CHAPTER

1

The Pursuit of a Dream: Education Can Be Improved

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INTRODUCTION

Over the past four decades, the work that my graduate students, visiting professors, students of my students, and I have done has been gaining popularity around the world, especially in Latin countries and the Far East. The question is often asked of me: How did you decide to use the theories and pursue the studies you and your associates have done? There is no simple answer to this question, partly because, over time, the theories, methods, and ideas that have guided our work have changed. This change has not been random or arbitrary, but rather a function of our previous studies and new complementary contributions by scholars in a variety of disciplines. Nevertheless, there has also been a constancy in our work with a focus on the question: How can we help people become better learners? From early in my career to the present day, my belief has been that we can never make this a better world to live in unless we can develop better ways to help people "get smart." It has been my conviction over the years that education, both formal and informal, can be dramatically improved—if we can make the study of education more like the study of science, i.e., guided by theory, principles, and productive methodologies. In short, I believed we needed new and more powerful *paradigms*, to borrow Kuhn's (1962) term, to guide educational research and practice.

This chapter is an autobiographical sketch of my search for better ways to educate. It is necessarily an abbreviated autobiography, and I cite only a few

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people who contributed to our work, but I hope it can serve to illustrate, especially to students and younger faculty in education, that it is possible to improve education; we can pursue the dream that education can be improved. The other chapters in this book go on to present work done by former students and/or associates, plus some excellent work done by others—all of which point to support the idea that education, and especially science education, is being improved. The study of science can be *meaningful* to everyone.

DEVELOPING A PASSION FOR LEARNING

My elementary school experiences were largely a frustration to me. Most of what was presented seemed repetitious, simple, and boring, while reading, especially oral reading to the class, was often embarrassing. The basal readers we used contained mostly nonsensical stories and often I would import a word, or the pronunciation of a word, to try to make sense of the reading. Coming out of the Great Depression, our home had very few books, and the family made no trips to the public library. I was highly curious about things, especially things related to nature, but there was little available at my reading level that presented the kind of information I needed to understand why plants grew, what made fire, what the sun and stars were. Science instruction was essentially nonexistent in my elementary school and math was mostly drill on simple repetitive textbook "problems."

By upper elementary school, my reading skills were better, but it was still difficult to find books at my level that *explained* how things worked. My brother, 5 years older and by then in high school, was helpful and encouraging, but his science and math courses did not deal adequately with theories and ideas; they presented mostly "facts" to be memorized. Except for a rather good physics course, the science I had in high school was predominantly memorization of word definitions and various "facts." Social science instruction was often worse, presenting few ideas and testing primarily for recall of dates, names, or other minutiae. Repeatedly I wondered throughout my schooling: Does education have to be so dull, so lacking in meaning or significance? And I recall some of my classmates struggling with what seemed to me the simplest of problems. Wasn't there a better way to help them learn?

Also about this time I was struck by the observation that many of my classmates appeared to have almost no capacity to reason things out. Were they just born stupid or were they being miseducated? I thought then that a good percentage of their problems could derive from poor education. I began to realize that I was fortunate to have a dad who, although he completed only four years of education in an eastern European village school, kept encouraging me to try to figure out on my own how things worked and why things were the way they were. If I misbehaved, his punishment was usually to cause me to reflect on why what I did didn't make sense. "Well," he would say, "if it doesn't make sense, don't do it!" Often it would have been less painful to get a spanking, but that was not his way, at least not with me.

When I was 13 years old, I began working after school and Saturdays, first shining shoes and then waiting on customers and pressing clothes in a dry cleaning shop. Working 20 or more hours per week took time from what could have been valuable learning experiences, but it also taught me to use my time efficiently, especially when I began college as a full-time student and working 35 to 40 hours per week. It was my good fortune to have the great University of Minnesota easily accessible to me, so I could live at home and continue work in the dry cleaners, covering all of my expenses.

I discovered "pocket books" in college and began to collect books (most costing 25 cents or less) on every subject, including some of the literary classics. George Gamow's books on science and similar books became a passion for me. Often I was less interested in my course textbooks than in the various other books I was reading. I did acquire an interest in teaching and proceeded to take courses to certify as a science and mathematics teacher. I also became interested in history and other social sciences and took coursework beyond the college requirements. By my senior year in college, I became passionate about learning, especially in science, and read extensively. I also began to help out in a plant physiology laboratory and began some of my own experimental work. Science became very exciting to me. Several of my botany professors were excellent mentors and helped me to gain confidence in my capabilities as a science student.

In contrast to my work in science and social sciences, I found my studies in education courses to be deeply troubling. These courses lacked viable theories and principles, and so much that was presented as theory or principles failed the criterion my dad had taught me to apply—they just didn't make sense, not in terms of their logic or coherence or in terms of their application to the real world. My year of internship in secondary science teaching was satisfying in terms of the students' receptivity to powerful ideas of science, but frustrating in terms of all the constraints the "system" placed on the kind of teaching I wanted to do. It was also evident that the system could not be changed by working in a classroom, so when I was offered a teaching assistantship in the Botany Department at the University, I jumped at the opportunity to pursue further studies in sciences and education.

GRADUATE STUDY IN BOTANY AND EDUCATION

Housed in the botany building, and doing work as a teaching assistant in botany and a research assistant in plant physiology, I also pursued studies in my major field, Education. Again, I found course work in botany and other sciences exciting, but courses in education, with the exception of statistics and a course in higher education by Professor Ruth Eckert, largely trivial at best or borderline nonsense at worst. For example, an "advanced" course in educational psychology, "Theories of Learning", used the popular textbook by Hilgard (1948), but all the theories presented were *behavioral* theories. Piaget, for example, was not mentioned. No cognitive learning theories, such as Bartlett's (1932, 1958), were mentioned. My conclusion was that the theories of learning presented were at best relevant to pigeons, rats, or cats, which were the experimental subjects in most studies, and perhaps for rote memorization tasks such as learning nonsense syllables. I argued vehemently with my course professor that I thought the theories presented were nonsense in terms of human learning; his defense was that he was using the most popular book in the field. Why, I wondered, do apparently intelligent people subscribe to such nonsense! I saw it as a classic case of the Emperor's New Clothes, where only the childlike naive could see that the emperor was naked. And it would be another decade before Ausubel's (1963) *Psychology of Meaningful Verbal Learning*, which strongly influenced my thinking, would be published. So I chose to design my thesis research using a cybernetic model, based largely on the writings of Norbert Weiner (1948, 1954).

The philosophy courses I took were strongly rooted in the *positivist* tradition, with criteria for truth and falsification the hallmark of rigorous, logical thinking. Minnesota was world famous as a center for "logical positivism," and my professors were some of the founding fathers of the center. Bright and distinguished as they were, I could not buy what they were selling. My experiences in the Botany laboratories did not square with their ideas; "truth" or "proof" appeared very illusive at best, and again I wondered why smart people could believe these things. I saw much more validity in ideas such as Conant's (1947) *On Understanding Science*. Later, Conant's disciple, Thomas Kuhn (1962), would publish his now famous *Structure of Scientific Revolutions* and help to advance what is now known as *constructivist* epistemology that is gaining popularity today. We shall discuss epistemological issues throughout this book.

