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CONCEPT MAPPING AS A MEANS FOR BINDING KNOWLEDGE TO EFFECTIVE CONTENT-AREA INSTRUCTION: AN INTERDISCIPLINARY PERSPECTIVE

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Abstract. The recognition of conceptual knowledge as a critical element in effective content-area instruction has been advanced by the development of concept mapping applications to instruction. This paper broadens awareness of how concept mapping can serve as a basis for linking instructional strategies that when combined with concept mapping form an instructional system teachers are able to use to improve the quality of student content-area understanding. Presented is a knowledge-based content-area teaching model incorporating interdisciplinary perspectives that provides the means for teachers' use of concept mapping in conjunction with research-based instructional strategies to improve the effectiveness of content-area instruction.

1 Introduction

The role of conceptual knowledge and the structural representation of such knowledge is becoming recognized increasingly as a critical element of effective content-area instruction (Romance & Vitale, 1997, 1999; Vitale & Romance, 2000, 2006). A leading dynamic force in this initiative has been the development of concept mapping applications to instruction coupled with the accessibility of computer-supported concept mapping tools (see Novak & Canas, 2006). In their recent article, Novak and Canas discussed the role of concept mapping in cumulative meaningful learning and different uses of concept mapping by teachers and students to enhance in-depth content understanding.

The purpose of this paper is to broaden awareness of how concept mapping can serve as a core element for linking together (i.e., "binding") other instructional strategies in order to build an effective instructional system that teachers are able to use to improve the quality of student content-area understanding. In doing so, the paper describes a knowledge-based content-area teaching model in which concept mapping is the key element but which also reflects several interdisciplinary perspectives. The first perspective considers meaningful understanding as a form of expertise (see Bransford et al, 2000) and emphasizes the importance of conceptual organization and accessibility as important characteristics of prior knowledge on which experts depend. The second perspective follows a knowledge-based approach to instruction which requires all instructional and assessment activities to be linked explicitly to a representation of the logical structure of the content discipline to be learned. The third perspective is an instructional systems view that research-based initiatives for improving content-area instruction must be sufficient to impact student performance and engineered so that teachers are able to use them with fidelity. Considered together, these three perspectives are suggestive of approaches to content-area instruction that broaden teachers' use of concept mapping in instruction.

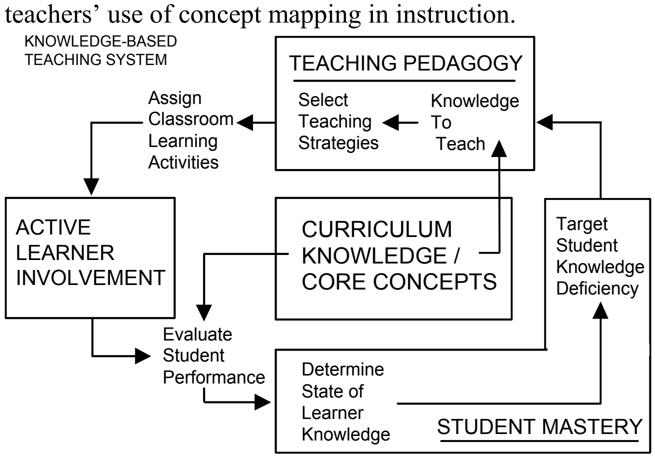

Figure 1. Knowledge-based intelligent tutoring system.

2 Cognitive Science Foundations of Knowledge-Based Instruction Models

The distinguishing characteristic of knowledge-based instruction models is that all aspects of instruction (e.g., teaching strategies, student activities, assessment) are related explicitly to an overall design framework that represents the logical structure of the concepts in the subject-matter discipline to be taught. In considering this design characteristic as a key focus for meaningful learning, knowledge-based instruction is best illustrated by the original architecture of computer-based intelligent tutoring systems (ITS) developed in the early 1980's (e.g., Kearsley, 1987). As Figure 1 shows, in ITS the explicit representation of the knowledge to be learned serves as an organizational framework for all elements of instruction, including the determination of learning sequences, the selection of teaching methods, the specific activities required of learners, and the evaluative assessment of student learning success. In considering the implications of knowledge-based instruction for education, it is important to recognize that one of the strongest areas of cognitive science methodology focuses on explicitly representing and accessing knowledge (e.g., Luger, 2002; Kolodner, 1993, 1997; Sowa, 2000).

