*, 1991) and annotation strategies tailored to the studying of maps (Moreland *et al.*, 1997) have proven effective. Hall *et al.* (1999) showed that performance was enhanced when students used the spatial structure (with informational content blanked out) from which to develop a summary. In the second category, Wiegmann *et al.* (1992) conducted three experiments that examined the effects of spatial configuration, map format, and link structure.

In the first experiment, two maps were constructed that were isomorphic with respect to content. One map was designed according to the gestalt principles of symmetry, proximity, and good continuation that account for how people recognize patterns. Objects that are similar (similarity), are grouped closely together (proximity), or show continuity are more easily recognized. In the web version of the same content, these principles were not used. Students who used the gestalt map outperformed those in the web map group. These results are consistent with those found by Wallace *et al.* (1998). Three presentation formats were contrasted: text, enhanced map, and unenhanced map. The enhanced map was designed to emphasize the principle of similarity (by using shape and color) and proximity (by using spatial grouping). Labels for links were not used in this particular experiment. Results showed a strong effect for the enhanced map, thus supporting the results of Wiegmann *et al.* who recommend that maps be designed according to gestalt principles.

In a second experiment, Wiegmann *et al.* (1992) compared students who learned from a single whole map with students who studied the same content presented as a series of stacked maps. In the stacked maps version, the content from the whole map was presented as a series of maps with a map overview of the content. Performance on the content presented in these maps depended on the student's level of field independence. Field dependent students did better on measures of recall when they studied from the whole map whereas field independent students benefited from the stacked maps.

In a third experiment, Wiegmann *et al.* (1992) examined the effects of variations in the representation of relationships (plain or embellished links) on the performance of students. In this experiment, participants studied from stacked knowledge maps that were designed using gestalt principles. The maps differed in the representation of the link structure. Links were either embellished and presented with arrowheads, labels, and configural information (i.e., barbed vs. solid lines) or they were presented as unembellished straight lines. Students with low verbal ability did better when their maps had plain lines whereas those students with high verbal ability performed better when their maps were embellished. Wiegmann *et al.* (1992) interpreted these results as suggesting that the availability of embellished links emphasizes semantic processing, an emphasis that would create problems for those with low verbal ability. In examining computer-based presentations, Blankenship *et al.* (1999) showed that animated maps (i.e., maps that are created during the presentation) lead to better performance than static maps (i.e., maps that are presented all at once). In summary, summarization and annotation strategies can improve map learning as can map designs that embody gestalt principles, appropriate link representation, and animation.

However, the specific features that facilitate learning may depend on individual differences (e.g., verbal ability) among students.

INDIVIDUAL DIFFERENCES AND MAP LEARNING

Knowledge maps have particular benefits for specific kinds of learners. The use of knowledge maps as an instructional strategy was expected to reduce the cognitive load for students with less verbal ability because the sheer amount of words available would be reduced and the complex task of identifying superordinate and subordinate ideas would be made easier by the visual accessibility of the macrostructure of the textual material. We have seen previously that one of the most robust findings in relation to the use of knowledge maps has been the enhancement of students' recall of superordinate ideas.

Research on the use of knowledge maps has consistently shown benefits for students with low verbal ability or skills (Dees, 1989; O'Donnell, 1992; O'Donnell and Dansereau, 1990; Rewey *et al.*, 1989). In a study that contrasted individual study, cooperative learning, and cooperative teaching, Rewey *et al.* (1992) found that cooperative learning and the use of knowledge map supplements were mutually facilitative for students with low verbal ability. Patterson *et al.* (1993) compared high and low verbal ability students who were taught with either a knowledge map or text as a communication aid during a cooperative teaching episode. Low verbal ability learners taught using a knowledge map performed better than low verbal ability students taught using a text on fill-in-the-blank and recall measures but not on multiple choice items. The performance of high verbal ability students did not vary as a function of text or knowledge map use.

