HELPING STUDENTS LEARN HOW TO LEARN:
A VIEW FROM A TEACHER-RESEARCHER{1}

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Introduction

In this paper, I will address four questions: (1) What do we know about how people learn? (2) Can we help our students learn how to learn? (3) What are major obstacles to helping students learn? and (4) What promise is there for the empowerment of people? The answers I shall offer are based largely on my teaching and experience with schools and on the research done by our group at Cornell University together with related work of other colleagues in the United States and in other countries.

What Do We Know About How People Learn?

In his Presidential Address to the American Psychological Association, Reed (1938) argued that psychologists should place more emphasis on meaning as a factor in learning. B. F. Skinner's The Behavior of Organisms was published the same year and behavioral psychology became dominant in North America, with most research focused on behaviors manifested by organisms, and extrapolation of "laws of learning" from lower animals to humans. Most research in North America on how humans construct and use meanings to guide their actions was successfully suppressed. There were, of course, the monumental studies by Jean Piaget in Geneva and the good work of George Kelly (1955) in the United States and others in England, but even these programs did not primarily address the construction and use of explicit meanings to guide actions in school learning and to serve as the foundation for constructing new meanings.

Our research program at Purdue University, and after 1967, at Cornell University, drew largely from the theoretical ideas of David Ausubel beginning with his 1963 book, The Psychology of Meaningful Verbal Learning. This and his later book, Educational Psychology: A Cognitive View (1968, 1978), have served as the principal psychological foundations for our research program.

In the epigraph to his 1968 book, Ausubel wrote:

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.

This has been for us a guiding principle in both our efforts to design new instruction and for much of our research on classroom learning. It is a simple idea, but the implications are profound. A challenge for us for many years was how do we "ascertain what the learner already knows?" Paper-and-pencil tests, both essay and "objective" tests, are notoriously poor in revealing what a person really knows and can utilize. Clinical interviews, patterned along the lines developed by Piaget but focusing on understanding of concepts and concept relationships in explicit knowledge domains, can be very effective. However, they require much skill in administration and are very time-demanding, both in administration and interpretation. Some practicable alternative was needed.

One of our research projects sought to study the change in children's conceptual understanding of the particulate nature of matter over the twelve-year span of schooling. This longitudinal study (Novak and Musonda, 1991) produced hundreds of interview tapes and transcripts and we faced the difficult problem of trying to interpret changes in the conceptual knowledge of the students from these transcripts. Drawing on ideas from Ausubel's assimilation theory, we focused attention on three key factors: (1) meaningful learning involves the assimilation of new concepts and propositions into existing cognitive structure, modifying those structures (2) knowledge is organized hierarchically in cognitive structure and most new learning involves subsumption of concepts and propositions into existing hierarchies, and (3) knowledge acquired by rote learning will not be assimilated into existing cognitive frameworks and will not modify existing proposition frameworks. Rethinking the meaning of these ideas led our research group to try out various schemes for representing knowledge structure, evidenced in interview transcripts leading to the development of a tool we now call concept mapping. Figure 1 shows two examples of concept maps drawn from interview transcripts for a child in grades two, and twelve. These concept maps illustrate three key ideas from assimilation theory: (1) meaningful learning leads to progressive differentiation of cognitive structure; (2) integrative reconciliation of new meanings with old meanings can "correct" misconceptions; and (3) knowledge learned by rote (or nearly by rote) is not properly assimilated into cognitive frameworks. Since 1975, we have found concept maps to be powerful tools to represent knowledge structures in all subject matter fields and for learners of any age (see Novak and Gowin, 1984).

[Figure 1 about here]

During the time we were developing the concept mapping strategy in our research program, my colleague, D. Bob Gowin, was developing strategies to help students understand the nature of knowledge and the nature of knowledge construction. His work led to the invention of the Vee heuristic in 1977 as a way to represent the twelve elements involved in the structure of knowledge. Figure 2 shows definitions of the elements of the Vee heuristic as we now employ them in our work.