The research foundations of knowledge-based instruction models are consistent with well-established findings from cognitive science. These cognitive science perspectives were reviewed in a recent report by the National Academy Press, *How People Learn*, edited by Bransford et al (2000). In doing so, Bransford et al stressed the principle that explicitly focusing on the core concepts and relationships that reflect the logical structure of the discipline and enhancing the development of prior knowledge are of paramount importance for meaningful learning to occur (see also Schmidt et al, 2001). Closely related to this view is work by Anderson and others (e.g. Anderson, 1992, 1993, 1996, Anderson & Fincham, 1994; Anderson & Lebiere, 1998, Anderson, Bothell et al, 2004, Anderson, Douglass, & Qin, in press) who distinguished the "strong" problem solving of experts as highly knowledge-based and automatic from the "weak" strategies that novices with minimal knowledge are forced to adopt in a heuristically-oriented, trial-and-error fashion. Also directly related are key elements in Anderson's (1996) ACT cognitive theory that (a) consider cognitive skills as forms of proficiency that are knowledge-based, (b) distinguish between declarative and procedural knowledge (i.e., knowing about vs. applying knowledge), and (c) identify the conditions in learning environments that determine the transformation of declarative to procedural knowledge.

Other research supporting the importance of prior knowledge stresses that the conceptual understanding and use of knowledge by experts in application tasks (e.g., analyzing and solving problems) is primarily a matter of accessing and applying prior knowledge (see Anderson, 1992, 1993; Kolodner, 1993, 1997) under conditions of automaticity. As characteristics of learning processes, the preceding emphasizes how extensive amounts of varied experiences (i.e., practice) focusing on knowledge in the form of the concept relationships to be learned are critical to the development of different aspects of automaticity associated with expert mastery in any discipline.

3 Considering Content-Area Comprehension from a Knowledge-Based Perspective

An important implication from the Bransford et al (2000) book supported by a wide variety of sources (e.g., Carnine, 1991; Glaser, 1984, Kintsch, 1998; Romance et al, 2004; Vitale & Romance, 2000, 2006) is that curriculum mastery is best considered a form of expertise and that student conceptual mastery of academic content should reflect how experts perceive the discipline. In this regard, emphasizing the in-depth understanding of core concept relationships within a discipline is a critical element of general comprehension and, by inference, of comprehension tasks that involve meaningful learning as well. In fact, the knowledge-based perspective of meaningful comprehension presented by Bransford et al (2000) would suggest the nature of meaningful comprehension in both general environmental learning and reading settings are equivalent, with the exception that the specific learning experiences associated with reading comprehension are text-based.

