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CONCEPT MAPPING: A USEFUL TOOL FOR SCIENCE EDUCATION

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Abstract

This article describes the genesis and development of concept mapping as a useful tool for science education. It also offers an overview of the contents of this special issue and comments on the current state of knowledge representation. Suggestions for further research are made throughout the article.

Origin of the Idea

Concept mapping, as it is described in the articles included in this special issue of *JRST*, had its origin in research we did at Cornell University to study changes in students' understanding of science concepts over a 12-year span of schooling (Novak & Musonda, in press). The study employed audio-tutorial (A-T) science lessons (Novak, 1972) to present basic science concepts to children in the first and second grades (six- to eight-year-olds) in Ithaca, New York during the 1971–1973 school years. Modified Piagetian clinical interviews (Pines, Novak, Posner & VanKirk, 1978) were administered to both A-T "instructed" students and to "uninstructed" students—those who did not receive the A-T lessons and who otherwise received very little science instruction in those grades in Ithaca, New York's schools at that time. Working with a sample of 191 instructed students and 48 uninstructed students, and interviewing these children several times in the first and second grades, we began to accumulate large numbers of recorded interviews and typed interview transcripts. We were overwhelmed by the task of determining how changes in conceptual understanding were occurring in the students and began to search for better ways to organize the mass of data we had. This led us to examine once more the theoretical underpinnings of the A-T program and the cognitive learning theory that was guiding our work.

The A-T science program was based upon Ausubel's (1963; 1968) assimilation theory of cognitive learning that had this fundamental assumption:

> If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly. (Ausubel, 1968, Epigraph)

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We designed each audio-tutorial lesson on the basis of discussions with children to determine what they already knew about the science ideas we wished to present. The science content was based, in part, on a curriculum developed earlier (Novak, Meister, Knox & Sullivan, 1966) and on our preliminary work using audio-tutorial instruction with children (Novak, 1966). Each A-T lesson was revised several times, based upon school trials, and some 150–200 person-hours went into the development of each 15–20-minute A-T lesson. The 28 lessons used in our 12-year study were part of a larger group of 60 lessons developed during the years from 1967–1973.

Our objective in the longitudinal study was to observe how concept meanings of individual students changed over time. Thus, for each domain of science knowledge presented in the lessons, we sought to ascertain what students knew both before and after A-T instruction, and how their knowledge changed in subsequent years. Prior to the development of the concept mapping tool, we classified students into "categories" (Hibbard & Novak, 1975) or "notions" (Nussbaum & Novak, 1976) of understanding. Although these systems for characterizing knowledge were useful, we were interested in more explicit description of changes in concept meanings. From Ausubel's (1968) assimilation theory of cognitive learning, we worked with the idea that new concept meanings were acquired through assimilation into existing concept/propositional frameworks. Thus, the task was how to present these frameworks and how to represent changes within these frameworks. Given the additional ideas from Ausubel's theory that cognitive structure is organized *hierarchically*, and that most new learning occurs through derivative or correlative *subsumption* of new concept meanings *under* existing concept/propositional ideas, we developed the idea of hierarchical representation of concept/propositional frameworks (Novak, 1977, pp. 88–93), which we later described as "cognitive maps" or "concept maps" (Novak, 1979; 1980; 1981). In our early work, we did not always "label" the lines which linked the concepts to form propositions, but it soon became clear that this was essential to represent concept/propositional meanings in an explicit hierarchical framework. Thus, the concept map tool evolved over a period of 3–4 years as a way of representing both specific concept/propositional meanings held by learners before and after instruction, and the changes in cognitive structure which occurred over a period of years.

