From Misconceptions to Constructed Understanding
The Fourth International Seminar on Misconceptions Research (1997)

Article Title: Implications Of An Instructional Strategy Emphasizing Structured Conceptual Knowledge -- Addressing Causes Of Learning Problems In Undergraduate Science

Author: Romance, Nancy R. & Vitale, Michael R.

Abstract: The argument advanced in this paper is that given the central role of conceptual knowledge in research about the teaching/learning process, college faculty should place greater emphasis on the role of structured knowledge in their discipline as a powerful framework for designing course curriculum, instruction, and assessment. Offered in the paper are strategies for instruction in freshman general science courses emphasizing the use of concept maps for representing conceptual knowledge and concept mapping as a process for constructing representations of conceptual knowledge for both faculty and students. In doing so, the implication of the paper is that faculty teaching freshman general science courses should use explicit techniques to emphasize the overall conceptual structure of the discipline being taught throughout the course rather than focusing on topics, concept sequences, or common misconceptions in isolation with the assumption that freshman students have the capability to organize and integrate the cumulative knowledge addressed.

Keywords:
General School Subject:
Specific School Subject:
Students:

Macintosh File Name: Romance-StructuredKnowledge
Release Date: 10-1-97 A, 10-31-97 B, 12-3-97 C

Editor: Abrams, Robert
Publisher: The Meaningful Learning Research Group
Publisher Location: Santa Cruz, CA
Volume Name: The Proceedings of the Fourth International Misconceptions Seminar - From Misconceptions to Constructed Understanding
Publication Year: 1997
Conference Date: June 13-15, 1997
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

by the efforts of the conference organizers at Cornell University, and the members of the Meaningful Learning Research Group. The transformation of this collection into a modern format was supported by the Novak-Golton Fund, which is administered by the Department of Education at Cornell University. If you have found this collection to be of value in your work, consider supporting our ability to support you by purchasing a subscription to the collection or joining the Meaningful Learning Research Group.

IMPLICATIONS OF AN INSTRUCTIONAL STRATEGY EMPHASIZING STRUCTURED CONCEPTUAL KNOWLEDGE--ADDRESSING CAUSES OF LEARNING PROBLEMS IN UNDERGRADUATE SCIENCE

Nancy R. Romance
Florida Atlantic University
Boca Raton, FL 33431 USA
Email: ROMANCE@FAU.EDU

Michael R. Vitale
East Carolina University
Greenville, NC 27858 USA
Email: EDVITALE@EASTNET.EDUC.ECU.EDU

Completion Date: 8-23-97

IMPLICATIONS OF AN INSTRUCTIONAL STRATEGY EMPHASIZING STRUCTURED CONCEPTUAL KNOWLEDGE--ADDRESSING CAUSES OF LEARNING PROBLEMS IN UNDERGRADUATE SCIENCE

Nancy R. Romance
Florida Atlantic University
Boca Raton, FL USA
Email: ROMANCE@FAU.EDU

Michael R. Vitale
East Carolina University
Greenville, NC USA
Email: EDVITALE@EASTNET.EDUC.ECU.EDU

ABSTRACT

The argument advanced in this paper is that given the central role of conceptual knowledge in research about the teaching/learning process, college faculty should place greater emphasis on the role of structured knowledge in their discipline as a powerful framework for designing course curriculum, instruction, and assessment. Offered in the paper are strategies for instruction in freshman general science courses emphasizing the use of concept maps for representing conceptual knowledge and concept mapping as a process for constructing representations of conceptual knowledge for both faculty and students. In doing so, the implication of the paper is that faculty teaching freshman general science courses should use explicit techniques to emphasize the overall conceptual structure of the discipline being taught throughout the course rather than focusing on topics, concept sequences, or common misconceptions in isolation with the assumption that freshman students have the capability to organize and integrate the cumulative knowledge addressed.

INTRODUCTION

A fundamental assumption in requiring core courses for freshman students is to build a common foundation of knowledge leading to an undergraduate degree while orienting beginning college students toward the postsecondary learning experience. From this perspective, the pursuit of such core knowledge and conceptual understanding serves to assist the learner in reasoning, critical thinking, and problem-solving within academic disciplines that, in turn, provide the means for the enhancement of knowledge already known. However, despite these as broadly accepted goals, the poor performance of many students in core freshman courses serves as a barrier for their progressing toward subsequent completion of undergraduate degrees.

In addressing the preceding, two possible sources of the problem can be identified: (a) a lack of general academic preparation of freshman students for the college experience and (b) instructional flaws in the key core courses required of entering freshman. The purpose of this paper is to address the second problem in light of the first by outlining some promising strategies for freshman instruction in general science courses based upon those used successfully within an upper division science methods course in education. In doing so, the implication of the strategy is that faculty teaching freshman general science courses should use explicit techniques to emphasize the overall conceptual structure of the discipline being taught throughout the course rather than focusing on topics, concepts, or common misconceptions in isolation that assumes freshman students have the capability to organize the cumulative knowledge gained. In fact, in considering the performance of students in upper division science methods courses who have successfully "passed" freshman science courses as an indicator of their instructional weaknesses, there is good evidence that lack of organized conceptual knowledge and the associated inability to construct such knowledge is a continuing deficiency.