My thesis research attempted to compare gains in "problem solving ability" for students enrolled in a conventional lecture–laboratory botany course with those who received regular course materials augmented with study guides to accelerate their progress. This allowed for a 6-week period devoted totally to individual research projects selected by the students. The idea was that individuals needed experience in real problem-solving activities to gain competence in problem solving. I recognized that 6 weeks was a small part of the lifespan of my students, but I thought some significant gains could be possible.

A major task was to design what I hoped would be a "content neutral" problem-solving test, since I did not regard any of the so-called "critical thinking" or "problem-solving" tests available to have validity for my study—and some published studies questioned whether these tests had any validity at all. This took much of my time for several months, including tryout and evaluation of earlier versions. In the end, I believe I did devise a complex paper-and-pencil test that validly and reliably measured aspects of individual's problem-solving ability, at least according to the criteria derived from the cybernetic theory of learning I was using. The test had some interesting psychometric properties that I reported later (Novak, 1961, 1977a, pp. 104–108).

While the "conventional" group had somewhat higher mean scores on the ACT test and "factual knowledge" tests, the "problem solving" group had a higher posttest mean score on the problem-solving test. Most of the mean differences were not statistically significant, including the latter (Novak, 1958). In retrospect, the results make sense; for viewed through our current "conceptual goggles," significant gains in problem-solving ability would require more and better organized relevant knowledge structures as well as better metacognitive processing—too much to expect under the best of circumstances in a 6-week period. Research results notwithstanding, the whole research experience, including preparation of a botany study guide with labeled photomicrograph (Novak, 1961), was enormously valuable and convinced me that difficult as the task may be, there can be a *science* of science education, and indeed, even a *science* of education. To help create new principles and theories that could lead to science of education was the exciting challenge that lay ahead.

After my first year of graduate studies, I married Joan, a girl I met in my chemistry lab during my sophomore year. She worked as a medical technologist for 3 years until our first child was born. Subsequently, we had two additional children in 3 years, and Joan was very busy being full-time mother and homemaker. Over the years, her love and emotional support helped to sustain me when personal or professional difficulties arose. Over the years I have increasingly come to appreciate my good fortune in having Joan's support, something few men and even fewer women have so constantly. Our children and now also our grandchildren have been a joy and source of pride.

TEACHING BIOLOGY AND BIOLOGY TEACHERS

After completing my doctoral studies, I took a position in the Biology Department at Kansas State Teachers College at Emporia. In addition to teaching botany, biology, and plant morphology, I taught a course called Methods and Materials for Biology Teachers, taken by both preservice and inservice teachers. The latter course was essentially a review of the "big ideas" of biology with appropriate laboratory and field studies that could be easily replicated in schools. I was struck by how weak many of the teachers were in understanding basic concepts of biology and other sciences, evidenced also in a study we did on the recommended college preparation of Kansas science teachers (Novak & Brooks, 1959). In the latter study, we were surprised at how few science courses were regarded as "an absolute minimum" or "essential," mirroring, in part, the poor preparation of teachers in science found in an earlier study by Brooks and Baker (1957). This may also reflect the limited value of science courses where learning and testing involves rote memorization rather than understanding basic concepts. Anderson (1949) found that rote learning of science was the pattern employed in the preparation of most science teachers; he also found that there was little relationship between student achievement and the science preparation of their teachers. Memorization may be an effective learning strategy for getting passing grades in science or other courses, but it is very ineffective for acquiring the kind of disciplinary knowledge necessary for effective teaching. Why, then, were so many science teachers using a rote learning approach in their college preparation?

I enjoyed my time in the Biology Department at Emporia and felt fortunate to be there. After all, my major in the PhD program was Science Education. There was an interesting twist of fate that operated in my career. While a graduate student at Minnesota, an invitation was received in the Botany Department to send a representative to a conference in Michigan to study the "feasibility" of developing a new high school biology program. None of the professors were interested in going, so they asked if I wanted to go, since I was an "educator"—a label they used with derision, but also with a note of kindness toward me. I thought it was wonderful to go to a meeting—all expenses paid! The conference was directed by Richard Armacost, then editor of the *American Biology Teacher* (ABT), and Jack Karling, Head of the Biology Department at Purdue University. John Breukelman, the first editor of ABT and a founding father of the National Association of Biology Teachers (NABT), chaired the discussion group in which I participated for 10 days. Following this conference, a proposal was sent to the National Science Foundation to fund what became known as the Biological Sciences Curriculum Study (BSCS). Three new high school biology programs were subsequently developed.

Gil Liesman, who was my officemate in Botany until he graduated, brought the vacancy at Emporia to my attention; and who was the Chairman of Biology at Emporia? John Breukelman! In 1967, Armacost was killed in an auto accident and candidates for his position were sought. A former graduate student who studied with my major professor, and now Dean of Education at the University of Kansas, recommended me to Purdue. And who turned out to be the key decisionmaker for who would be hired for the position? Jack Karling! What remarkable things came from that early conference in Michigan—and much more was to follow as I became active in NABT.

When I moved in 1959 to Purdue University with a joint appointment in Biology and Education, my principal work was instruction in methods courses and intern teacher supervision, plus supervision of MS and PhD students. Here again I was surprised at how little *conceptual* understanding of biology and other sciences was evidenced in my certification candidates and also in many experienced teachers enrolled in our summer programs. During 1959–1962, the Department of Biological Science underwent a major curriculum overhaul, in which I participated as cochairman of the curriculum committee. Most of the existing introductory courses were scrapped and a new seven-semester sequence was developed, including Principles of Biology, Cell Biology, Developmental Biology, Genetics, and Ecology. All courses used examples from plants, animals, and microbes to varying degrees, and all placed major emphasis on understanding basic concepts. As teaching candidates emerged from the new program, there was a striking difference in their mastery of biology and related science concepts and their ability to use these in innovative independent research projects. Teaching candidates were now acquiring an understanding of basic biology concepts needed for effective teaching (Novak, 1963).

Another important change in my thinking and the work of my graduate students occurred in the early and mid-1960s. Our research studies were producing results that consistently pointed to the idea that information storage and information processing were not distinct brain functions, as cybernetic theory would suggest, but rather interdependent and related to the kind of learning approach utilized. As our "cybernetic paradigm" was beginning to crumble, David Ausubel (1963) published his *Psychology of Meaningful Verbal Learning*, presenting a new and exciting theory of learning that seemed to explain all the troublesome aspects of the data we had been gathering. By 1964, all of our research projects and also our instructional improvement projects shifted to the "meaningful learning paradigm" espoused by Ausubel. It was also in the early 1960s that I became familiar with Piaget's work through seminars with a colleague, Charles Smock, who had studied with Piaget. While our research group found much of value in Piaget's studies and developmental ideas, our data did not support his "developmental stages" ideas. Moreover, Piaget was a *developmental* theorist and we saw *learning* theory as more fundamental to understanding both learning processes and developmental processes. Ausubel's assimilation theory seemed to be more powerful and more parsimonious in explaining learning, learner success, and learner failures (Novak, 1977b).