Two studies of note in regard to the role of knowledge maps in supporting less verbally skilled learners are those by O'Donnell and Adenwalla (1992) and Amer (1994). Both studies focused on scientific texts and involved learners expected to have difficulty with text processing. Scientific texts often have a high vocabulary level and include complex verbal material. O'Donnell and Adenwalla (1992) compared the use of knowledge maps and texts by cooperating dyads and individuals in an undergraduate biology class of deaf students. Deaf students typically experience more difficulties in processing textual materials than their hearing counterparts. The results of this study indicated that knowledge maps were effective with deaf students as evidenced by recall and multiple choice tests, thereby supporting the notion that students with restricted verbal experience can benefit from knowledge maps.

In a similar vein, Amer (1994) focused on Egyptian students for whom English was a second language and who frequently reported difficulties in comprehending scientific texts. Participants took college science courses presented in English. Amer compared two methods for increasing comprehension with a control condition. Students were assigned randomly to a knowledge map condition, an underlining condition, or the control condition. Training was provided to students on how to use knowledge maps or use underlining as a comprehension strategy. Both treatment groups outperformed the control group on an open-ended questioning measure although they did not differ from one another. Those who used knowledge maps, however, outperformed the underlining group and the control group on a measure of summarization quality.

Knowledge maps may assist low verbal learners because they draw attention to the macrostructure of the content and encourage top down processing (Chmielewski and Dansereau, 1998). This type of processing may aid students low in verbal ability. In a study conducted by O'Donnell (1994), students were provided with a set of stacked knowledge maps whose content was organized as flowing from the top of the page to the bottom or from the left hand side of the page to the right (a flow that is typical with reading). The task used in this experiment involved a search for information. Students were required to complete a *fill-in-the-blank* test that was organized in a set of subsections that differed in the kind of information to be located. One section involved a simple direct reading of the map in a top-down or left to right manner, that is, completing the question involved mainly imitating the structure of what was presented in the map. A second set of questions required bottom-up processing in which case students needed to locate the target information and move up one node. Other kinds of questions involved inferences (no direct information was available in the map), negations in which the item to be completed was a negation of what was actually in the text, and integrations which required linkages across sections of the map. The format of the map affected responses to the declarative and bottom-up types of items with the top-down maps yielding higher performances. Students with low verbal ability who used left to right maps performed worse than any other group. Although knowledge maps typically help learners with low vocabulary skills, the results of this research suggest that when the organization of such maps encourages the processing required by texts, the benefits of knowledge maps may be eroded.

The influence of other individual difference variables, in addition to verbal ability level, has also been explored. Prior knowledge of the content domain has been shown to have important effects on students' processing of knowledge map content (Lambiotte and Dansereau, 1992; Lambiotte *et al.*, 1993, O'Donnell, 1993; O'Donnell and Dansereau, 2000). However, these effects appear to depend on the task and content area. Students with low prior knowledge of the target information in a lecture in biology learned most when knowledge maps accompanied the lecture and least when key terms were used instead of maps (Lambiotte and Dansereau, 1992). For listeners with high prior knowledge, the opposite was true. The results were interpreted in light of Mayer's model of assimilation coding (Mayer, 1979). According to this model, an advance organizer provides an anchoring structure to which new information can be attached or activates existing schemas that will structure incoming information. For high prior knowledge students, the use of knowledge maps during the lecture may have presented a structure for the content that conflicted with existing structures. Low prior knowledge learners in this context appear to benefit from the structure provided by the maps. In other work, Lambiotte *et al.* (1993) found that students who were low in confidence benefited from using knowledge maps when learning statistical information but those with high confidence did better with lists.

In a search task in which students located the information necessary to complete a set of fill-in-the-blank items, knowledge maps in comparison to text facilitated search for declarative and bottom-up kinds of information (O'Donnell, 1994). High prior knowledge participants who also had good vocabulary skills were effective in their search. When students had good vocabulary but lacked prior knowledge, their performance was indistinguishable from those with low vocabulary. As the search for information is a more active process than encoding a lecture, the available schemas that might be expected to be associated with prior knowledge seem to have facilitated performance.