The paper consists of the following sections. First, a rationale considering instruction as the development of a conceptual knowledge-base is overviewed. Second, a general discussion of the role of conceptual knowledge in learning is presented. Third, the uses of concept maps as an instructional strategy are detailed. And, fourth, implications for undergraduate instruction are summarized. Within these sections, the paper focuses specifically upon "concept mapping" as a potentially powerful curriculum-based solution to enhance learner performance.

INFORMAL RATIONALE FOR CONSIDERING CONCEPTUAL KNOWLEDGE-BASES AS THE CENTRAL CONSTITUENT OF INSTRUCTION

The thesis of this paper is that given the central role of knowledge in research about the teaching/learning process, college faculty should place greater emphasis upon the role of structured knowledge in their discipline as a powerful framework for designing course curriculum, instruction, and assessment. A major issue in pursuing this concern is how to address the representation of concept relationships in instruction. In general, the use of concept mapping-- the visual representation of networks of concept relationships-- as an integral part of undergraduate classes can facilitate student organization of knowledge and learning. In this regard, "concept maps" can serve students as advance organizers, study guides, comprehension aides, basic formats for extended response type essay items or other forms of evaluation, and blueprints for writing detailed, informationally coherent passages. For faculty, concept maps can serve as an effective instructional tool for facilitating unit and lesson planning and as a means for modeling the use of concept mapping techniques guiding student learning. With the increased availability of technology in classrooms and homes, the use of computers to facilitate the process of development of concept maps is greatly enhanced. As part of an instructional environment, mapping software opens up a range of possibilities for learners, including negotiation of knowledge, levels of knowledge representation, variations and flexibility in representation and increased ease of use by all learners. Thus, as a dynamic representation tool, concept mapping has broad applicability wherever there is a body of knowledge to be learned and applied.

ROLE OF CONCEPTUAL KNOWLEDGE IN LEARNING

In recent years, attention has focused on the role of knowledge in learning. Such knowledge, referred to as prior knowledge, provides the basis for the learner to gain new knowledge through cognitive processes such as assimilation, accommodation, or problem-solving. As new knowledge is added to existing knowledge, learners organize and reorganize their understanding forming schema (Dansereau, 1995) that, in turn, are useful for further learning, problem solving, comprehension, and recall of information. This continuous knowledge-building cycle requires schema to be restructured into the organized knowledge networks necessary for developing conceptual understanding within a domain. In this regard, Vosniadou & Brewer (1987) suggested that the restructuring of individual schema results from general logical capabilities and increased knowledge within a specific domain. Further, in examining the novice-expert discussions, researchers (Chi, Glaser, & Rees, 1982; Novak, 1977; Carey, 1985) have suggested that knowledge restructuring results from increased experience and/or instruction in a specific domain (e.g., physics).

Decidedly, the role of knowledge in learning must be considered a critical constituent in the design of courses for all disciplines and levels of learners within postsecondary education. Extensive research from a variety of disciplines (e.g., Alexander, 1996) has highlighted the importance of the study of knowledge, including its role in learning and instruction, how knowledge influences the learner, and how knowledge can be modified. In all of this research, conceptual relationships are considered to serve as the fundamental form of knowledge underlying meaningful learning and understanding. Such conceptual knowledge refers to facts, concepts, principles and their interrelationships within a certain domain and is characteristic of what might be typically called domain-specific knowledge in disciplines such as science, history, geography or mathematics. Further, conceptual knowledge refers to concepts and concept relationships represented in the form of propositions which, when applied within procedures, algorithms, or rules, become procedural knowledge necessary for successful problem-solving and learning new knowledge (Lippert, 1988).

DeJong and Ferguson-Hessler (1996) have summarized some underlying qualities of conceptual knowledge that explain its basis for meaningful learning:

1. Conceptual knowledge should be deep not surface-- with such knowledge representing core concepts and fundamental understandings which have wide applicability within a domain and prompt rich questions and explanations. It is fundamental in terms of reasoning and necessary for domain-specific problem-solving. Lack of deep knowledge is manifested by superficial treatment of a topic, trial and error approaches, rote learning, as distinguished from knowledge exhibited by experts (Glaser, 1991; Snow, 1989).
2. Advanced conceptual knowledge such as that of experts which is structured or chunked into meaningful units which can be easily and quickly accessed. These are most suited for retention and provide a framework for the integration of new knowledge (Reif, 1984; Reif & Heller, 1982; Camacho & Good, 1989; Prawat, 1989). Domains of science, as an example, lend themselves to hierarchical structure which provides learners with ability to integrate and develop deep understanding. DeJong and Ferguson-Hessler (1996) suggest that depth and structure of knowledge are not independent, but that this interrelationship is necessary for the level of abstraction and generalizations representative of experts in a domain.
3. Conceptual knowledge which is accessed often can be described as having the property of "automaticity" as evidenced by its rich organization, ease of access, and the fact that its use does not require major cognitive overhead. In effect, automaticity frees the learner to attend to other details of the task or problem at hand (Schmidt & Boshuizen, 1993). Driving an automobile is an example of richly automated knowledge which can be used in conjunction with a multiplicity of other tasks such as listening to the car radio while talking on the mobile phone while traveling on the interstate highway.
4. Conceptual knowledge can be represented in the form of propositions or diagrams (Paivio, 1975; Larkin & Simon, 1987; Anzai, 1991; Kozma, et al, 1996; Vosniadou, 1996). These multiple forms of representation make the knowledge more useful and accessible for in-depth problem solving and computational efficiency.
5. Conceptual knowledge is often closely associated with expertise in problem-solving in specific domains. In turn, such domain-specific knowledge in the minds of experts facilitates the further development of