During the later 1960s and 1970s there emerged what might be called the "battle of educational paradigms." In the world of psychology departments, behaviorism or behavioral psychology held a very firm hegemony, and any "mentalistic" theory of learning or development was suspect. Cognitive learning ideas were virtually shut out from the academy, and Ausubel had great difficulty getting many of his papers published in leading psychology journals. Mager's (1962) *behavioral objectives* were the only valid foundation for instructional planning in the eyes of psychologists and also in the eyes of many educators who failed to see the limiting psychological and epistemological foundations of behavioral objectives. In the world of science education, there was overwhelming acceptance of Piaget's ideas by almost the entire community. Our group at Purdue University and later (1967) at Cornell University was almost alone in our critical views regarding Piaget's theories and enthusiasm for Ausubel's ideas. So rigid and so dominant were many of the proponents of Piaget's ideas that *none* of the numeous research proposals I submitted to the National Science Foundation (NSF) or the U.S. Office of Education (USOE) were accepted for funding, at least not until 1978, when Mary Budd Rowe helped to steer one of my NSF proposals through her division. For 2 successive years, none of the research papers proposed by me and my students were accepted for presentation at meetings of the National Association for Research in Science Teaching.

By the mid-1970s, the "cognitive revolution" had begun in psychology departments and educational psychology programs. While behaviorism, and narrow interpretations of Piaget's work, remain alive and well in school and corporate settings, these are dying paradigms in the scholarly studies focused on human learning. The climate for the kind of work we were doing 30 years ago is now much improved. In fact, in 1978 I received my first NSF grant for a study dealing with the feasibility and value of using concept maps and Vee diagrams in junior high school classes (Novak, Gowin, & Johansen, 1983).

Throughout the 1960s and 1970s, when so much criticism of our work was prevalent from educationists and, to some extent, psychologists (although the latter with few exceptions ignored our work), my students and I were supported both intellectually and financially primarily by the science community. My students were often favored for teaching assistantships in science departments. We also received support from the U.S. Department of Agriculture Hatch program, the College of Agriculture and Life Sciences at Cornell University, and Shell Companies Foundation. So often I had occasion to be thankful for my affiliations with science departments and scientists, including Nobel Laureate scientists such as Roald Hoffmann and Kenneth Wilson. These associations provided much of the validation of our work during the 1960s and 1970s. My students, and a number of visiting professors, provided much of the caring and personal support anyone needs to pursue the difficult task of theory development to guide educational improvement.

CREATING A THEORY OF EDUCATION

As our research and instructional improvement programs evolved, building heavily on Ausubel's (Ausubel, Novak, & Hanesian, 1968, 1978) assimilation theory of meaningful learning, several patterns began to emerge. First, it was clear that learners who developed well-organized knowledge structures were *meaningful* learners, and those who were learning primarily by rote were not

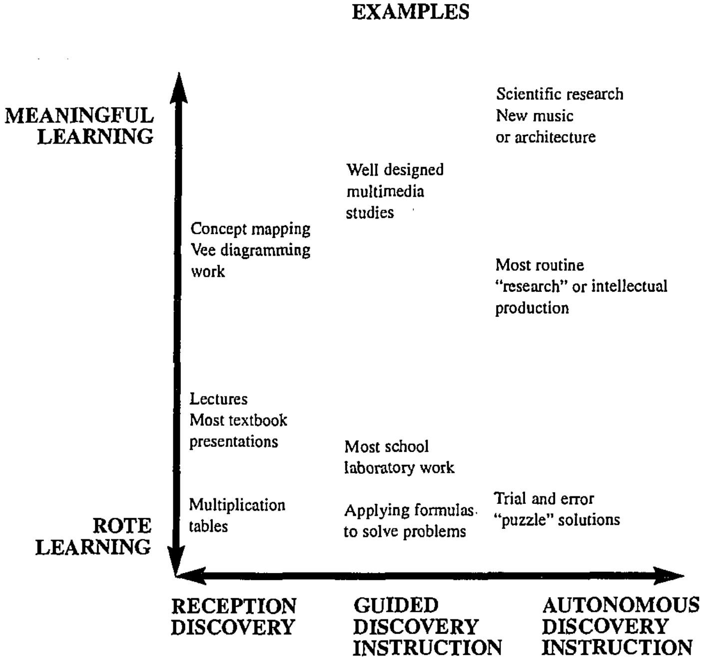


FIGURE 1

The rote–meaningful *learning* continuum is distinct from the reception–discovery continuum for *instruction*. Both reception and discovery instruction can lead to rote learning *or* meaningful learning. School learning needs to help students move toward high levels of meaningful learning, especially in reception instruction that is the most common.

developing these structures and/or their knowledge included many misconceptions. Second, while experience with what Ausubel called "concrete empirical props" and science educators call "hands on experience," was important, it was also important to carefully clarify the meanings of words (or concept labels) and propositional statements. Much of this could be done by didactic or reception instruction, provided that it was integrated with appropriate experience. In agreement with Ausubel, our work showed the importance of distinguishing between *learning* approach and *instructional* approach. With regard to instruction, either reception instruction or inquiry (or discovery) approaches can be very rote or very meaningful learning experiences. This is illustrated in Figure 1.

A third pattern that was evident was that learners' approach to learning was somewhat related to their epistemological ideas, albeit the nature of the relationship even today remains problematic and is one of our continuing research concerns. We observed some tendency for those students who were most positivistic in their epistemology ideas to favor rote learning approaches, and those who were more constructivist tended to favor meaningful learning strategies. In any case, it was evident that philosophical issues, and especially epistemology issues, needed careful consideration in education.

Finally, it became increasingly evident that in educating we "reap what we sow." Instruction and evaluation emphasizing or favoring rote learning strategies lead to little improvement in learner's usable knowledge structures, whereas the reverse was the case when meaningful learning strategies were encouraged or favored.

Parallel to the evolution in psychology of learning in the 1960s and 1970s was an evolution in philosophy and epistemology. As already noted, some of this was sparked by Conant and later Kuhn, but then a cascade began, stimulated by people such as Toulmin (1972) and Brush (1974), and an unstoppable rush away from positivistic epistemologies occurred. More recent philosophers, such as Feyerabend (1988) and Miller (1989), argue for "realists" epistemology, and von Glasersfeld (1984) and others argue for "constructivist" epistemologies.

These parallel developments in psychology and philosophy encouraged me to take a try at synthesizing *a theory of education*. The dream I had as a graduate student in the early 1950s, that education could become more like science and be guided by theory and principles, seemed within reach. Given a sabbatical leave in 1973–1974, I had the time needed to attempt the synthesis that led to publication in 1977 of *A Theory of Education*. I had already organized a course called Theories and Methods of Education that afforded me the opportunity to share my ideas with students and visiting faculty, including the coauthors of this book, and I benefited from their criticisms, insights, and application of the *Theory*. In my view, progress in our research and instructional development programs accelerated significantly after we had a viable theoretical foundation to work from.