During the 1960s, there was considerable debate in the science education community as to whether or not young children could understand "abstract" concepts such as *energy*, *molecule*, or *evolution*. Our early work suggested that the primary limitation for young children was not their "cognitive operational capacity," as indicated in the work of Piaget (1926), but rather the quantity and quality of their relevant knowledge acquired through experience and instruction. We therefore set out to study this question through the use of A-T lessons administered to first- and second-grade children. Our key hypothesis was that, with carefully designed instruction, six- and seven-year-old children could acquire useful levels of understanding of *any* basic science concept, including concepts of energy and energy transformations, the particulate nature of matter, and the conservation of matter/energy. It was from this key hypothesis that we developed what eventually became the 12-year longitudinal study of children's science concept learning just described, and from which our version of concept mapping originated. Figures 1 and 2 show examples of concept maps drawn by our research team using interviews with the same student in the second and the twelfth grades. In the community of cognitive psychologists during the past few years, there has been a

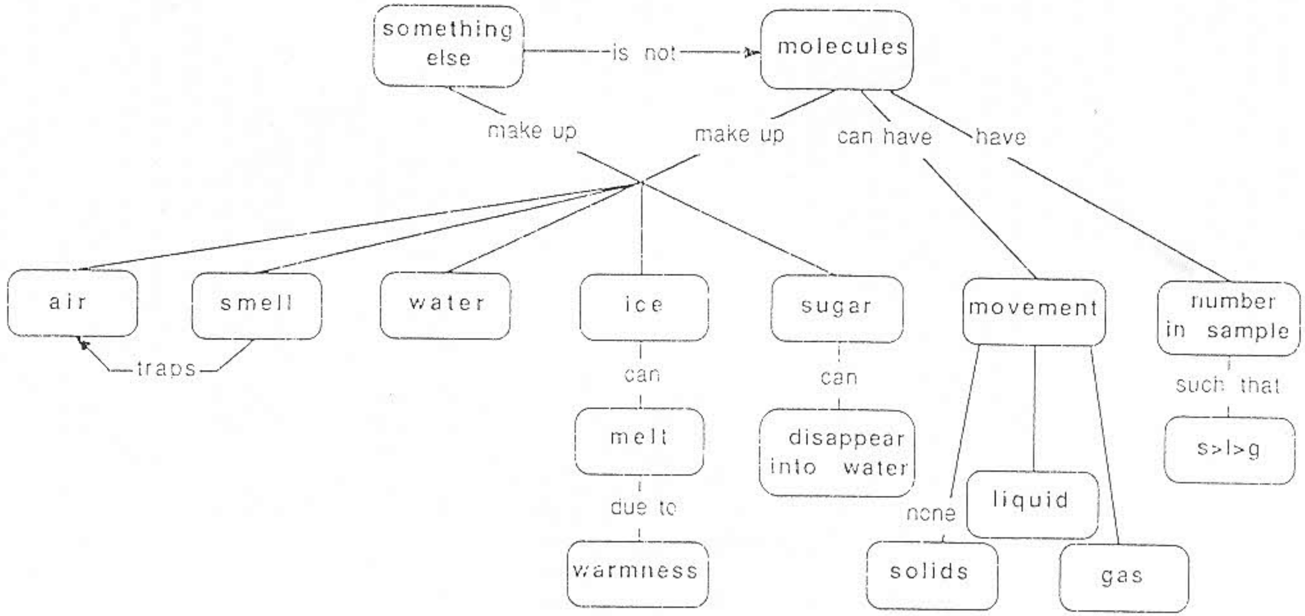

Fig. 1. A concept map for Phil drawn from an interview administered after he completed audio-tutorial science lessons in grade one.