both conceptual knowledge and advanced problem solving proficiency (Larkin, 1989; Reif, 1984; Kozma, et al, 1996).

Concept Maps As A Knowledge Representation Scheme. Building upon the preceding framework, this paper considers the potentially powerful benefits of integrating concept mapping techniques into the design of college level curriculum and instruction. As a specific technique, concept maps have been found to have valuable applications in profiling student conceptual understanding, planning conceptually rich lessons, and providing the conceptual architecture for the design of curriculum units. By definition, a concept map is a knowledge representation scheme which uses structures called nodes and links. Nodes contain concepts and links are lines labeled with words that are used to connect the nodes and depict meaningful relationships between two or more concepts. These richly interconnected information structures form propositional networks (Stillings, 1995; Wandersee, 1990) which establish pathways to facilitate conceptual understanding and the accessing of information stored in long term memory. They graphically represent how knowledge in a domain or about a specific topic is organized.

Novak (1991), a major contributor to our knowledge about concept mapping, suggests that the basis for the use of concept maps in teaching and learning lies in the fact that every person creates or structures their own knowledge. If we are to instructionally guide the learner in creating new meanings and deeper levels of conceptual understanding, then concept mapping can be an effective instructional tool to use in undergraduate content or methods courses. If instruction is to avoid producing fragmented learning outcomes having minimal transfer, it must be driven by curriculum and instructional designs that teach students the core concepts in a discipline -- core concepts that subsequently serve as the basis for mastery learning (Vitale & Romance, 1992). By mastering the hierarchical organization of core concept relationships, students are more able to understand the nature of the discipline and reason deductively in higher order thinking and problem-solving applications. As such, concept maps are designed to parallel human cognitive structure (Wandersee, 1990) in the sense that they show how concepts are represented hierarchically.

In a similar fashion, Vosniadou (1996) has suggested that gaining conceptual understanding requires consideration of the logical placement and development of related concepts in order to influence their acquisition by the learner, a fact often overlooked in the development of curriculum or textbooks. Recent analyses drawn from the TIMSS (Third International Mathematics and Science Study) Report (Bracey, 1997) indicated that American curriculum is overloaded with concepts taught at any one grade in mathematics and science in contrast to international counterparts who focus, in depth, on a few core topics for the course of the academic year. The TIMSS Report (Bracey, 1997) has argued that the plethora of concept-topic fragments (vs. a core concept emphasis) in American instructional materials and curriculum prohibits the learner from engaging in the in-depth, concept development necessary for conceptual understanding. Another critical findings from the TIMSS' Report indicated that America teachers spend a smaller percentage of instructional time developing concepts when compared to any of the international counterparts included in the study. Thus, in rethinking course curriculum at the undergraduate level, the number, organization and planning for the systematic development of core concepts are worthy considerations in terms of curriculum restructuring necessary for improved student performance.

General Structure of Concept Maps. As a visual representation, concept maps can be created via simple hand-drawn boxes or sticky-notes arranged on a surface (chalk board; chart tablet), or through use of computer software packages such as Inspiration (1996). Examples of maps created with computer-based software can be found in Appendix A. Shavelson et al (1994) have identified a number of substantive variations in developing concept maps. These include whether:

1. maps are hierarchical or free-form in nature
2. concepts are be provided to or determined by the learner
3. learners are provided with or develops their own structure for the map
4. students have flexibility in determining the position of the concepts on the map
5. there is a limit on the number of lines connecting concepts
6. connecting links must result in the formation of a complete sentence between two nodes

7. maps are constructed by one student or a group of students
8. maps are created for a specific purpose, e.g., assessment; chapter review; study guide
9. maps are colored or have visual symbols besides the nodes
10. maps creatively depict the concepts of a domain

These variations in concept mapping formats offer the instructor a great deal of instructional flexibility in designing appropriate concept mapping learning activities for students. The variations in formatting concept maps require the instructor to first model the concept mapping process keeping the number of variables at a minimum and, then, to guide learners in developing group concept maps before actually inviting learners to create one themselves.