A 12-YEAR LONGITUDINAL STUDY OF SCIENCE LEARNING

Given the "battle of paradigms" that was going on in the 1960s and 1970s, it seemed to our research group essential to determine what basic science ideas young children could understand and whether or not this understanding would facilitate future learning, as predicted from Ausubel's theory. However, my work with lower elementary school teachers as I was writing and testing science ideas in the early 1960s for our elementary science series, *The World of Science* (Novak, Meister, Knox, & Sullivan, 1966), indicated that most of these teachers did not understand or could not teach basic concepts of atoms, molecules, energy, and energy transformations, etc. Therefore, I decided to adopt an audiotutorial strategy we had developed with college botany students at Purdue University (Postlethwait, Novak, & Murray, 1964; 1972, Chapter 6) and use it to teach primary school children. An earlier sabbatical at Harvard University in 1965–1966 afforded me the time and resources to develop, evaluate, and refine several audiotutorial lessons working with first-grade (6- to 7-year-old) children. When I returned to Purdue University, we obtained some U.S. Department of Education funding through the Lafayette Public Schools and began further development, testing, and refining of audiotutorial lessons. When I moved to Cornell University in 1967, we obtained similar support through Ithaca Public Schools and also support from Shell Companies Foundations. By 1971, we had developed some 60 audiotutorial science lessons designed for children in Grades 1 and 2. Incidentally, when these lessons were placed in school learning centers rather than primary grade classrooms, even fifth- and sixth-grade students (10–12 years old) worked with the lessons with enthusiasm. Most teachers who took the time to work through the lessons found them "very enlightening."

Incidentally, our work with audiotutorial instruction in botany courses grew out of the labeled photomicrographs and other materials I developed for a Study Guide for my Ph.D. study. Postlehwait began using these photos and drawings to supplement taped comments for students who had missed lectures. Student response was so positive that he began to add lab demonstration materials and within a year, the traditional laboratory and much of the lecture material was dropped in favor of self-paced, audiotutorial study in a new "learning center" that was established in the Biology building. Hundreds of visitors came to Purdue to see the learning center in operation and Postlethwait's approach was replicated in many schools and universities around the world. Application of this instructional strategy in elementary school classrooms proved to be very successful, albeit we found we had to discourage classroom discussion led by the teacher on some topics to avoid introduction of teacher misconceptions, so prevalent at the elementary school level.

From our pool of 60+ audiotutorial lessons, we selected 28 for administration to children on a schedule of roughly one new lesson every 2 weeks. The lessons were carefully sequenced to provide for early introduction of basic concepts and progressive elaboration of these concepts in later lessons. Some modifications in lessons were made as they progressed over a 2-year period. Figure 2 shows a child working with materials in a carrel unit. Children were interviewed every 4–6 weeks to record their understanding of concepts presented. A group of 191 children were given this instruction during 1971–1973; we called this group the "instructed" group. A similar group of 48 children enrolled in the same classrooms with the same teachers, during the 1972–1974, 1 year later, did not receive the audiotutorial science lessons; we called this group the "uninstructed" group.

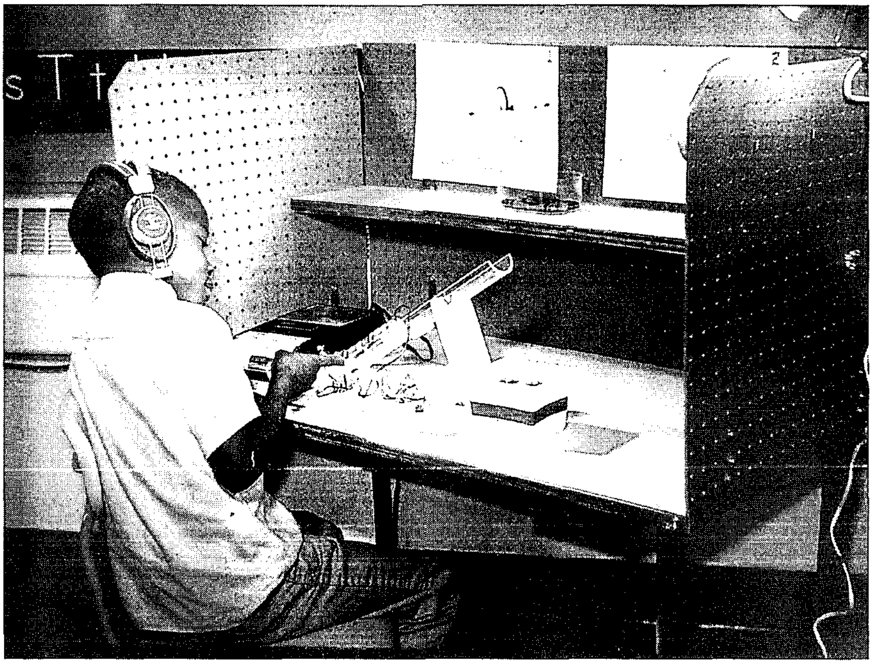


FIGURE 2
A 6-year-old child working in an audiotutorial carrel during our 12-year longitudinal study.

By the end of the second year of the study, when "instructed" and "uninstructed" students could be compared, it was evident that instructed students were benefiting from the lessons. After grade two, all students received instruction in science as delivered in Ithaca public schools. We did periodic interviews of both instructed and uninstructed children throughout their tenure in Ithaca schools, although for various reasons we had to limit subsequent interviews to concepts dealing with the particulate nature of matter, energy, and energy transformations.

During our first year of interviewing, we recognized the problem of interpreting interview tapes and transcriptions. Discerning patterns in changes in children's conceptual understandings from these tapes and/or transcriptions was overwhelming. We began to accumulate file drawers full of interview transcripts. It became obvious that we needed a better method or tool for representing children's cognitive structures and changes in cognitive structures. Reviewing again Ausubel's ideas and his theoretical principles, we decided to try to represent children's ideas as hierarchically organized frameworks of concepts and propositions. In short, we invented a new knowledge representation tool: *concept maps* were constructed from interview transcripts to represent the knowledge evidenced by the child. Figure 3 shows two concept maps constructed for one of our students; the upper map represents the student's knowledge in Grade 2 and the lower map represents the student's knowledge in Grade 12. It is evident that this child was learning science meaningfully and was elaborating her conceptual frameworks. Although both her Grade 2 and her Grade 12 concept maps show some misconceptions and missing concepts (e.g., the concept of space is missing in grade 12), it is evident that Cindy has been building and elaborating her knowledge of the nature of matter and energy.

From the time our first instructed children received instruction and were interviewed until the time when the last uninstructed students were interviewed in Grade 12, a period of 13 years had elapsed. Many graduate students participated in the study and both M.S. and Ph.D. students used some of the data for their thesis work. Finally, Dismas Musonda compiled data for the entire span of the study and his Ph.D. thesis served as a primary data base for a publication on the study. Because of the extraordinary nature of the study and data obtained, it was necessary to revise and resubmit the paper three times before it was accepted for publication (Novak & Musonda, 1991). In response to editorial requests, graphic presentation of the data was dropped, but one of the original figures is reproduced here in Figure 4.