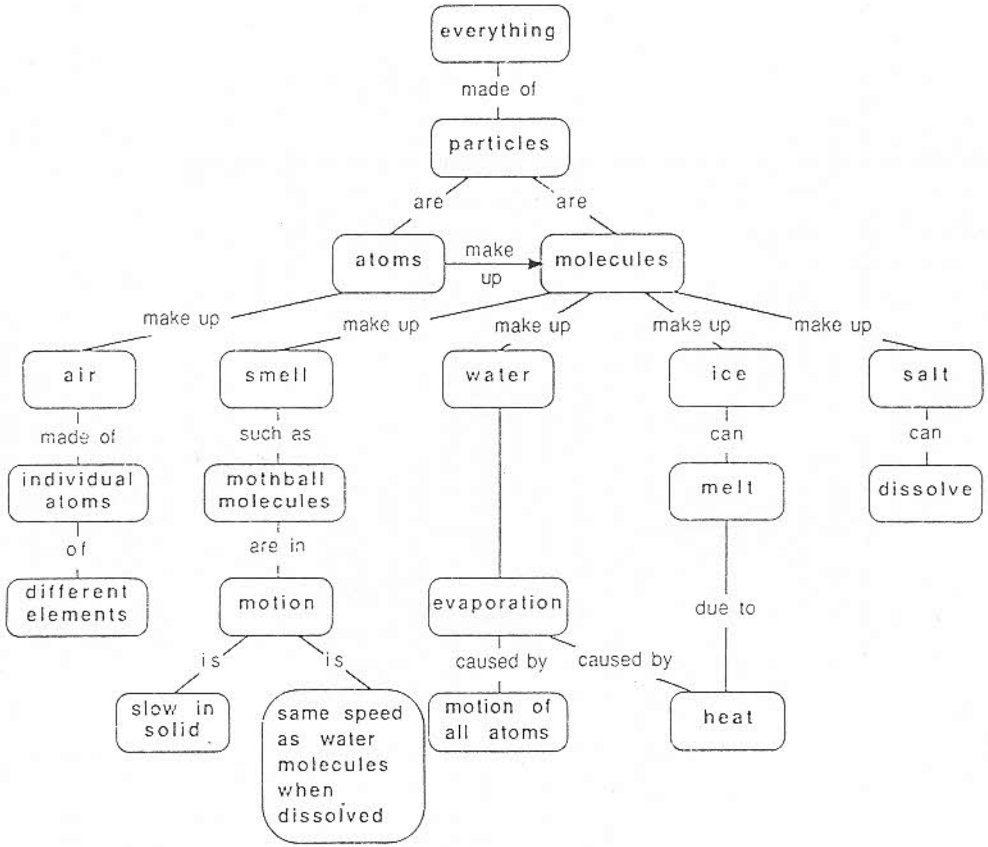

Fig. 2. A concept map for Phil drawn from an interview in grade twelve, after he completed his junior high school science, biology, chemistry, and physics. Note that his tendency to learn by rote did not correct misconceptions on relationship between solute and solvent molecules, and other faulty conceptions are presented.

growing recognition that Piaget underestimated the cognitive capabilities of children. His monumental works remain as an enormous resource for understanding children's construction of meanings, but newer theoretical views are beginning to guide our interpretation of cognitive development in children. Donaldson (1978), Carey (1985), Driver (1983), Bruner and Haste (1987), Flavell (1985), and Matthews (1980; 1984) are a few of the leading scholars who now confirm that children have substantial cognitive abilities—far beyond those suggested by narrow interpretations of Piaget's work. For example, Flavell (1985) states:

> It can be argued, with Piaget, that the cognitive systems of infants are indeed fundamentally and qualitatively different from those of older humans. Although Piaget also believed that the cognitive systems of early-childhood, middle-childhood, and adolescent-adult thinkers are likewise qualitatively different from one another, there is growing doubt in the field that these differences, too, are that radical and stage-like. Older minds may appear to be more qualitatively different from younger ones than they really are. One reason for this is that older minds have accumulated much more organized knowledge, or *expertise*, in many more knowledge domains than younger ones have, and we now know a number of specific ways that the possession of expertise in a domain can dramatically improve the quality of one's cognitive functioning within that domain. We would hesitate to say that older minds truly are qualitatively different from younger ones—constitute distinct and different cognitive systems—if disparities in domain-specific expertise were largely responsible for the appearance of qualitative difference. For one thing, the older mind might look almost as immature as the younger one when operating in domains in which it, too, is an utter novice. More generally, both child and adult minds can vary considerably over domains and occasions in the quality of their cognitive performance. At present, therefore, it is difficult to identify really clear-cut, stage-like "cognitive metamorphoses" during the childhood and adolescent years. It is far easier, instead, to defend and document the existence of very important and substantial "developmental trends" during these years. (p. 114)

In our work, we have found that primary-grade children (Symington & Novak, 1982) are capable of developing very thoughtful concept maps which they can explain intelligently to others. The challenge we face as science educators is primarily how to organize better instructional material and how to help students learn this material.