Technical Criteria for Evaluating Concept Maps. Whether concept maps are used as a form of assessment or as a product in partial completion of a set of requirements for a college course, suggested criteria should distinguish "good" concept maps from those that do not represent the underlying organization and structure of the knowledge to be learned. Scoring mechanisms for concept maps have been developed by several researchers (e.g., Wallace & Mintzes, 1990; Novak, 1984) and provide a structure for evaluating student learning. While much research is continuing in this area, those who have used the maps as part of their instructional lesson or as a guide for unit planning or teaching report very powerful results (e.g., see the Proceedings of the Annual Conference of the National Association for Research in Science Teaching Conference, 1997). In addition to quantitative approaches, concept maps also can be evaluated using a broader set of standards such as the following originally developed (Romance & Vitale, 1997) for use in elementary and secondary science methods classes in terms of whether:

1. The topic is presented in a thorough and comprehensive manner
2. The major organizing concepts and "big ideas" around which the map is developed are acceptable
3. The propositional networks which are formed represent valid concept relationships and the hierarchical nature of the discipline
4. The propositional networks created by linking words are presented in the form of a complete thought or complete sentence

5. The concept map is visually clean and coherent in its design, i.e., the map is not cluttered with trivial concepts
6. The map suggests examples of concepts presented

Such evaluative perspectives provide guidelines for assigning points and thus for evaluating student performance regarding their understanding about important concepts to be learned. Such maps can provide faculty with a robust tool for students to use to help them organize the information they are learning in ways that enable them to build meaningful conceptual understanding within and across domains. Additionally, as students become proficient in creating their own maps, their vocabulary improves and their ability to comprehend text also improves. While the full potential of such instructional interventions has yet to be documented fully, its use in classrooms by teachers and learners has provided rich evidence of its power to enhance the role of knowledge in the teaching and learning process.

CONCEPT MAPS AS A USEFUL INSTRUCTIONAL TOOL

Increased interest in and use of concept maps has resulted in the identification of many valuable instructional purposes for mapping. For example, concept maps are particularly useful as tools for planning and analyzing instructional units of study, thereby identifying gaps in the curriculum. Like an architect's blueprint, a concept map covering a unit is revealing in terms of the learner's level of knowledge and understanding as depicted by the concepts represented, their organization, and their prioritization. In a fashion similar to concept mapping a unit of study, such techniques applied to the analysis of textbooks would reveal the suitability of the conceptual development of the text in terms of the instructors' objectives and student needs. Vosniadou (1996) in analyzing astronomy units in elementary texts in the U.S. and Greece has indicated that concepts critical to understanding the unit were completely missing. In this sense, concept mapping can facilitate evaluation of instructional materials and planned lesson activities. Thus, college instructors can utilize concept maps as an "advance organizer" for students to improve notetaking skills or as a guide to enhance student textbook comprehension or as activities to be completed by groups of students as meaningful cooperative learning experiences. Another related instructional application for concept mapping is its use as an alternative form of assessment. Shavelson et al (1994) discussed the potential of concept mapping as an alternative assessment tool and highlighted some difficulties in the actual scoring of maps (Wallace & Mintzes, 1990).

As students themselves become proficient in developing concept maps, they gain numerous instructional advantages. For example, concept mapping activities are a useful technique to promote conceptual understanding through identification of cause-effect relationships, prioritizing and organizing concepts, and building more meaningful concept relationships. Concept maps also serve as "advance organizers" to increase student comprehension of text-based materials, to guide more effective expository writing, and to improve note taking and study skills. As students reflect on their own learning of concepts and concept relationships, concept mapping aids in the development of metacognitive skills. Finally as a representational scheme, concept maps can be used by students as a framework for more effective project planning and implementation.

CONCEPT MAPPING AS A DYNAMIC INSTRUCTIONAL PROCESS

As an introduction to concept mapping, one effective and interesting technique is to guide the entire class in the development of a concept map focusing on a current topic of study. Familiarity with the topic serves to enhance the initial concept mapping process and increases the number of students who actively participate. Engaging students in the development of a class concept map involves a dynamic interplay between students and teacher and between students themselves as they begin to discuss the meaning of each concept in terms of how it relates in some meaningful way to other concepts and, most importantly, which concepts serve as big ideas and organizers for other subordinate concepts. In this process, a logistical procedure employed in the development of a class concept map is the use of sticky notes which contain the concept statements. The sticky notes are then arranged on the chalkboard according to input and recommendations from the students. While use of sticky notes might seem like an out-of-date technology, the technique fosters confidence in students' ability to reconceptualize and restructure their ideas while developing the concept map. In addition, chalk lines can be drawn between concepts, represented by sticky-notes, allowing, again, the necessary flexibility to make any changes in propositional networks of concepts developed on the map.

Once students have had opportunities to collectively create concept maps, they are able to work in groups (2-3 students) or individually to design new concept maps. Within this small group format, students find themselves discussing conceptually rich ideas and navigating through the knowledge to establish an acceptable and meaningful organization of the concepts presented. The concept mapping process actually invites students to address their own understanding of concepts and as well as serving as a forum which encourages students to change or restructure their understanding and knowledge as necessary to reflect big ideas, similarities and differences and, in general, their new thinking about topics in a domain. As an individual endeavor, concept mapping provides a window into student thinking by exposing their conceptual frameworks at a more in-depth level than any traditional assessment instrument. As students continue to refine their own maps, the teacher can observe the metamorphosis in their thinking from an initial naive state of knowledge to a more conceptually rich explanation of concept relationships. Thus, concept mapping serves as an effective instructional tool for moving learners from a naive state to a more refined representation of concept relationships.