[Figure 2 about here]

All meaning making begins with objects or events observed, or records of objects and events. New knowledge is constructed when, using the "thinking elements' on the left side, when we succeed in perceiving a new regularity or a new relationships between previously known regularities and new regularities we observe in events, we construct a new concept. We define concept as a perceived regularity in events or objects, or records of events or objects, designated by a label. A principle is two or more concepts linked to form a statement about how something works or appears to be. Concepts and principles are the major elements usually dealt with in science teaching, but other elements on the left side of the Vee are often ignored or given scant attention.

For the young child, perception of regularities in the world is a genetically given capacity as is also the ability to use language labels to code (symbolize) regularities. By age three, all normal children have acquired several hundred words (concept labels) and can use these to form thousands of propositions, many of which are principles. This incredible learning accomplishment is achieved without formal instruction and largely by discovery on the part of the child as to what older people mean by words and phrases they use. From this point on, children can use language to ask questions and gain new concept and propositional meanings by reception learning. Meaningful reception learning proceeds remarkably well--until the child begins formal schooling when so much school learning is essentially rote learning, or close to rote learning. Rewarded for "correct" answers to near meaningless drill and practice questions, most students, and female students more so than males (see Ridley & Novak, 1983), move toward approaches to learning that are progressively more detached from their world of experiences and the frameworks of meanings they have constructed. All children begin life as highly meaningful learners, and most later move toward largely rote mode learners, especially in science and mathematics. As shown in Figure 3, the unfortunate reality is that most school instructional practices move children away from meaningful learning and toward essentially rote learning. Students learn to learn in a way that is disempowering rather than empowering.

[Figure 3 about here]

Another important understanding that has emerged in the last few decades is that human memory is not a simple "empty vessel" to be filled, but rather an interactive set of three memory systems. These are shown in Figure 4. Notice that arrows point both ways between these memory systems because what we can perceive that impinges upon us is dependent upon the limitations of each memory system and on what and how knowledge is organized in long term memory. There is also the important role of emotions or affect in the acquisition of new knowledge but this is a domain for which we have only primitive understanding. I believe there is considerable evidence to argue that meaningful learning underlies the constructive integration of thinking, feeling and acting leading to human empowerment. However, only a small amount of research is available

that is directly relevant to this hypothesis. Increasingly, our research emphasis is centered on this hypothesis, including recently completed studies with female scientists (Kerr, 1988), drug abusers (Mazur, 1989) and anorexic women (Hangen, 1989). It is supported by work such as Gilligan's (1982) In A Different Voice, and Best's (   ) We All Have Scars and Belenkey, et al. (1986) Woman's Ways of Knowing.
[Figure 4 about here]

In teaching science and mathematics where we are dealing with large bodies of subject matter with potentially high levels of interrelationship, the severe limitations of "working or short-term" memory need special attention. Even the Einsteins and Hilberts can only process about seven "chunks" of information in working memory and it is in working memory that meaning making occurs. The principal difference between geniuses and we ordinary mortals is that the geniuses have structured their knowledge in long-term memory in such a way that they can deal with big "chunks," that is, powerful concepts, principles or theories. Their creative power derives from their capacity to use "higher order" concepts and propositions in dealing with new information and an emotional penchant to do so. Almost any biography of a genius, in any field, describes this use of big ideas and the passion to search for new integrations between new and old knowledge (Ghiselin, 1955).

In recent years, there has been a substantial increase in helping students gain skills in thinking, including articles in The Science Teacher. Pizini et al. (1988) counseled on "Rethinking Thinking in the Classroom"; Cronin (1989) made suggestions for "Creativity in the Science Classroom"; Barba (1990) offered "Problem Solving Pointers"; and Blakeman (1990) offered suggestions to improve critical reading of books. Numerous other authors, and all major recent reports dealing with critiques of education emphasize that we need to help students learn how to think, not just to memorize.

Concept maps, and also the Vee heuristic, help us to construct new meanings because they serve to help us organize the knowledge we put into long-term memory and also because they can serve as a kind of mental scaffold to help put pieces of knowledge together in our working memory. These are powerful tools to help students learn how to think critically and more creatively. The work of Alex Johnston (1980) in chemistry, Robbi Case (1987) in science and math and similar research supports the thesis that working memory efficiency is constrained or enhanced by the quantity and quality of our knowledge structures. The research on experts and novices of Chi et al. (1981), Larkin et al. (1980), Simmons (1990), and others also shows that experts tend to attack problems with "big ideas," ideas at a high level on a concept map, whereas novices tend to work with narrow, explicit concepts or principles. All of these studies point toward the conclusion that empowerment of learners requires that we help them to organize and use carefully developed hierarchial knowledge structures.