As new graduate students joined our research group, they found that concept maps were not only a useful tool to represent changes in the knowledge structure of students over time, but also helped them to "learn how to learn." They found that concept maps were useful to represent knowledge in any discipline and aided in organizing and understanding new subject matter. Gradually, hearing the message from my students, I introduced a new course in 1975 that evolved into my present course for undergraduate students, *Learning to Learn*. Concept mapping plays a key role in the educational activities of this course and, together with other metacognitive tools, helps students take charge of their own meaning making (Novak, 1985). In the work that my students, other colleagues at Cornell University and elsewhere, and I have done since 1975, concept mapping has become an important tool to help students learn to learn meaningfully, and to help teachers become more effective teachers. The articles included in this issue will present extensions of some of this work.

Cognitive and Affective Learning

The article in this issue by Jegede, Alaiyemola, and Okebukola reports on the continuing studies in Nigeria utilizing concept mapping. In this article the researchers report that students in a class using concept mapping, when compared with a group using conventional lecture/expository instruction, received significantly higher mean scores on an achievement test dealing with nutrition in green plants and respiration in cells. An important aspect of their research is that they also studied the effect of concept mapping on students' anxiety toward science using Zuckerman's Affect Adjective Checklist (see Table I in their article). They found that reduction in anxiety was highly significant for the concept mapping group. Analyzing their data with respect to gender, the researchers found that males made greater achievement gains than females and also showed greater reduction in anxiety scores.

In our research program at Cornell University, we have been placing increasing efforts on the study of affective factors as they interrelate with cognitive factors in the empowerment or disempowerment of learners. Self-concept and personality traits are surely determined, in part, by heredity, but environment is probably equally, or perhaps even more, important in influencing self-concept development (Harris, 1989). In our work we find that positive self-concept development can be encouraged by helping students "learn how to learn" and here we must emphasize *meaningful* learning. There is, of course, a short-term enhancement of self-concept that derives from high achievement as a result of intensive rehearsal and rote learning (e.g., "cramming" for a test). However, this knowledge is soon lost or is not applicable in real-world contexts, resulting in a nagging sense of being a fraudulent learner. In the extreme, this subconscious and sometimes conscious awareness of lack of control of meanings can lead to pathologic behavior. For example, in a study of women with bulimia or anorexia eating disorders, Hangen (1989) found that each of her subjects was strictly a rote learner in high school (and college); although they achieved high grades, they never felt that they had an understanding and control over the subject matter. Much more research is needed on how the *quality* of cognitive learning influences affective learning.

Concept Mapping in Teacher Education

Beyerbach and Smith (in this issue) used a computerized concept mapping program to assess preservice teachers' knowledge of "effective teaching." Students worked with a partner using *Learning Tool*, a commercially available software program. They also kept "reflective journals" describing their experiences using *Learning Tool*. Beyerbach and Smith found that preservice teachers showed awareness of their evolving knowledge about "effective teaching." They also reported anxiety about the use of the computer program, and heightened awareness of how students must feel when given tasks that are unfamiliar and potentially ego threatening. Both the concept maps they produced and their reflective journals illustrated the preservice teachers' growing understanding of pedagogy.

In our studies of the learning patterns of Cornell University students, we have found that the large majority engage in essentially rote learning most of the time (Edmondson, 1985; 1989; Donn, 1990). The same patterns have been observed in students preparing to teach. If prospective teachers are to adopt practices that encourage meaningful learning, it seems evident that they must also seek to learn subject matter meaningfully.

The use of concept mapping and other metacognitive tools in teacher education programs may play a useful role in two ways. First, these tools may help prospective or in-service teachers to move their own learning approaches toward more meaningful (and less rote) practices. They will seek to make subject matter more *conceptually transparent* (Novak, in review). That is, they will emphasize the meanings of key concepts and principles (and their interrelationships) in ways students can form a *conceptual* understanding of the subject. Second, they will become skillful in the use of metacognitive tools, including computer-mediated tools, and thus hold more confidence in using these tools with their own students. The studies by Beyerbach and Smith and Hoz, Tomer, and Tamir (in this issue) point to the need for empowering teachers to learn meaningfully so that they can be more successful in helping their own students learn meaningfully.