One interesting application of the above ideas was the use of concept maps in elementary science methods classes (Romance & Vitale, 1997) to represent an instructional unit of study from which students with little prior science understanding were to develop a series of lesson plans. These undergraduate students gained rich conceptual knowledge in a science domain by building meaningful concept maps that served as valuable tools to assist their cumulative understanding of difficult science concepts. (See Appendix for several sample concept maps developed by individual students.) In the study, elementary science methods students who initially possessed weakly organized conceptual knowledge in science were found to develop concept maps decidedly different from students enrolled secondary science methods classes who had greater prior knowledge of science concepts. Within the elementary science methods class, instructor input and critique of student-developed maps coupled with numerous opportunities for students to restructure their maps resulted in more conceptually appropriate representations of science concepts. What was noteworthy in the process was the improved attitude and confidence level of elementary science methods students as they observed, first hand, how their own knowledge and understanding of the concepts improved. Providing opportunities for students to witness a change in their own conceptual framework as a result of critiques or instruction (Regis & Albertazzi, 1996) is a powerful learning experience that can serve all undergraduate students well as they attempt to master science courses. Once learned, students also will be able to apply the concept mapping techniques to enhance their performance in other courses as well. In this context, analysis of student concept maps by faculty can provide a rich set of information about students' naive concepts, misconceptions, and changes in student conceptual knowledge (Wallace & Mintzes, 1990) thereby providing a basis for evaluation of current curriculum in light of more in-depth information about the level of student conceptual understanding.

SUMMARY AND IMPLICATIONS FOR POSTSECONDARY INSTRUCTION

This paper explored the implications of the role of structured conceptual knowledge in science teaching and learning within a context of undergraduate science instruction. In emphasizing the goal of science instruction as the development of student conceptual understanding through well-designed, conceptually rich instructional environments, the paper presents preliminary recommendations for a specific instructional emphasis that is based upon the organization of the core concepts of the discipline rather than focusing instruction upon isolated concepts or student misconceptions without explicitly addressing the relationships among core concepts in the discipline.

Also offered in the paper are perspectives for the use of concept mapping for the design of instructional environments whose goal is the development of student conceptual understanding within science courses comprised of two key constituents that operate interactively across time. The first consists of instructional strategies using concept maps that provide scaffolding support (via social modeling) to guide student exploration and continuing constructive development of the conceptual knowledge-base underlying various learning activities. The second consists of concept maps as student (and faculty) tools that provide the learner with the flexibility and support in the elimination of misconceptions through construction of their own understanding of the conceptual relationships that underlie a particular curriculum domain. In interpreting the implications of the paper for undergraduate instruction, it is the interactive relationship between the two uses of concept maps (i.e., instructional strategies, student tools) that focuses instruction on the development of "in-depth" student conceptual understanding in science.

Within the preceding, the implications of the paper suggest research issues from cognitive science and related areas that focus upon the constructed development of student conceptual knowledge that can be addressed methodologically within an instructional framework that emphasizes concept mapping as a means for studying the interaction among the forms of instructional strategies and student tools considered above. Thus, an important implication of the argument advanced in the paper is the need for research at the postsecondary level focusing on the effect of concept maps in (1) providing a means for multiple representations that encourage students to externalize their preliminary ideas, identify misconceptions, and make their thinking explicit to others, (2) providing students with an opportunity to reflect on their own knowledge representation schemes, compare their thinking to peers or experts, and continue the knowledge negotiation process by developing progressive approximations of their own understanding until they have reached an appropriate level of conceptual understanding, and (3) providing students with the means to activate, reorganize, and add to their prior knowledge as a representation scheme for the construction of conceptual understanding.

APPENDIX

The sample concept maps reflect varying levels of science background knowledge and expertise among students. The Heat and Temperature Map 1 was constructed by an elementary education undergraduate who devoted considerable time and energy in researching the topic. The Biological Classification Map 2 was constructed by a secondary science teacher who had two degrees in science. The Heat and Temperature Map 3 was constructed by an elementary education major enrolled in a preservice science methods course. This map reflects the initial representation of the student before instruction about the topics of heat and temperature. Given that the methods course did not focus on these concepts, one might only conjecture as to the actual conceptual understanding of the preservice student and how meaningful instruction on this topic in the elementary classroom might actually occur.

REFERENCES

Alexander, P. (1996). The past, present, and future of knowledge research: A reexamination of the role of knowledge in learning and instruction. Educational Psychologist. 31(2), 89-92.

Anzai, Y. (1991). Learning and the use of representations for physics expertise. In K. A. Ericsson & J. Smith (Eds.), Toward a general theory of expertise: Prospects and limits (Pp. 64-92). Cambridge, England: Cambridge University Press.

Bracey, G. (1997). Research: More on TIMSS. Kappan. 78(8), 656-657.

Camacho, M., & Good, R. (1989). Problem solving and chemical equilibrium: Successful versus unsuccessful performance. Journal of Research in Science Teaching. 26, 251-272.