The complex relationships between knowledge mapping and prior knowledge deserve fuller explanation and require further study. In a study by O'Donnell and Dansereau (2000), students studied two texts; one described the autonomic nervous system and the other described probability theory. Students reported significantly more prior knowledge about the autonomic nervous system than about probability theory. Given the influence of prior knowledge on the effectiveness of knowledge mapping that we have already noted, such differences in material are important to understand. Outcome measures included recall and organization of the recall. The recall scores reflected the quality and quantity of recall and the organization scores provided a measure of the inclusion of the macrostructure of the material. Treatment effects were found only for organization scores on the probability passage used but were found for recall of the material on the autonomic nervous system. It may be that in the absence of prior knowledge of the content, the initial encounter with the probability material only allowed for the abstraction of organizational information.

As noted earlier (Wiegmann *et al.*, 1992), field dependence/independence is also associated with the benefits of knowledge maps. Chmielewski *et al.* (1998) assigned students to one of two groups. The groups differed on whether they used knowledge maps that demonstrated common region or knowledge maps not demonstrating common region. *Common region* (Palmer, 1992) is a relatively new gestalt principle of organization where objects that share a common region of space can be perceived as grouped together. Based on the previous work of Wiegmann *et al.* (1992), we would expect students to perform better with maps that conform to this gestalt principle of organization. The results of this study, however, showed an interaction of map type with measures of field dependence/independence. Students who were field-dependent outperformed field independent students when maps had common region whereas the reverse was true when maps did not. It is not clear whether the variation in the maps resulted in maps of differential difficulty. Additional work on the role of field dependence/independence and knowledge maps is needed.

RESEARCH SUMMARY

The research on knowledge mapping in the last 12 years has produced a number of consistent findings in spite of some variation in tasks, kinds of knowledge maps used, and measures employed. Among these findings are the following:

- Students recall more central ideas when they learn from a knowledge map than when they learn from text.
- Students with low verbal ability or low prior knowledge often benefit the most from the presentation of information in a knowledge map format on measures of recall.
- Students who use knowledge maps as supports when interacting with peers in cooperative learning environments learn more effectively.
- Information presented in well-structured maps that are designed according to Gestalt principles is recalled better than when presented in less well-structured maps.

However, these kinds of results are not found with all types of materials used in the various studies. Differences in learning have been found in response to different kinds of material. For example, Patterson *et al.* (1992) found that students recalled more ideas from a passage on cocaine than from one on alcohol. O'Donnell and Dansereau (2000) found a different pattern of results with material on probability theory and on the autonomic nervous system. Further study of the influence of particular kinds of content is needed.

FUTURE RESEARCH

There are a number of fruitful areas for future research. One of these stems from the fact that map results have varied somewhat across content areas. Knowledge maps themselves are designed to reflect various knowledge prototypes (Lambiotte *et al.*, 1989). However, it is possible that some combinations of knowledge structures may lend themselves to processing in a map format and others may not. The underlying nature of the material may contribute to its suitability for mapping. Procedural knowledge, represented in a knowledge map, provides an easy processing route for learners whereas declarative knowledge often provides a number of alternative routes. One of the main benefits of a knowledge map is highlighting the macrostructure. Implicit in the availability of a macrostructure is some inherent redundancy in the content that makes some of the microstructure less necessary. O'Donnell *et al.* (1990) noted that the same kinds of strategies could not be used successfully for processing procedural content as for processing declarative content. The fit of knowledge maps to various kinds of knowledge structures and combinations of structures is worthy of further study.

The interaction of verbal ability and the use of knowledge maps is intriguing. With various groups of students who have language difficulties (low vocabulary, deaf or hearing-impaired, ESL students, etc.), knowledge maps were effective. It is thought that these benefits accrue because of reductions in processing load due to the limited vocabulary and simplified grammar used in knowledge maps. Bahr and Dansereau (2000) used maps in which "split nodes" (one half of each node contained English and the other half contained the German translation) were compared with a typical list method for teaching German vocabulary. Maps led to significantly better scores on cued recall. This work suggests that the reduction in processing load that seem inherent in map processing can be further enhanced by modifying the presentation of the map. Further work is needed to confirm that "load" is reduced and to examine ways of amplifying those benefits.