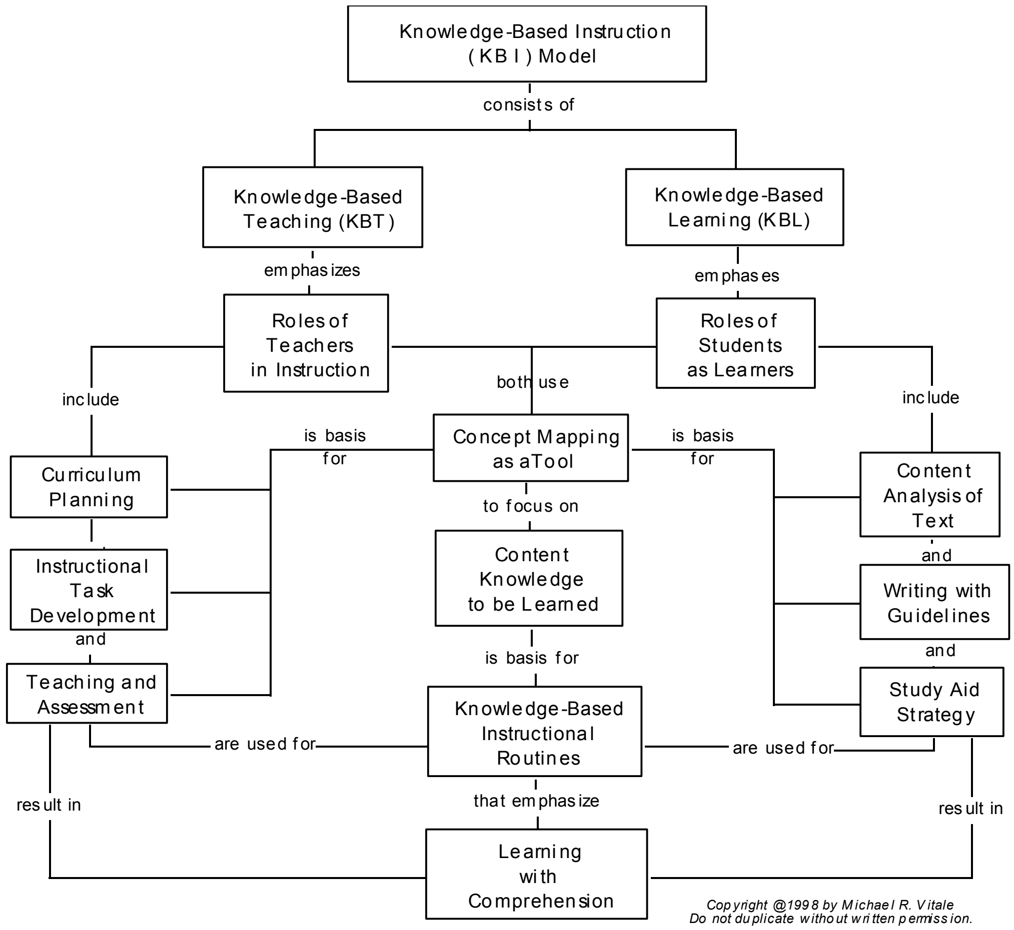

Figure 2. Overview of the Knowledge-Based Instruction (KBI) Model using concept mapping as a core component.

Figure 2 shows the framework of a Knowledge-Based Instructional (KBI) model that evolved over a 10 year period beginning with a series of research studies in grades 3-4-5 (see Romance & Vitale, 2001; Vitale & Romance, 2006). These studies repeatedly found that embedding reading within in-depth science instruction in daily 2-hour instructional time periods resulted in greater achievement growth in both content-area understanding of science as well as reading comprehension. As the research program evolved, the instructional model used in grades 3-4-5 (*Science IDEAS*) began to place greater emphasis on teachers and students using propositional concept maps as a knowledge-representation tool to organize and represent the conceptual relationships they were learning (see Novak & Gowin, 1984). Subsequently, as the research agenda expanded to other instructional levels ranging from middle school (e.g., Vitale & Romance, 2006) to post-secondary instruction (e.g., Haky et al, 2001; Romance, Vitale et al 2000), in which the use of propositional concept mapping was expanded to include having the concept map serve as an instructional guide (e.g., post-secondary biology, chemistry, physics faculty used concept mapping to engender meaningful student learning). In outlining the architecture of the knowledge-based instruction model (KBI), Figure 2 illustrates how concept mapping provides a knowledge-based focus for all elements of instruction. Specifically, the left branch focuses on the use of concept maps by teachers and the right branch on the use of concept maps by learners. The specific form of concept mapping used in the KBI model was adapted from Novak and Gowin (1984) and, in general, the efficacy of concept mapping as an instructional support tool is well-established in a variety of content areas (e.g., BouJaiude & May, 2003; Brown, 2003; DiCecco & Gleason, 2002; Gahr, 2003; Romance & Vitale, 1999; Sen, 2002) and is an active area of development (e.g., Jacobs-Lawson & Hershey, 2002; Nicoll et al, 2001; Novak & Canas, 2006).