Several remarkable things are shown in Figure 4. First, it is obvious that the instructed students showed fewer "naive" or invalid notions and more valid ideas than the uninstructed students. This difference was statistically highly significant and practically very important. We see that instructed students had less than half as many invalid notions and more than twice as many valid notions as uninstructed students. Furthermore, Figure 4 shows that instructed students became *progressively better*, both with regard to valid and invalid notions, but this was not the case for uninstructed students, especially from Grade 7 on when formal instruction in science began in Ithaca schools. These data strongly support the theoretical foundations for the study, namely that when powerful anchoring concepts are learned early in an educational program (Ausubel calls these "subsuming concepts"), they should provide a foundation for facilitation of later learning. Obviously this occurred. Since the instructed and uninstructed samples (by Grade 12) did not differ significantly in ability as suggested by grade-point averages and SAT scores (Novak & Musonda, 1991), the only factor that could account for the differences observed was the power of the early audiotutorial science lessons.

The content of the science lessons offered in Grades 1 and 2 was relatively abstract and certainly not commonly taught in these grades. The fact that these lessons had a highly facilitating effect on future learning indicates that they were learned meaningfully, at least for a substantial percentage of the students. Clearly these results cannot be explained with either behavioral theory (there was very limited reinforcement and rehearsal of ideas) or Piagetian

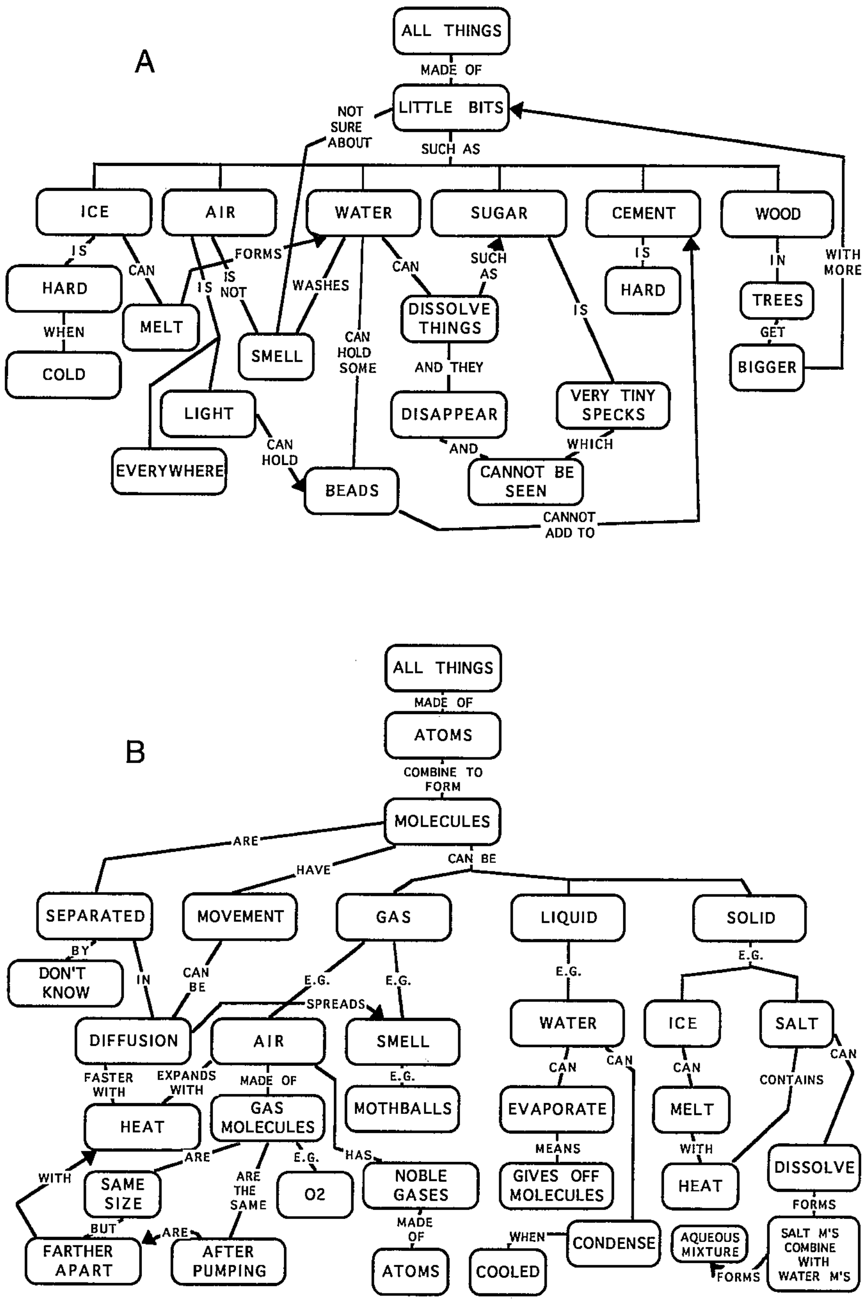


FIGURE 3

Concept maps showing changes in a child's understanding of the particulate nature of matter from Grade 2 (A) to Grade 12 (B).

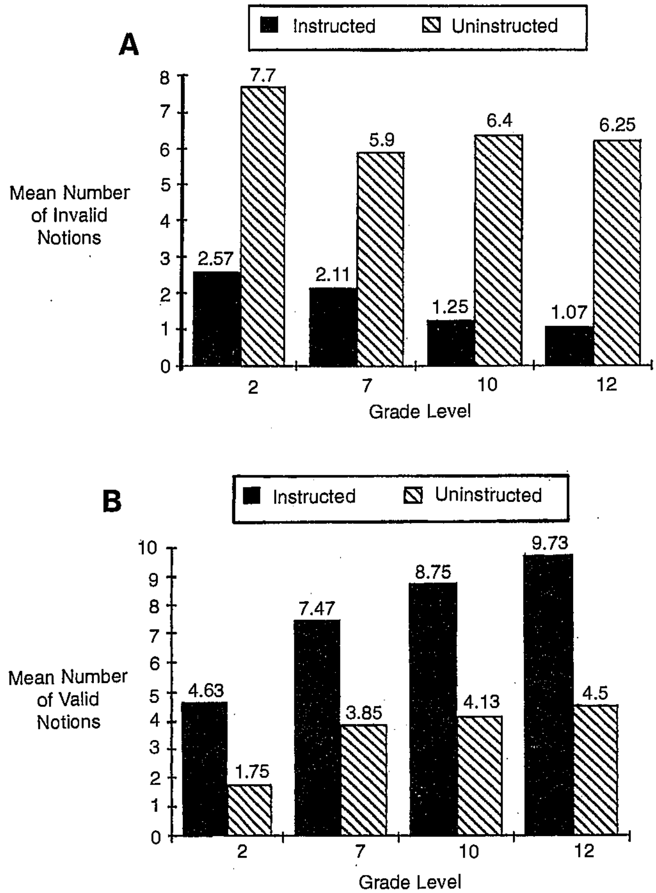


FIGURE 4

Bar graphs showing the frequencies with which "instructed" students (grey bars) and "uninstructed" (dark bars) evidenced naive notions about the structure of matter (A) and valid notions. Note that only the instructed students show continuous improvement over the years.

theory, which posits little success with abstract science concepts at ages six to eight (see, for example, Shayer & Adey, 1981). The results are consistent with results from more recent studies such as those of Matthews (1980) and Carey (1985). Our 12-year-study, the only one of its kind reported to date, clearly indicated that our program was on the right track, both theoretically and in terms of practical consequences for education.