We have found that the best concept maps for instruction, especially when introducing a course or new area of study, are relatively simple maps of ten to fifteen concepts. Figure 5 is an example of a concept map I use to introduce some key ideas in my courses. These major ideas shown on the map can be easily processed in working memory. It is simple, and yet it deals with some profoundly important ideas. As the course progresses, more complex maps may be useful to provide a composite of ideas studied. After students have had experience constructing their own concept maps, both simple and more complex, they can profit from maps such as that shown in Figure 6. This map integrates most of the concepts and principles I teach in my course "Learning How to Learn."
[Figures 5 & 6 about here]

Concept maps can be used to represent elements on the left side of the Vee. Figure 7 is an example that relates to an event I use in my classes, i.e., five different short-term memory tasks are given to students and records are made of the number of students recalling "chunks" for each task. Left out in this Vee is the "philosophy" and "world view" guiding the inquiry, but these could be added to concept maps to complete the left side of the Vee.
[Figure 7 about here]

Can We Help Our Students Learn How to Learn?

First, let me describe what I mean by helping students "learn how to learn." The central concern is to help students learn how to take charge of their own meaning making. It is the kind of empowerment that Paulo Freire described in his Pedagogy of the Oppressed (1970) and The Politics of Education (1985). It is helping our student to understand that our minds are not storage bins into which we can pile knowledge indiscriminately. This is what Freire (1985) calls the "banking" view of learning. It is helping our students to understand that learning is not an activity that can be shared; it is the responsibility of the learner. As Gowin (1981, p. 131) points out, "teachers do not cause learning; learners do." Teachers may help to set the agenda for learning and they can share the meanings of the material with learners. They can also appraise learning, for it takes someone who understands the subject to judge that the learner now understands. And students need to know that understanding is never complete; it is an iterative process where we move gradually from less understanding to more understanding, until we reach the point where new inquiry is extending the boundary of our understanding. Seeking understanding in any field can be a life-long process. Learning is also an affective experience; it is the pain and anxiety of confusion, and the joy and excitement when one recognizes that new meanings have been acquired. In my view, the construction of new knowledge in any field is no more than a special kind of meaningful learning (Novak, in press).

My interest in helping students learning how to learn gained impetus in 1974 after I had written A Theory of Education and began using this book with my graduate courses. A surprising number of my students began telling me that studying Ausubel's learning theory, ideas about how new knowledge is constructed, and alternative instructional and evaluation strategies was interesting, but what was most valuable to them was that they were learning how to learn! After a few semesters of hearing students say this, it finally dawned on me that it might be a good idea to organize a course for undergraduate students explicitly directed at helping them learn how to learn.

My first effort in this direction was in 1976. I used the manuscript for A Theory of Education supplemented by other readings including Fromm's (1956) The Art of Loving and Harris' (1967) I'm OK, You're OK. I asked students to draw concept maps for segments of one or more courses they were taking. I also asked them to identify specific examples of instructional practice that were congruent with ideas from Ausubel's assimilation theory, and examples of practices that violated these principles. Most students had no difficulty identifying examples of negative practices. An occasional student described a course they were taking that was strikingly in line with the principles presented in A Theory of Education--and these were courses that were highly satisfying to the students. I did not have students do clinical interviews; these later proved to be a valuable addition to my course.

Many of the students who came to my course were looking for something more like a "how to study" course, courses which typically emphasize strategies for getting higher grades. There are dozens of "how to study" books in print that suggest strategies for organizing time, learning to concentrate, taking notes, reading skills, test taking strategies and writing papers. Most of these books say almost nothing about how to take charge of your own meaning making. They are not directed toward the empowerment of learners but rather toward playing the school game to get higher grades. There is some value to the ideas and skills in how to study books and classes; of course it is helpful to learn to schedule time for class, study, other work, and recreation, and to use scanning techniques before beginning careful reading of texts. But the central concern, the empowerment of learners to learn meaningfully, is usually absent or lost in a barrage of "study skills." I realize now that I was naive to assume that every student at Cornell University wanted the empowerment to learn meaningfully; at the freshman and sophomore levels, most are interested only in high grades. It is only as juniors and seniors that a substantial majority recognize the worthlessness of memorizing for exams without achievement of understanding. It is then that they are receptive to the idea of learning how to learn meaningfully.