Carey, S. (1985). Are children fundamentally different kinds of thinkers and learners than adults. In S. F. Chipman, J. W. Segal, & R. Glaser (Eds.), Thinking and learning skills (Vol. 2), (Pp. 485-517).

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. Sternberg (Ed.), Advances in the psychology of human intelligence (Pp. 7-76). Hillsdale, NJ: Lawrence Erlbaum Associates.

Dansereau, D. F. (1995). Derived structural schemas and the transfer of knowledge. In A. McKeough, J. Lupart, & a. Marini (Eds.), Teaching for transfer: Fostering generalization in learning. (Pp. 93-121). Mahwah, NJ: Lawrence Erlbaum Associates.

DeJong, T., & Ferguson-Hessler, M. G. M. (1966). Types and quality of knowledge. Educational Psychologist. 31(2), 105-113.

Glaser, R. (1991). The maturing of the relationship between the science of learning and cognition and educational practice. Learning and Instruction. I, 129-144.

Kozma, R. B. , Russell, J., Jones, T., Marx, N., & Davis, J. (1996). The use of multiple linked representations to facilitate science understanding. In S. Vosniadou, E. De Corte, R. Glaser and H. Mandl. (Eds.). International perspectives on the design of technology- supported learning environments. Mahwah, NJ: Lawrence Erlbaum and Associates.

Larkin, J. H., & Simon, H. a. (1987). Why a diagram is sometimes worth a thousand words. Cognitive Science, 11, 65-100.

Larkin, J. H. (1989). What kind of knowledge transfers? In L. B. Resnick (Ed.), Knowing, learning and instruction: Essays in honor of Robert Glaser (Pp. 284-306). Hillsdale, NJ: Lawrence Erlbaum Associates.

Novak, J. D. (1977). An alternative to Piagetian psychology for science and mathematics education. Science Education, 61, 453-477.

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

Paivio, A. (1975). Neomentalism. Canadian Journal of Psychology, 29, 263-291.

Prawat, R. S. (1989). Promoting access to knowledge, strategy, and disposition in students: A research synthesis. Review of Educational Research. 59, 1-41.

Regis, A., & Albertazzi, P. G. (1996). Concept maps in chemistry education. Journal of Chemical Education. 73(11). 1084-1088.

Reif, F. (1984). Understanding and teaching problem solving in physics. In Research on physics education: Proceedings of the First International

Workshop Lalonde Les Maures (pp. 15-53). Paris: Centre National de la Recherche Scientifique.

Reif, F., & Heller, J. I. (1982). Knowledge structure and problem solving in physics. Educational Psychologist. 17, 102-127.

Romance, N. R., & Vitale, M. R. (1996). Knowledge representation systems: Basis for the design of instruction for undergraduate course curriculum. Paper presented at the Eighth National Conference on College Teaching and Learning, Jacksonville, FL.

Schmidt, H. G., & Boshuizen, H. P. a. (1993). On the origin of immediate effects in clinical case recall. Memory and Cognition, 21, 338-351.

Shavelson, R. J., Lang, H., & Lewin, B. (1994). On concept maps as potential "authentic" assessments in science. CSE Technical Report 388: CRESST University of Santa Barbara, CA.

Snow, R. E. (1989). Toward assessment of cognitive and conative structures in learning. Educational Researcher. 18, 8-15.

Stillings, M. A., Weisler, S. E., Chase, C. H., Feinstein, M. H., Garfiels, J. L., & Rissland, E. L. (1995). Cognitive science: An introduction. Cambridge, MA: The MIT Press.

Vitale, M. R., & Romance, N. R. (1992). Content knowledge and methodology in teacher preparation. (Pp. 219-238). In D. Carnine & E. Kameenui (Eds.) Higher order thinking: Designing curriculum for mainstreamed students. Austin, TX: PRO-ED, Inc.

Vosniadou, S., & Brewer, W. F. (1987). Theories of knowledge restructuring in development. Review of Educational Research, 57(1), 51-67.

Vosniadou, S. (1996). Learning environments for representational growth and cognitive flexibility. (Pp. 13-23). In S. Vosniadou, E. De Corte, R. Glaser & H. Mandl (Eds.). International perspectives on the design technology supported learning environments. Mahwah, NJ: Lawrence Erlbaum & Associates.

Wallace, J. D., & Mintzes, J. J. (1990). The concept map as a research tool: Exploring conceptual change in biology. Journal of Research in Science Teaching. 27(10) 1033-1052.

Wandersee, J. H. (1990). Concept mapping and the cartography of cognition. Journal of Research in Science Teaching. 27(10), 923-936.

Willerman, M., & MacHarg, R. A. (1991). The concept map as an advance organizer. Journal of Research in Science Teaching. 28(9), 834-848.

Biographical Notes

Dr. Nancy Romance is Professor of Science Education and Director of the Florida Region V Center for Educational Enhancement at Florida Atlantic University, Boca Raton, FL.

Dr. Michael Vitale is Associate Professor of Educational Research and Co-Director of the Laboratory for Applied School Research at East Carolina University, Greenville, NC.