It has been common in the sciences that the necessity for developing new tools for making or processing records obtained in research have led to practical applications. For example, development of oscilloscopes to study and record electromagnetic wave patterns led to the development of television. In an analogous manner, the concept mapping tool, as we developed it, proved to be a useful tool in many education applications. First, making concept maps from interviews has permitted us and others to observe specific changes in learners' cognitive structures with relative ease and a degree of precision that was not possible by reviewing interview recordings or transcripts alone. They are useful for identifying and remediating misconceptions or "alternative conceptions" (Novak & Musonda, 1991; Wandersee, Mintzes, & Novak, 1994; Mintzes, Wandersee & Novak, 1997). Subsequently, we and others have found that interviews in any knowledge domain can be better interpreted using concept maps, including interviews with consumers, patients, or counselors. Second, concept maps can help learners organize subject matter and facilitate learning and recall of any subject matter (Novak & Gowin, 1984; Novak & Wandersee, 1990). Third, concept maps can be a valuable evaluation tool—one I have used extensively in my own classes (Novak & Ridley, 1988). Fourth, they can be useful for teachers and other educators for organizing and planning instructional material (Symington & Novak, 1982; Novak, 1991). Fifth, they can identify cognitive-affective relationships that can be enormously helpful in counseling settings (Mazur, 1989). Sixth, they help in team building and reaching consensus on project goals and objectives (Edmondson, 1995). Seventh, they can enhance creative production, since creativity requires well-organized knowledge structures and an emotional proclivity to seek new interrelationships between diverse domains of knowledge. These and other applications of the concept mapping tool have had a major impact on our programs, including recent applications in corporate settings. Other knowledge representation tools will be discussed in Chapter 4.

DEVELOPMENT OF THE VEE HEURISTIC

Much of our research dealt with instruction in science laboratories. A continuing problem observed was that students often proceeded through the laboratory work doing what was prescribed in the laboratory manual, but often not understanding *why* they were doing what they were doing nor what the meaning of their records, graphs, tables, charts had for understanding better the science they were studying. My colleague, Bob Gowin, had found this to be the case in other disciplines as well. Gowin's PhD work was in philosophy, and he maintained a strong commitment to understanding the structure of knowledge and the process of knowledge creation. Gowin (1970, 1981) first proposed five questions that need to be answered to understand the structure of knowledge expressed in any work:

1. *The telling question.* What is the telling question of the work?
2. *The key concepts. Conceptual structure.* What are the key concepts?
3. *Methods.* What methods were used to answer the telling question?
4. *Knowledge claims.* What are the major claims in the work?
5. *Value claims.* What value claims are made in the work? (1981, p. 88)

These questions proved useful to our students in analyzing research papers or other documents and for interpreting laboratory work. However, the latter required that more attention was needed on the events or objects observed and on other epistemological elements such as the philosophy or epistemology guiding the inquiry and the "world views" held by the inquirer. In 1977, Gowin conceived a new way to represent all of the elements and to suggest their interrelationships. He created the "Knowledge Vee." This gradually underwent some modifications, and Figure 5 shows our current form of the Vee heuristic as used in our current work and definitions for 12 elements involved in the structure and creation of knowledge.

We proceeded to use concept maps and the Vee heuristic in many of our research studies and to aid in the design of instruction. While most students, teachers, and professors immediately see value in concept maps, it has been our observation that the Vee heuristic is more difficult to grasp. One reason for this may be that most of us are brought up in patterns of thinking about knowledge and knowledge discovery that are primarily positivistic in character. The highly fluid, complex process of knowledge creation represented in the Vee can at first be overwhelming. With time and effort, however, we have found that the value of the Vee heuristic is recognized and concept maps are seen as useful to represent some aspects of the Vee, namely the structure of concepts and principles guiding the inquiry (or the "left side") and the structure of knowledge and value claims (on the "right side"). I know of no other heuristic tool for representing the structure of knowledge, and I would predict that in 20 to 30 years, it may become more widely used in schools and corporations.

LEARNING HOW TO LEARN

While writing the draft of A *Theory of Education*, I organized a new course, "Learning To Learn." Initially I thought the course would be appropriate for freshman and sophomore students, but mostly juniors and seniors enrolled. We had also found in earlier work with a special program for freshmen that very few Cornell students think they have problems learning. For the most part, they achieved predominantly A grades in their high school work, and even in most courses taken by freshmen. It is not until their sophomore or junior years at Cornell University, when they take courses where rote memorization will not suffice to get A grades, that students realize they must either

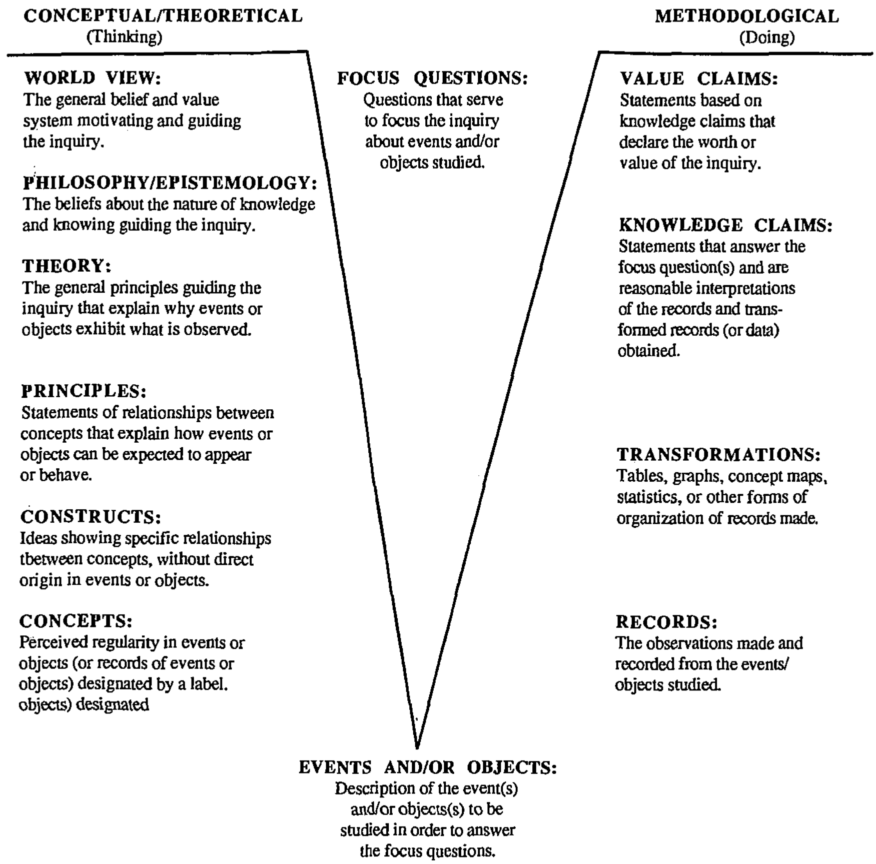


FIGURE 5

Gowin's Vee showing key epistemological elements that are involved in the construction or description of new knowledge. All elements interact with one another in the process of constructing new knowledge or value claims or in seeking understanding of these for any set of events and questions.

be less able than they thought they were before or they must be doing something wrong in their studies.