The study by Hoz, Tomer, and Tamir is a pioneering effort that deserves special attention. There has been relatively little research on either teacher subject matter knowledge or teacher pedagogical knowledge (e.g., see the 1,000-plus-page *Handbook of Research Teaching*, Wittrock, 1986). The common assumption is that teachers gain in both these areas with increased teaching experience. In fact, most school salary schedules are based primarily on years of service, with credit hours of coursework or advanced degrees earned as additional criteria. There is much debate on "merit systems" for salary increments and there are many reasons why "merit pay" is rejected by most teachers. The fact is that schools now employ a merit system for compensation of teachers, namely *years of service* and *degrees earned*. The study by Hoz and his colleagues clearly raises questions about these salary criteria, if knowledge of subject matter and pedagogical knowledge are related to competence as a teacher. There has been relatively little recent research to test the latter assumption, but in the past, Anderson (1949; 1950) found little relationship between subject-matter preparation and student achievement in school science.

In the recently developed MAT (Master of Arts in Teaching) program for science and mathematics teachers at Cornell University, we chose to select students in the junior year of their undergraduate studies and to have them begin coursework in education at the same time. The two major reasons for this decision were that we wanted to introduce our students to "constructivist" ideas on teaching and learning while they were still engaged in taking coursework in science and mathematics. We also hoped to help them to "reconceptualize" their subject matter knowledge as they progressed in their coursework and to see science and/or mathematics, not as largely the rote learning of definitions, formulas, or problem-solving algorithms but as a conceptually rich tapestry of interrelated ideas. We wanted them to observe, from early on, the faulty learning patterns and knowledge structures of college and high school students, in part by conducting structured clinical interviews of students and by doing tutorial work. For most of the students in our programs, the meaning of *meaningful learning* was totally new, and shifting their learning to predominantly meaningful learning patterns was not easy. Given that these students generally have SAT (Scholastic Aptitude Test) scores in the 600s and B+ grade averages in their subject-matter majors, the problems we have experienced with our students were certainly not due to lack of aptitude. They are most likely endemic to any college student population and are probably worse for teacher-preparation programs at less demanding, less competitive institutions.

This situation is not hopeless, however. We have been pleased with the progress we have seen in our MAT students as they advanced through our three-year program. While the Beyerbach and Smith study and the Hoz, Tomer, and Tamir study suggest some of the problems and issues that need to be addressed, they also show some of the promise for the use of tools such as concept mapping in research and teacher preparation.

Concept Maps for Instructional Design

In the early 1960s, the National Science Teachers Association funded activities of a Curriculum Committee to help schools plan science programs for grades K-12. The Committee organized a seminar of scientists and science educators in order to identify "major conceptual schemes" that could guide curriculum development (Novak, 1964; NSTA, 1964). Although there was a burst of interest in the proposals put forward, it would be difficult to identify significant changes that resulted from the NSTA work or the numerous federally funded science curriculum projects of the 1960s (Stake & Easely, 1978; General Accounting Office, 1984). The general picture recognized today is that American science education lags behind that of most technologically advanced countries.

One reason, I believe, that the NSTA curriculum effort made less impact than was expected was that it was very difficult to describe how a curriculum built around the "major conceptual schemes" of science would differ from what was already in place. Concept mapping, I believe, provides a way to overcome this problem. As Wandersee has noted in his opening paper, concept maps can be used to present both a global view of a K–12 science curriculum built around basic science concepts, and varying degrees of "magnification" to the level of a specific science lesson—with each map showing key concepts and concept relationships necessary to understand the larger or the more explicit domain of science. As he points out, it is possible to "telescope" from a macro to a microscopic concept map for the domain to be studied.