My course, Learning To Learn, is designed to make meaningful the ideas shown in Figure 6. It is premised on the world view that most of the ills in the world can only be solved through better education, and that empowering people to take charge of their own meaning making is ultimately the fundamental challenge of modern civilization. It builds on a constructivist epistemology (see von Glasersfeld, 1984; Novak, in press) that views all knowledge as a human construction, and as with any human construction, ideas are subject to change over time, or even "extinction," such as the ideas of a flat earth or phlogiston, or Euclidean geometry as ultimate truth. It presents Ausubel's assimilation theory of learning, ideas from cognitive science, emerging ideas on the interplay of thinking, feeling and acting, and the relationship between the psychology and philosophy of constructivism (Novak, in press).

One of the ideas central to my course is that all meaning making is event-based. The events I use are lecture-discussion of key concepts, principles and theories, with an emphasis on discussions designed to negotiate meanings between students (who construct questions in pairs) and between me and the students. This would be more difficult with a class of one-hundred or more but works well with smaller groups. I ask students to concept map sections of readings, to prepare Vee diagrams for topics of interest to them, and to plan and execute clinical interviews, using concept maps and Vee diagrams both for the design of the interview and the interpretation of the interviewee's ideas. Students choose their topics for interviews and their interviewees. Topics vary from "What do people think is a beautiful woman?" to "What do students know about gas chromatography before and after a series of lectures on the subject?" I have found that the experience of interviewing others is the most powerful event in helping students to understand and gain commitment to the constructed nature of knowledge and meaning making. They often observe that taking courses in a subject may contribute nothing to understanding that subject when the learning is primarily by rote--an observation that is all too common.

Interviewing is a powerful teaching/learning tool. I would advise any teacher to include interviewing in conjunction with class studies. For example, teams of three to five students could select a topic currently being studied, or recently studied, and collectively construct a concept map and Vee diagram to guide the preparation of interview questions. Topics that have significant value issues associated with them can be the most stimulating, e.g., what do people think about amniocentesis, groundwater quality, acid rain, etc.? Study teams can interview classmates, older or younger students, and/or adult. Each teacher can prepare a brief report on their findings, perhaps illustrating different views held by interviewees by making concept maps of the ideas expressed by a sample of interviewees.

The experiences in Learning How to Learn cause many of my students to ask, "Why is schooling, including university education, so far off the mark from what is known about empowering learners?" This question comes up with increasing frequency as the course progresses, and we often use part of the last class meetings to discuss the problem. Some of the ideas we have developed follow.

What are the Major Obstacles to Helping Students Learn?

Joseph Schwab (1973) identified four commonplaces that are present in any educative event: (1) the learner; (2) the teacher; (3) subject matter or the curriculum; and (4) the social milieu. In line with Schwab's argument that these commonplaces are distinct and one cannot be absorbed in the others, I choose to call these elements of education. I also add (Novak, 1988) a fifth element: (5) evaluation. In so much of schooling, the focus of teacher and students' attention is centered on the evaluation of students and this is usually done with relatively invalid "tests." In the United States, pressure for "accountability" is exacerbating the problem to the point that the achievement tests administered become virtually the sole concern of some teachers and their students. The problem of constraints on learning conferred through testing is not unique to the United States but is world-wide, and even more severe in some Third World countries where the subject matter may be even more irrelevant to the lives of students, but passing or failing a test can open doors or terminate opportunity for further education and associated career options.

Testing, as contrasted with a wider array of more valid measures for evaluation, is one of the constraints that may impede helping students learn how to learn meaningfully. Many teacher-made tests require specific, verbatim answers with little or no reference to the meanings or application of the knowledge being tested. However, it is not only teacher-made tests that are at fault. As Stephen Gould (1981) has argued, even the "best" tests result in stifling Mismeasurement of Man. The constraints of testing are a major contribution to the motivation problem to get students to choose to learn meaningfully and not by rote. Learning by rote can have relatively quick and easy payoff; it is over the longer term or when knowledge must be applied to novel problems or settings that meaningful learning becomes convincingly more valuable. Even over the course of a semester, meaningful learning can be recognized by students to become more efficient than rote learning.