At first, many of the students who enrolled in "Learning to Learn" were essentially seeking better tricks for memorizing, taking notes, and preparing for exams. They wanted a "quick fix" for their declining grade point average. They were not looking for a course that would help them develop new ways of learning and new insights into the nature of knowledge. The dropout rate the first year or two from my course was about 30%. Most of those students who persisted ended the semester with a new sense of empowerment over their own learning. It was not uncommon for students to tell me they never knew there was another way to learn other than rote memorization. They were grateful to me for "turning their lives around" as they gained skill and confidence in *meaningful* learning, aided, in part, by concept mapping and Vee diagramming tools. In 20 years of teaching this course, I never had a single student who completed the course who failed to gain skill and confidence in their ability to learn meaningfully. Some admitted they would continue to learn by rote in some courses—courses that were poorly taught or courses that held little interest for them. Many in later years have written to tell me that their high success in graduate studies would have been unlikely without "Learning To Learn."

The sorry fact is that Cornell University students are among the very best high school graduates. And yet, most of them have done most of their previous learning largely by rote. Studies of student learning approaches in this country and abroad have shown that similar patterns prevail in other countries (see Chapter 5). The result is that students may graduate from both high school and university, and yet very little of what they memorized is functional knowledge. For example, in a widely circulated video tape, *A Private Universe*, graduating seniors, graduate students, and faculty were asked to explain why we have seasons. Twenty-one of 23 persons interviewed at random could not give a satisfactory explanation—including one graduating senior who had just recently completed a course, "The Physics of Planetary Motion"! Obviously he had been learning almost totally by rote, as may have been the case for many others interviewed. The universality and pervasiveness of rote-mode learning patterns in schools and universities is astonishing, given our current knowledge of the limited value of such learning. As Pogo has said, "We have met the enemy, and the enemy is us"! Forty years after my own disappointing school learning experiences, I find that, for the most part, not much has changed. Why? What can be done about it? These remain nagging questions.

Although research on the value of the Vee heuristic for facilitating learning is not as extensive as that on the value of concept maps, our data indicates that secondary school and university students can benefit from using this tool (Novak, Gowin, & Johansen, 1983). Figure 6 illustrates how the question of "Why do we have seasons?" can be thought through using the Vee and associated concept maps. An interesting research project might be to assess the value of this kind of instruction in elementary, secondary, and/or college classroom setting.

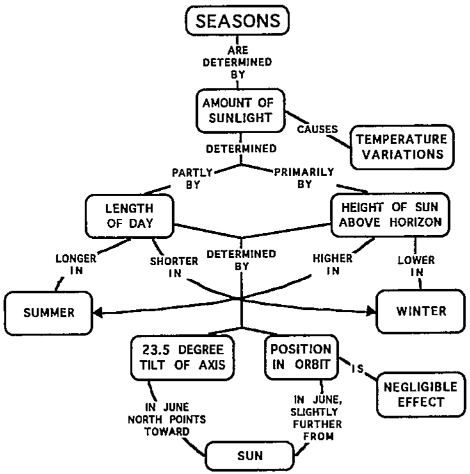
There is hope for improvement of education in the future. I take heart in the fact that *Learning How To Learn* at this writing has been published in nine languages with other translations projected. The ideas and strategies that will be presented in this book are slowly taking hold, not only in the U.S. but also in countries around the world. The 350+ graduate students and visiting professors who have done theses or worked with me are everywhere in the world, and their students and their students' students (my "intellectual great grandchildren") continue to multiply and add their efforts to the slow pro-

CONCEPTUAL/THEORETICAL
(Thinking)

WORLD VIEW:
The universe is knowable through the rational methods of science.

PHILOSOPHY/EPISTEMOLOGY:
Humans constuct their own meanings for how the universe works.

THEORY:
Newton's theory and theories of heat and electromagnetic energy can predict seasons.



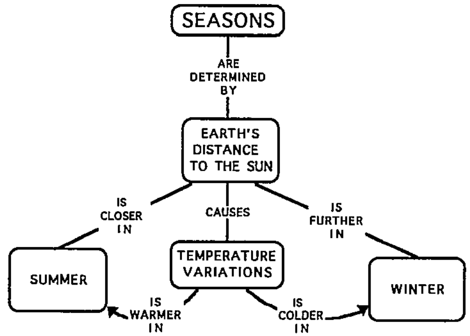
FOCUS QUESTION:
Why do we have seasons?

EVENTS:
Changes in seasons over a year

METHODOLOGICAL
(Doing)

VALUE CLAIMS:
Most people have not been learning science in ways that build useful understanding

KNOWLEDGE CLAIMS:
Shown as a concept map:



cess of educational reform. Thousands of others who embrace similar ideas are pushing for educational change, changes that move learners from the disempowering effects of rote learning to the empowering consequences of rich, meaningful learning.

For me, another source of optimism for future improvement of education is my belief that the theoretical foundations for education are improving. The growing consensus on the validity of constructivist epistemological ideas and cognitive learning principles suggest that the science education community and the education community in general are moving forward (Linn, 1987). My efforts to synthesize epistemological ideas and psychological ideas as they relate to the construction of knowledge were first published in 1987. Both disciplinary and personal knowledge is acquired through *Human Constructivism*. Further discussion of these ideas will be offered in Chapter 2.

Although we have been working with professors to apply the Vee heuristic and concept mapping to their research work for more than a decade, our first systematic effort to study the value of the Vee and concept maps as a tools to facilitate research and new knowledge creation began in 1993. We were fortunate to enlist the cooperation of Professor Richard Zobel who headed the "Rhizobotany group," a research group at Cornell University focused on the understanding of roots and root functions. Some of the preliminary findings were that even experienced researchers in the group had only a sketchy knowledge of the overall intellectual activities of the group. Concept maps and Vee diagrams helped the group see where individual projects contributed to broader research questions. Some of the researchers evidenced little knowledge of, or interest in, epistemological issues. A preliminary report on this work has been published (Novak & Iuli, 1995).