In using the KBI model, propositional concept maps are used to represent knowledge whose units consist of objects (usually concept labels enclosed in boxes) and links denoting labeled relationships (typically consisting of verbs). In building propositional concept maps, two major enhancements of Novak's original procedure are emphasized by the KBI model. The first is that each set of linked objects forms (or approximates) a simple complete sentence (e.g., OBJECTS expand when HEATED, ENERGY FORMS include …). The second is that propositional concept maps are organized hierarchically, with core concepts (or big ideas) at the top, subordinate concepts below, and specific examples (if any) on the bottom. Figure 3 illustrates a propositional core concept map developed from the content in an earth science program.

Keeping Figure 3 in mind, the KBI model shown in Figure 2 represents teachers' use of propositional concept maps to identify core concepts to be taught and then, subsequently, to plan instruction that is as conceptually coherent as possible. In developing such concept maps, teachers are encouraged to use submaps to represent increasing levels of curriculum detail. The second teaching component of the model includes three different strategies for enhancing instruction: (a) use of concept maps as visual support for

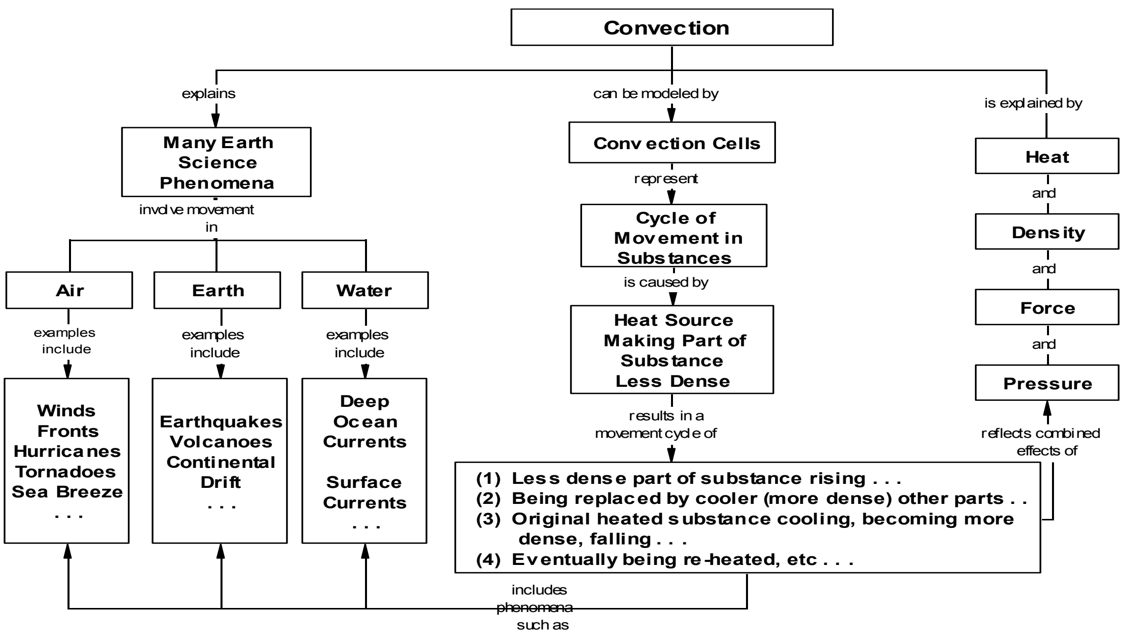

Figure 3. A propositional concept map for convection. The map provides a conceptual framework for instructional planning and for student meaningful understanding.

students during instruction, (b) use of concept maps as a framework for assessment, and (c) use of concept maps as a referential framework to motivate student learning. The third KBI teaching component includes advanced teacher skills based on instructional design principles (e.g., Allen et al, 2004; Dick et al, 2005; Engelmann & Carnine, 1991) for generating content-area instructional activities that require applications of the knowledge represented in the concept maps. Logically, this third teaching component represents an instructional transformation of the declarative knowledge represented in propositional concept maps into procedural (or applied conceptual) knowledge. In the KBI model, these activities consist of instructional enhancements used by teachers for modeling (or demonstrating) knowledge applications, for guided or independent student practice, or for authentic assessment. Thus, within the KBI model, the process of generating application activities can be used either for authentic assessment or as contexts for teaching concept applications or dynamic concept relationships (e.g., in science, a substance can be made to expand by heating it). Within the framework of the KBI model, Figure 4 illustrates the use of a propositional concept map as a curricular guide for insuring the instructional coherence of a unit on evaporation at the mid-elementary school level.