We have found that by their junior or senior year in college, most students begin to recognize that rote learning methods are comparatively bankrupt for achieving anything of lasting value. Nevertheless, many seniors at Cornell University will persist in learning primarily by rote, memorizing answers to last year's exams, and making achievement on the instructor's tests as the sole criterion of what pays off. There is a subtle immorality to this game and both teacher and students are engaged in a kind of intellectual fraud. This is not the kind of experience that will persuade students that they have a responsibility to help make the world a better place for future generations.

The curriculum is another source of difficulty for efforts to encourage meaningful learning. For most courses at every grade level, there is the common problem that too much subject matter is presented with too little time to explore the concepts underlying the science or mathematics being presented. Facts and principles presented frequently are not related to any kind of experience that is familiar to the learner. There is relatively little attention given to how scientists and mathematicians went about constructing the knowledge being presented, and even less regarding the history and evolution of basic ideas that underlie the science or mathematics presented.

There is far too little of an "event sense" of the knowledge, that is, seldom are students asked to see the relationship between statements (knowledge claims) they are memorizing and the kind(s) of events and records of events that were used to construct the knowledge claims. In terms of the Vee heuristic, most of the learning deals almost exclusively with the right side of the Vee, and even then with little to link records or events that are relevant. Consideration of elements on the left side of the Vee is rare, and when theories or philosophies are mentioned, they are seldom linked explicitly to other elements to show the simple but also profoundly subtle ways that new knowledge is generated.

In both math and science instruction, the subject matter is generally conceptually opaque. That is, students (and often teachers) seldom see the framework of concepts and concept relationships that make sense out of the statements they are memorizing or the math problems they are solving by applying some algorithm. To be learned meaningfully, subject matter must be made conceptually transparent (Novak, 1991). Students need to be helped to construct and apply hierarchical conceptual frameworks to the interpretation of the facts, statements and procedural rules they are memorizing. In the sequence of educative events, there is a place for rote learning, as when one first identifies a rule or principle, but then we must move rapidly to see what the rule or principle means. We can memorize the principle: F=ma. But what does it mean to say that force is equal to mass times acceleration? What is mass? What is force? What is acceleration? Where did these ideas come from?

Subject matter is not simply subject matter. Depending upon how it is presented, it may be conceptually transparent or conceptually opaque. In much science teaching, it is mostly the latter.

Do we need "learning to learn" courses in secondary schools? I do not think so. What is needed is for each teacher to incorporate learning tools and evaluation practices that will require students to use meaningful learning approaches if they wish to be successful. It is important, however, to help students understand why the learning tools are being used and how they help to understand learning and knowledge construction. If this is done from grade one onward, it should be easier, rather than more difficult, to encourage meaningful learning in older students. Research studies are beginning to document that the use of concept maps and Vee diagrams in science and mathematics instruction can be very helpful (Novak, 1990a, 1990b).

The growing practice in U. S. schools of introducing courses in "thinking skills" is, in many cases, counterproductive. It burdens further an already crowded school curriculum and often does nothing to change the mode of instruction and learning in other classes. It is an administrative expedient, but I see no evidence for substantive improvement in school learning arising from "learning skills" courses, in spite of some claims (Adams, 1989). However, I do see the need for and value in special workshops or short courses for teachers at all levels to learn how to help their students learn how to learn meaningfully, at least until this has become a standard feature of all teacher preparation programs, including programs for testing teachers.

Finally, we turn to the social milieu as an element in education that too often constrains rather than enhances teacher's efforts to help students learn meaningfully. Already discussed is the negative influence of school/state testing programs. The political reality in most countries is that some kind of evaluation of students (and indirectly, of teachers and schools) is probably here to stay. What is needed are far more imaginative evaluation schemes than are currently being employed on a large scale. Some of the work that Tamir (1974), and his colleagues in Israel have been doing point toward promising alternatives. We believe that the use of concept maps and the Vee heuristic represent promising alternatives but there is the problem that we cannot evaluate students using a tool they have never seen before.