If maps do indeed reduce cognitive load (at least on certain kinds of tasks), they may be very effective in supporting student learning in multimedia and hypermedia environments. Given the consistent evidence that knowledge maps emphasize macrostructural knowledge, they may serve as power tools for providing learners with guidance within instructional hypermedia. Initial findings on the use of knowledge maps as navigational guides in web-based environments (Hall *et al.*, 2000) are promising. Learners, especially low ability learners or learners with low prior knowledge

(Last *et al.*, 2001), often become disoriented when using instructional hypermedia (Dillon and Gabbard, 1998; Kim and Hirtle, 1995; McDonald and Stevenson, 1996). These kinds of learners benefit from knowledge maps presented in paper formats. Additional work is needed to understand the contributions that can be made by knowledge map representations in a hypermedia environment to support and guide student learning.

The promising effects on transfer demonstrated by Chmielewski *et al.* (1998) are also worthy of continued research. Further efforts to replicate and extend these findings may yield important practical information in preparing students to be more effective in their studies. Although the outcome measures in this study do not involve higher order thinking skills, it is possible that the exposure to knowledge maps can enhance such study. Work by Okebukola (1990) and Wallace and Mintzes (1990), for example, show that concept mapping can enhance understanding of complex concepts and conceptual development.

Dansereau and his colleagues have extended the use of knowledge maps to counseling in drug abuse treatments (e.g., Czuchery and Dansereau, 1999; Dansereau *et al.*, 1993). Counselors and clients generate maps to illustrate client's problems, issues, and plans. The generative approach to mapping in this work has much in common with the premises for concept mapping outlined by Novak (1990) in that the client's personal knowledge is the basis for subsequent knowledge construction. The general research approach adopted has been to compare clients who receive mapping-enhanced counseling with those receiving standard counseling. Mapping clients have higher ratings of their therapeutic process (Czuchery and Dansereau, 1999; Newbern *et al.*, 1999), have more positive affect responses to treatment (Pitre *et al.*, 1998), are less likely to test positive for opiates or cocaine during treatment compared with standard clients (Dees *et al.*, 1997), and continue to show benefits after 12 months (Joe *et al.*, 1997). These studies demonstrate that mapping can be successfully used for complex tasks involving reasoning and personal judgment. Future adaptations of knowledge mapping might extend this work to areas such as peer counseling and conflict resolution in schools.

The successful co-generation of knowledge maps by clients and counselors in response to the client's entering knowledge and beliefs represents a very different kind of learning than that in the majority of studies using knowledge maps. Future research might include comparisons of the efficacy of self-generated, group generated, and expert-generated maps on a range of outcomes that include measures of reasoning. To date, the most complex outcomes associated with the use of knowledge maps are those found in the studies of substance abuse counselors and their clients.

IMPLICATIONS FOR PRACTICE

The work presented here has mostly focused on expert produced knowledge maps. The need to prepare knowledge maps that can be used as supplements or as primary sources of information can be time consuming. However, the preparation of materials that can be used in this way can have important benefits for instructors. By making their own maps, instructors articulate the content they wish to teach and the relationship between various parts of the overall content. This itself can lead to clearer communication of goals and subsequently to improved learning. Maps and graphic organizers have been used for this purpose in statistics classes (Schau and Mattern, 1997). The following guidelines can be helpful in teaching students how to use knowledge maps.

- Begin with a content that is extremely familiar to students so that they do not need to search effortfully for appropriate information.
- Provide a completed knowledge map of the content with its textual analog.
- Ensure that students can recognize the isomorphic relationships of the text and the knowledge maps presentations (i.e., they can reproduce the example knowledge map from the text; they can reproduce the text from the knowledge map).
- Use a number of well-constructed maps as initial examples (i.e., maps that are designed according to gestalt principles).
- Have students work in pairs to summarize the content from the maps using techniques such as scripted cooperation.

Brief training for students in how to develop knowledge maps for themselves can have successful results in improving students' comprehension (Chmielewski and Dansereau, 1998). Such training typically needs to include a discussion of link types and a focus on the nature of the relationships among ideas. The attention provided to the structure of knowledge will assist students in comprehending material.

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