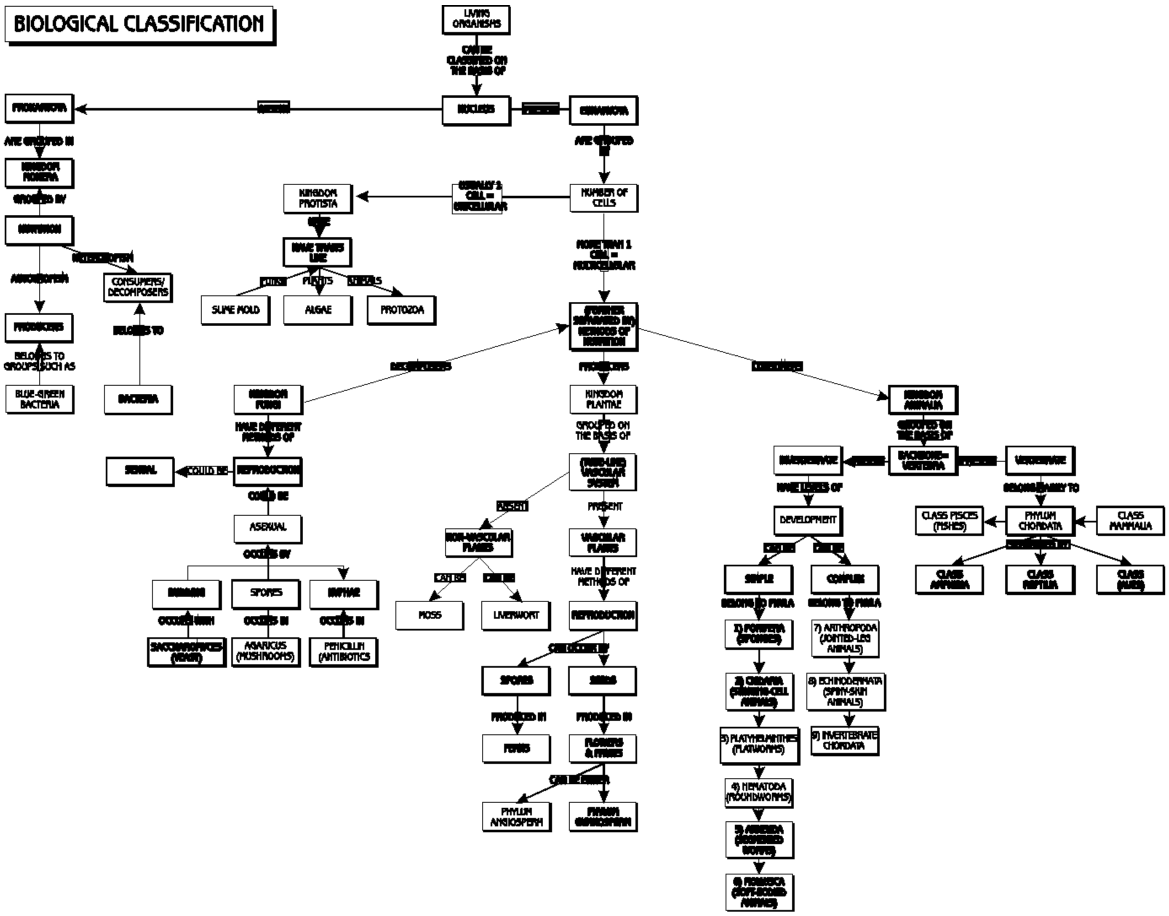

Figure 1: Author: Prakash Rathmanathan (used with permission)