The purpose of the three learner (vs. teacher) KBI components is to focus student learning on the core concepts and concept relationships in the curriculum content. In the first component, for example, students use a knowledge-focused reading comprehension strategy to identify the core concepts and relationships in their textbooks and related reading materials followed by construction of a propositional concept map that enhances comprehension. And, although educational text materials might be expected to present coherently-organized information, most content textbooks do not do so (e.g., see Holliday, 2002, 2003; McNamara et al, in press). In the second component, students use concept maps to guide their writing and composition within the content domain. And, in the third component, students learn to use concept maps as study guides that represent cumulative curriculum knowledge. Again, although the components could be applied separately (if teachers supply the appropriate concept maps), the logical use of the three is for teachers to begin by introducing students to the first component, then the second, and then the third.

In considering the KBI model, all of the components are clearly related through propositional concept mapping, which, in turn, reflects and focuses on the conceptual knowledge to be learned. By using concept mapping as a form of linkage, teacher and student components are able to complement each other. At the same time, teachers using the KBI model have a great deal of flexibility in terms of which components of the model to use to enhance their classroom instruction. In general, research findings in post secondary settings for undergraduate instruction in chemistry and biology (e.g., Haky et al, 2001; Romance, Vitale et al 2000) have been supportive of the feasibility and effectiveness of the KBI model for enhancing content-area student learning. In particular, results of this KBI research initiative have shown a substantial enhancement of student academic achievement in college chemistry and beginning biology, areas that typically suffer high rates of student dropouts or failures.

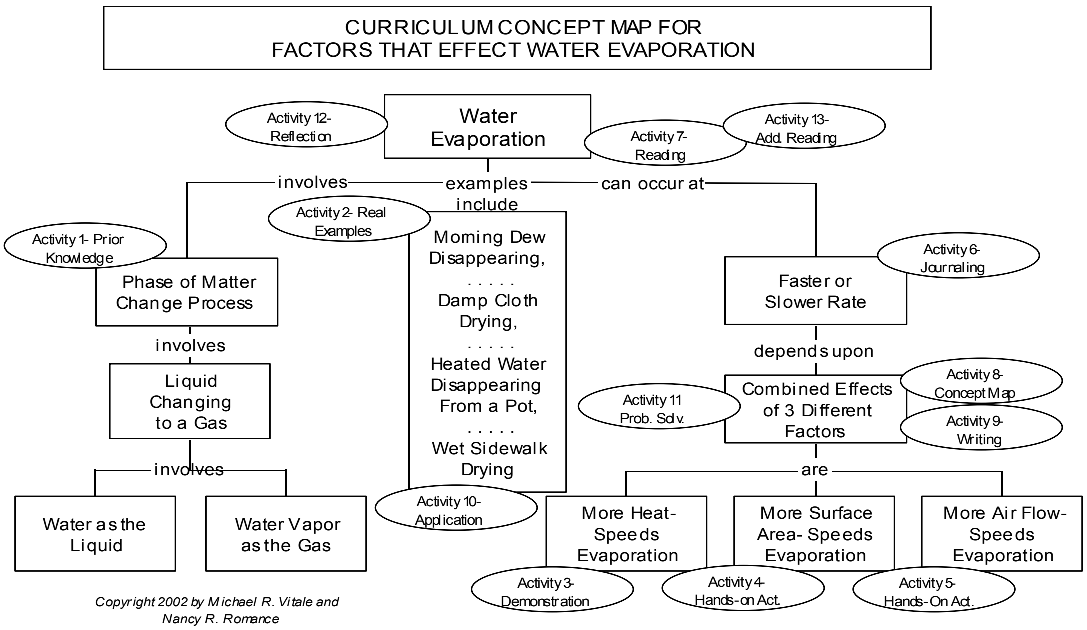

Figure 4. Simplified illustration of a propositional curriculum concept map used as a guide by teachers to plan a sequence of knowledge-based instructional activities