I began a revision of *A Theory of Education* during my sabbatical in 1987–1988, but pressures of other work required that I set this aside. During my sabbatical in 1994–1995, I resumed work on this manuscript; however, our research studies between sabbaticals and the initiation of work with corporations (described below) led me to restructure substantially the earlier work and to write essentially a new book. With the title "Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations" (Novak, in press), the manuscript is currently in production with Lawrence Erlbaum Associates, Inc. I believe this new book can provide a useful foundation for improvements in education in any field and in any context. In addition, this book, of which you are now reading the first chapter, should contribute to the improvement of science education.

FIGURE 6

A vee diagram for the question "Why do we have seasons?", showing a concept map on the left side that depicts a valid knowledge structure held by scientists and a concept map on the right side illustrating the typical knowledge structure held by children and adults.

MY THIRD CAREER—HELPING CORPORATIONS LEARN

For some two decades, I have had occasional students with experience in business and had participated in meetings and seminars with persons from the business world. While I found individuals who saw the relevance of our work to business, they were predominantly from lower ranks in business organizations and their efforts to introduce the ideas and tools generally met with quick dismissal by upper-level management. In 1991, Alan McAdams, Professor in the Cornell Johnson School of Business and Management, invited me to coteach a course with him in the business school. For some years he had been an enthusiast of concept mapping, and he wanted to learn more about education. I was eager to learn more about business and the corporate world. We enjoyed good success with our new course (it received the highest student ratings for any course in the School) and taught it again in 1992. Most of the students were MBA candidates with 6 to 8 years of experience in the business world. As part of the course project activities, we worked with for-profit and not-for-profit organizations, using concept mapping and Vee diagrams as tools to better understand the structure and function of the organizations.

What we found was that all of the organizations studied had some serious problems in one or more of the following areas: personnel knowledge about the "mission" or strategic plan of the organization, functioning of individual units, barriers to communication, and failue or limited ability to learn as an organization. Both McAdams and I were struck by the energy and enthusiasm of our students for the work we were doing, but also by the resistance of most of the organizations to the implications of the findings from our studies. One thing became eminently clear to me: nonprofit and for-profit corporations *could* benefit significantly by applying ideas from *A Theory of Education* and *Learning How To Learn*. The problem was finding an organization with the right leadership to demonstrate the value of the tools and ideas.

There is the saying, "Nothing is more unstoppable than an idea whose time has come." Something very important has happened in the business world in the past decade—*globalization*. While it is true that worldwide trade has been part of the business world at least since prehistoric times, new transportation, communication, and other technologies have evolved to the point where almost any product can be made almost anywhere and shipped at relatively low cost everywhere. Suddenly, U.S. and other nation's businesses have found themselves head to head in competition with businesses all over the globe. In 1988, Prestowitz observed, in *Trading Places: How We Are Giving Our Future To Japan and How To Reclaim It*, that although the United States was once the economic giant of the world, we were rapidly giving this position to Japan. While he placed much of the blame on poor trade policies with Japan and other countries, there were other problems facing corporate America. Peter Senge (1990), Marshall and Tucker (1992), and Peter Drucker (1993) were among the business sages who were saying business will not get better until American corporations become better at learning and better at creating new knowledge. Nonaka and Takiuchi's (1995) book *The Knowledge Creating Company: How Japanese Companies Create the Dynamics of Innovations* has been "required reading" for many corporate executives.

Fortuitously, I had the opportunity in June of 1993 to meet an executive of a major U.S. corporation who was seeking "better tools" to facilitate research and development work. I held my first meeting with a research team in late December, 1993. The consensus was that concept mapping and the ideas I presented could be of value to Corporate R & D work. Another meeting was held in April, 1994, and gradually the number of scheduled meetings increased. I was faced with a difficult decision: Should I continue in the secure position of full professor at Cornell University and pursue only token efforts to apply our ideas in the corporate world or should I resign from Cornell and free myself to pursue my hunch that a better way for me to improve education in schools and universities may be to improve education and knowledge creation in corporations? I chose in July, 1995 to pursue my hunch.

So far, so good. At this writing, the receptivity and application of tools and ideas with at least one corporation has been accelerating. The "pilot programs" we have run show promise and have probably contributed to some new product development. As with all R & D work involving teams, it is difficult to assign value to one individual's contribution or to which strategies led to success. In the end, the *value* of our work will have to be a subjective judgment. There are some criteria that are empirical in nature, e.g., the number of members of research teams who ascribe significant value to concept mapping and related ideas, and this kind of data is being gathered. At this writing it is too early to be explicit in our knowledge claims regarding the value of metacognitive tools in corporate settings, but the overwhelming reaction has been positive.

Unfortunately, the necessity for confidentiality prevents me from discussing specific projects we have done and the kind of outcomes that have been derived from these projects. In time, this information can and will be released. It is also my hope that we can gather the best evidence possible in an enterprise that is not focused on research. If we can demonstrate significant gains using metacognitive tools to aid in improving the production of new knowledge and the use of knowledge in the corporate setting, one thing is certain. Global competitive pressures will require that almost all corporations must move to employ our strategies or similar strategies. The time frame for this to occur is a matter of years, not decades or centuries.

CONTINUING THE PURSUIT OF A DREAM

There is much more to be done. At best, a very small fraction of learners in our world are engaged in predominantly meaningful learning practices, whether in schools, universities, or workplaces. While I remain skeptical of data that suggest American students are improving in their "critical thinking skills," there is a growing recognition that something is wrong with the way many students are being taught and the learning patterns that result from this. See, for example, the many research papers on student misconceptions available via Internet (Novak & Abrams, 1994). Probably no science educator in touch with the research believes that to be effective, all a teacher (or textbook) needs to do is to present the "facts." The extent to which learner- and teacher-held epistemologies influence the quality of learning is still recognized by only a minority of educators, but this situation appears to be improving rapidly. Just in the past 10 days while writing this chapter, I have been contacted for help by six researchers in the U.S. and other countries who are centering their research on questions of the relationship of learner epistemologies and success in meaningful learning.

So positive changes are occurring. I believe that if corporate America, and the corporate world in general, move to employ new ideas on knowledge creation and knowledge utilization, the entire process may accelerate enormously. For one thing, corporations may have the incentive—good profits at best and survival at the least—to move ahead in applying new educative tools and ideas. They could bring enormous resources, and their own examples, to bear on these problems—resources measured in the hundreds of *billions* of dollars! These long-term self-interests require that they help schools and colleges improve their educational practices. They can bring their resources to bear on current problems and needed educational innovations. These are revolutionary times in the business world, and this will, in due course, require, and help to bring about, revolutionary changes in education. This, I predict, shall happen in the next 20 years or so—about half of the time of my career in education. These are exciting times for educators and learners!

We cannot, however, rely on corporations to do the basic research needed to understand more effective ways to teach science and to educate science teachers. Most likely, these studies will be done in schools, colleges, and universities. There is now tremendous opportunities for young scholars who choose to pursue such work. It is to these people, especially the "new generation" of scholars, we hope this book can serve as a "handbook" of fundamental ideas and research approaches.

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