As noted previously, most preservice and in-service teachers we have worked with still see science as a large body of information to be mastered, and less often as a method for constructing new knowledge about the universe. It remains an enormous challenge to help teachers and *their* teachers (i.e., college and university professors) see science as an evolving framework of concepts and concept relationships, and a methodology for *constructing* (not discovering) new concepts and new concept relationships. There are fundamental epistemological problems that need to be addressed, as well as fundamental psychological problems that need attention (Novak, 1987; Duschl, 1990). Solving these problems will not be easy.

In their article for this special issue of *JRST*, Starr and Krajcik discuss some of the uses of concept maps as a heuristic for curriculum development. Working with teachers in grades four through eight, a series of concept maps was constructed during six three-and-one-half-hour sessions. They found significant changes in the maps the teachers prepared, moving toward better hierarchical arrangement with more fundamental superordinate concepts and greater detail, explicitness, and integration of concepts. They conclude that the use of concept maps with these teachers changed their view of curriculum—with important implications for teaching and learning.

Fisher's paper in this issue describes the work that she and her colleagues have been doing in developing another form of knowledge representation system—based upon the use of the computer. The SemNet™ program utilizes the capability of the Macintosh computer to store and access information in multiple ways, thus permitting the storage of specific concepts and concept relations in a variety of patterns. However, the SemNet™ display does not permit printouts of anything similar to a concept map. To construct these, Fisher and her colleagues have used a cut-and-paste technique which they have found useful for curriculum planning.

Concept maps have been used by the authors of the recent BSCS (1990) Blue Version high school science text, *Biological Science: A Molecular Approach*, for both planning and writing the book. Although chapter authors only received minimal training in the technique of concept mapping, most produced good maps to represent the knowledge structure of their chapters. Moreover, it was relatively easy to see the interrelationships between concepts in various chapters. The published version contains a section in its Teacher's Edition that briefly explains concept mapping and provides sample maps for each chapter. Similar materials can be found in other recently published science textbooks.

The design of programs that help make science "conceptually transparent" to the teacher and the student should help to address a frequently cited problem, namely, the "scientific illiteracy" of much of our population. Wandersee and Good, for example, team-teach a graduate course entitled "Scientific Literacy and Meaningful Learning" that emphasizes this linkage. Lloyd's article in this issue addresses the scientific illiteracy problem and points to another problem. Textbooks form the curriculum for most science courses and those textbooks written for the least-able students evidence the least elaboration of concepts. Yet most studies dealing with reading comprehension show that texts which provide more *elaboration* of the ideas presented are more comprehensible, especially to novices, than texts which offer less elaboration. Lloyd reviews other issues related to reading comprehension and some relevant research.

Lloyd selected the topic of photosynthesis and compared three different textbooks, targeting three different student populations, on the degree of elaboration of the concept of photosynthesis. Using concept maps to represent the concepts and relationships in each textbook, Lloyd found the least elaboration of photosynthesis in the textbook written for the least-able population of students. This, she concludes, is not likely to help these students understand photosynthesis—a basic biological phenomenon. She also noted significant differences in the more "advanced" textbooks, but here, too, there were shortcomings in clarity of exposition revealed by her concept maps.

We need more studies of the type done by Lloyd, and also related studies that compare student achievement resulting from instruction with textbooks of greater and lesser elaboration. A study with two or three student populations on two or three textbook passages would help to provide a more definitive answer to the question of the extent to which better elaboration of concepts in textbooks might improve the scientific literacy of our graduates.

Concept Maps for Exploring Changes in Meaning Frameworks

One of the questions that has been of interest to many science educators is how instruction can elaborate and/or modify existing knowledge frameworks. Numerous studies have shown that students bring relevant knowledge frameworks of varying degrees of quantity and quality to new learning tasks (Helm & Novak, 1983; West & Pines, 1985; Novak, 1987). The challenge has been not only to help students elaborate the conceptual understanding they already possess, but especially to modify those knowledge structures that contain *misconceptions* or *alternative conceptions or frameworks*. The latter has been notoriously intractable to conventional classroom instruction. Concept maps have been useful in helping students to recognize and modify faulty knowledge structures (Feldsine, 1983; Novak & Gowin, 1984).