4 Engineering an Amplified KBI Model for Teacher Use

Although the KBI model (see Figure 2) was research-grounded and conceptually sound, only the parts directly involving concept mapping were feasible to implement on a large scale. Rather, the advanced instructional components of the model were difficult for teachers to implement in a consistent fashion without extensive and continuing support. What was needed, in fact, was an alternative model that included all of the key elements of the KBI model feasible to implement and added the other implicit KBI elements in a form that was more natural for teachers to incorporate in instruction.

Figure 5 shows the architecture of the amplified KBI model. As Figure 5 shows, the strategies are grouped into two categories (curricular/conceptual, instructional enhancements) that together form a modular-oriented instructional system. In the system, while all of the components are complementary, each component could also be implemented independently as an enhancement to regular instructional practices. In addition, as components comprising a professional development system, they are orderable with regard to the sequence of introduction (and groups) for content-area teachers.

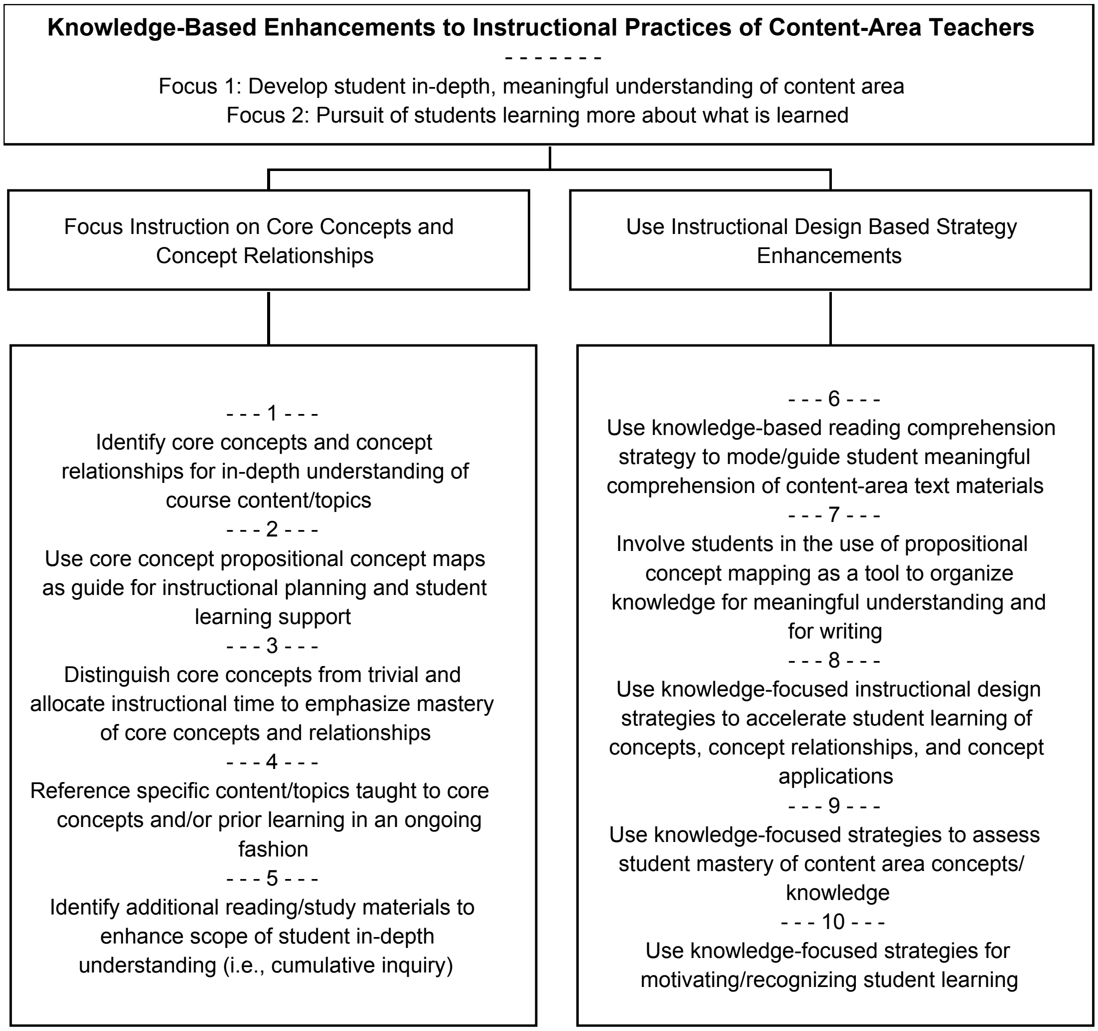

Figure 5. Amplified KBI model restructured to operate as modular enhancements to the instructional practices of content-area teachers. Note that concept mapping (#2), (#7) are used to bind other instructional enhancements to teaching within a knowledge-based instructional systems framework.

Within a professional development setting, the sequence of the initial group of amplified KBI components are: (#4) Referencing specific concepts taught to core concepts and/or prior learning in an ongoing fashion, (#6) Using a knowledge-focused reading comprehension strategy to model and guide student meaningful comprehension of content-area text materials (this strategy also emphasizes students actively relating what they are reading to prior knowledge), (#5) Identification of additional reading/study materials to enhance (#6) Using a knowledge-focused reading comprehension strategy to model and guide student meaningful comprehension of content-area text materials (this strategy also emphasizes students actively relating what they are reading to prior knowledge), (#5) Identification of additional reading/study materials to enhance student understanding, and (#2) Using propositional concept maps as a guide for instructional planning and student learning support.