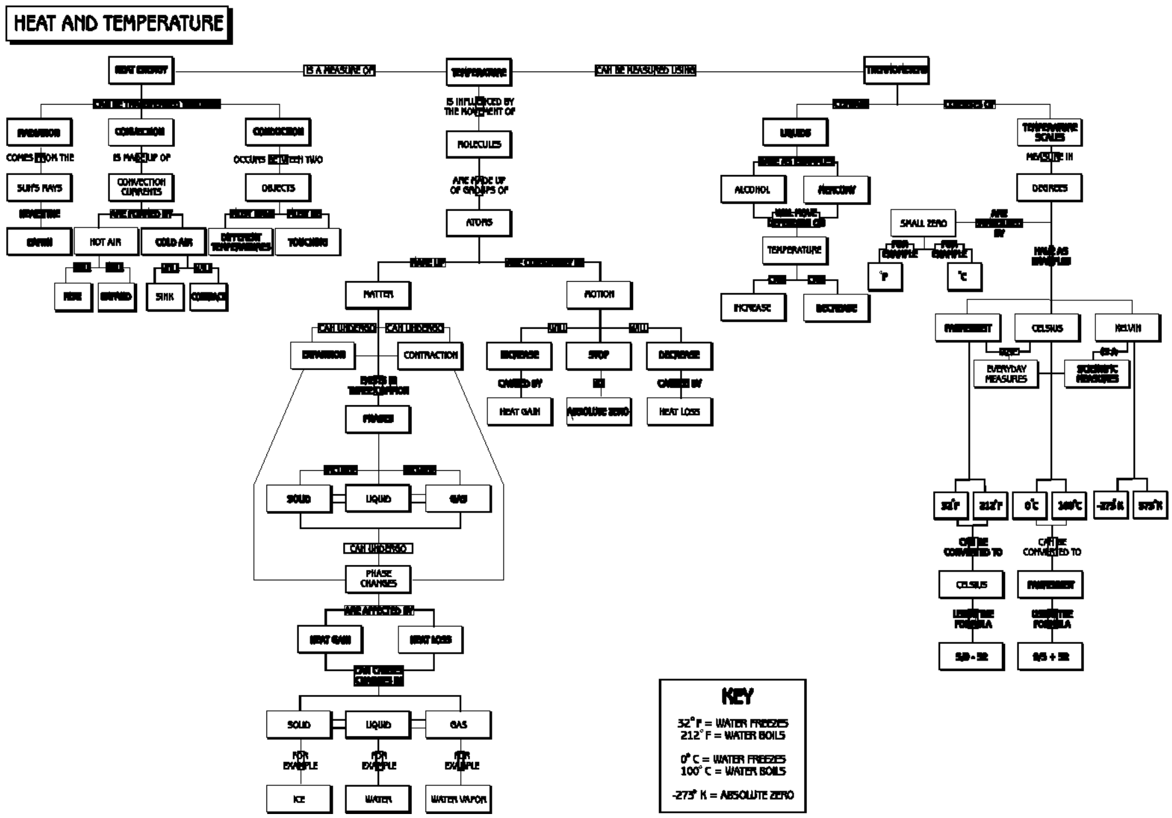

Figure 2: Author: Bridgett Beverly (used with permission)

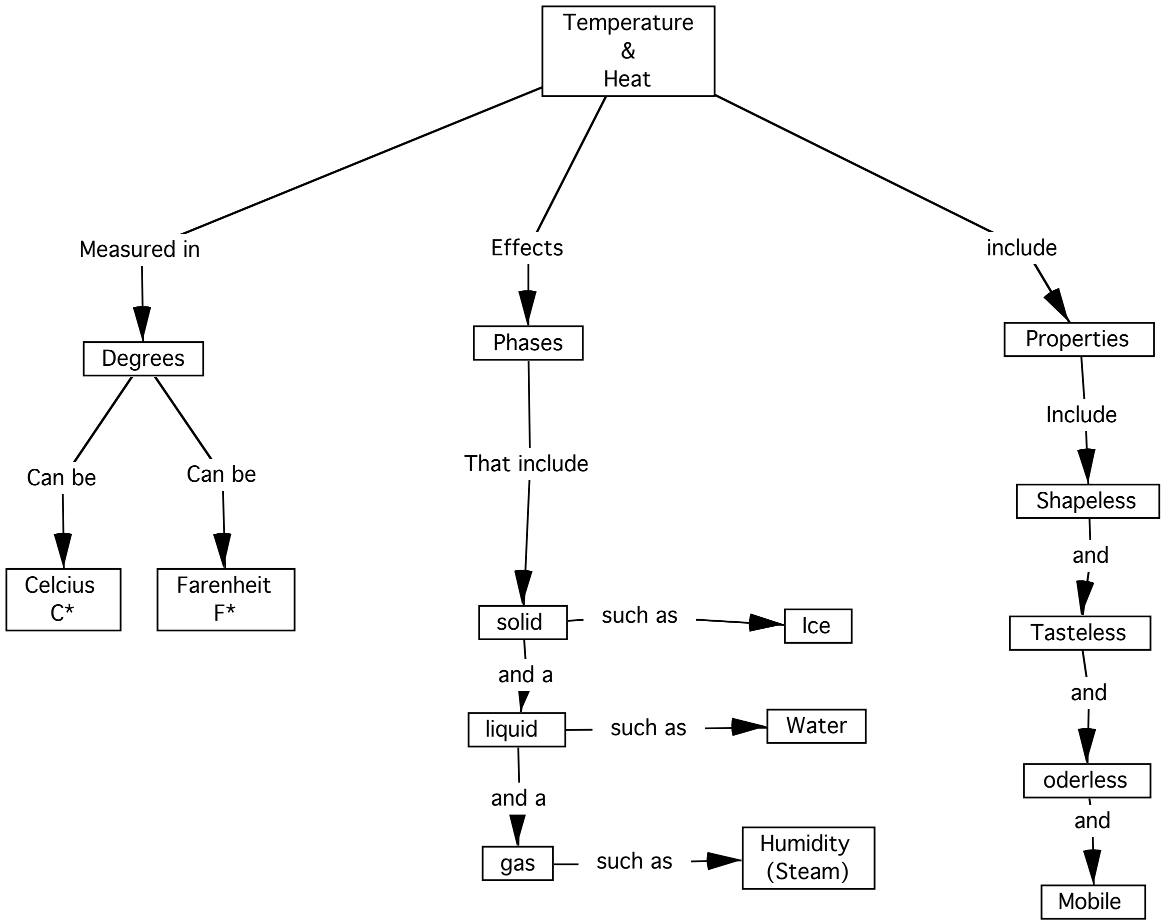

Figure 3: Initial Concept Map of Elementary Education Major