The study reported by Wallace and Mintzes in this issue addresses the problem of "conceptual change," or as I prefer to call describe it, "modification of limited or inappropriate conceptual frameworks" (Novak, 1983). Using a computer program on "Life Zones in the Ocean," Wallace and Mintzes examined the knowledge frameworks of 42 students instructed in life zones via the program and 49 students who received an alternative computer program experience. All students (preservice elementary teachers) received training in concept mapping and constructed concept maps on the topic of "life zones" prior to and after instruction with the computer programs. Their findings were impressive in that although there was little difference observed on a multiple-choice/free-response test on "life zones" when the two groups were compared before and after computer instruction, the group using the "Life Zones" program showed very substantial gains in the quality of their concept maps. These data show that concept maps can be a highly sensitive tool for measuring changes in knowledge structure, especially when carefully controlled, quality instruction is offered. We need more research of this kind to study not only overall gains in knowledge, but also explicit changes in the quality and quantity of concept/propositional frameworks held by students before and after instruction. The concept map tool was developed to meet our research need to represent changes in children's concept/propositional frameworks, and it is gratifying to see the robustness of the tool evidenced here.

In his comment, Zoller raises the issue of whether or not concept maps can apply to all subject matter. In the one and one-half decades that we have worked with this tool, we have not found *any* subject matter domain that is not amenable to representation with concept maps. To be sure, some domains are rarely considered in concept/propositional frameworks, but they can, nevertheless, be so represented. Some researchers make the distinction between *conceptual* knowledge and *procedural* knowledge. We see no epistemological foundation for this (Novak, 1987). In *Learning How to Learn* (Novak & Gowin, 1984), we show concept maps for defense in basketball, judging meat quality, music composition, and art—all highly *procedural* knowledge domains. There are significant epistemological issues that need to be addressed regarding representation of knowledge and knowledge structures, but that discourse moves beyond the scope of this special issue. The forthcoming special issue of *JRST* edited by Professor Marcia C. Linn and her colleagues will undoubtedly speak to many relevant epistemological concerns.

SemNet™: An Alternative Knowledge Representation Tool

With the availability of the very user-friendly Macintosh computer, Fisher and her colleagues began development of a new knowledge representation tool in 1983 which they call SemNet™. A good discussion of the origins of SemNet™ and related computer-based knowledge representation software is included in her article.

Summary

The nature of knowledge representation raises deep philosophical, psychological, and practical questions. Interest in this subject has increased dramatically in recent years and I would anticipate that this increase will continue exponentially for the next decade or two. Recent books, such as Schiffer and Steele's (1988) *Cognition and Representation* and Cummin's (1990) *Meaning and Mental Representation*, are examples of publications oriented toward questions arising primarily from the field of artificial intelligence. In my opinion, most of the issues discussed in such books have little or no relevance to concept mapping, SemNet™, or other knowledge representation systems that are *useful in classroom settings*. Moreover, they address research methodologies driven largely by empiricist/positivist epistemologies. For three-quarters of a century, behavioral psychology, driven by empiricist/positivist epistemology, dominated the field of psychology and influenced education (e.g., the use of "behavioral" objectives). Cognitive psychologies have now largely displaced behavioral psychology, especially with respect to human learning. However, empiricist/positivist epistemology is still alive and flourishing in many areas of "cognitive science" and artificial intelligence. I doubt that the "elegant" research underway in these fields will bear any greater fruit for improving school learning, especially learning that *empowers* learners to learn, than did 75 years of behavioral psychology.

Concept maps, SemNet™, or any other learning tool is no "magic bullet," no "quick fix" for classrooms where rote learning predominates. Emerging constructivist ideas on the nature of "meaning making," and classroom teaching and learning, show promise for a "quantum leap" in improving the quality of education; however, there remains much work to be done. The recent international conference on the history and philosophy of science in science teaching held at Florida State University points toward new thinking that is needed in order to employ learning tools effectively (see Herget, 1989). The forthcoming *JRST* special issue on "Students' Models and Epistemologies of Science," edited by Linn, Songer, and Lewis, will surely add to the philosophical foundations needed to advance our work to improve science education.

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