The second group of amplified KBI components addressed in professional development are: (#7) Involving students in the use of propositional concept maps as a tool to organize knowledge for meaningful understanding, (#1) Identification of core concept and concept relationships necessary for in-depth understanding of the course content, and (#9) Using knowledge-focused instructional strategies to assess student mastery of concept area conceptual knowledge.

Finally, the third group of KBI components addressed in professional development are: (#8) Use instructional design strategies to accelerate student initial learning of concepts, concept relationships, and concept applications, (#3) Distinguish core concepts from trivial and allocate instructional time to emphasize mastery of core concepts and relationships, and (#10) Use knowledge focused strategies for motivating/recognizing student learning.

In interpreting the amplified KBI model, items #1, #2 , #4 ,#5, and #7 were included in the original model, while items #3, #6, #8, #9, and #10 represent a significant detailing of enhancements- which would either fit logically within the lower-left (Teaching and Assessment) box on the original KBI model (#3, #8, #9, #10) or as an enhancement to the student concept mapping box (#6). The resulting revision, therefore, explicitly specifies teacher activities in the form of strategies that research (e.g., Engelmann & Carnine, 1991; Vitale & Romance, 2006) has shown significantly enhance the effectiveness of content-area instruction.

5 Summary and Implications of the Amplified Knowledge-Based Model

As designed (i.e., engineered), the amplified KBI model has the potential to improve the quality of instruction in any content domain for which conceptual coherence is a requirement for in-depth, meaningful understanding. In doing so, it represents a significant enhancement to instructional strategies that focus on concept mapping alone. Although in the amplified KBI model, concept mapping as a knowledge explication technique is the key element, the additional enhancements in the amplified KBI model provide a means through which concept maps (or mapping) can bind these enhancements to the operational elements of teaching considered from an instructional systems point of view.

Presently, the amplified KBI model is being implemented with middle school science teachers as part of a multi-year NSF-funded project designed to study the means for accelerating student science achievement in grades 3-8 in preparation for high school. Through the present, teachers have responded positively to the model and are implementing the different components in conjunction with their introduction and follow up in project professional development sessions. The project is assessing both the feasibility and impact of the amplified KBI model on student content-area achievement at the upper elementary and middle school levels.

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