On the other hand, the inclusion of semi-structured concept maps and Vee diagrams in state or national evaluation programs would provide strong incentives to teachers to use these tools. Concept maps have been used in Victoria, Australia in high school leaving exams with some success (Martin, personal communication).

There is a growing body of evidence that the use of instructional practices that encourage meaningful learning leads, in time, to improvement on "standardized tests" as well. One of the difficulties we have had to demonstrate this decisively is that most of our research has dealt with a single teacher, in one subject area, and for at most one school year. We have not yet had the opportunity to work with a school district where one-third or one-half of the teachers were committed exclusively to meaningful learning practices in several subject areas and over several years of schooling. Currently I am working with some schools that are attempting to move in this direction, and there may be other schools similarly committed. Bar-Lavie in Jerusalem, Israel, is working to develop a school for gifted and talented students committed to meaningful learning (personal communication).

Money is always a factor in any enterprise, and schooling is no exception. However, it costs no more to develop syllabi and textbooks that are conceptually transparent rather than conceptually opaque.{2} It costs no more to emphasize meaning building, to use ego enhancing strategies such as cooperative learning or to educate teachers in these strategies, rather than traditional strategies. Better evaluation practices may cost more than the standardized tests we are using, but these are costs societies can easily meet; they are trivial compared with other costs of schooling. Money is not the major obstacle to the improvement of school learning. It costs us nothing to change our minds about what is valuable in school learning.

What Promise is there for the Empowerment of People?

In his book, Megatrends, Naisbitt (1982) described ten "megatrends" he believes point the direction not only for the United States for the entire industrial world. The ten megatrends he identified were:

1. Industrial Society--->Information Society
2. Forced Technology--->High Tech/High Touch
3. National Economy--->World Economy
4. Short Term--->Long Term [planning]
5. Centralization--->Decentralization
6. Institutional Help--->Self-Help

7.Representative Democracy--->Participatory Democracy
8.Hierarchies--->Networking
9.North--->South (USA)
10.Either/Or--->Multiple Option

Whether you agree with Naisbitt's list of megatrends or not, it is undeniable that most if not all of these changes have already occurred or will be experienced. Number three on his list will gain new impetus with the European common market that goes into effect in 1992. Some of the other trends may emerge more slowly, and indeed we educators will be a key factor in how rapidly and with what quality some of these trends will occur. For instance, the trend away from "institutional help" to "self-help" depends upon how well we help our students take charge of major facets of their own lives. Each of the trends calls for a citizenry that is educated to find new solutions, new ways of doing things, new ways to solve problems. This much we know about human learning: only a schooling focused on meaningful learning can empower students to take charge of their future in constructive, creative ways.

In much of the world, hunger and poverty are the overwhelming concerns. For some two billion citizens of the world, getting enough to eat, and clothes, and shelter are the overriding problems, not the chance for full creative expression of innate aptitudes. The "green revolution" of the 1960s and 1970s has never visited these people. We do, however, know how to produce food in abundance, to make better use of other natural resources, and we can learn how to make world distribution systems that can at least reduce poverty if not eliminate it. What is required is a growing commitment on the part of those peoples who now enjoy plenty to help those who have so little. But this kind of altruism cannot be built on an education that is inherently fraudulent, designed for grades or test scores even when this attainment does not confer empowerment of the student. If we want moral citizens we must provide them with education that is inherently moral.

It has been said that there is nothing so unstoppable as an idea whose time has come. Let us hope and work together to beat swords into plowshares and also to use resources to improve the quality of education. I believe we know enough to take a quantum leap forward toward schooling, especially in sciences and mathematics, that will help our students learn how to learn. This kind of education will lead to a kind of human-empowerment that is necessary if we are to take care of our Spaceship Earth, and each other.

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Figure 2.Gowin's Vee showing epistemological elements which are involved in the construction or description of 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.

Figure 3.The rote-meaningful continuum showing key characteristics of rote learning contrasted with meaningful learning. Pressured by poor evaluation and poor instruction, most students engage in predominantly rote learning in school.

Figure 4.Three memory systems operate in human learning, each interacting with the others. The severe limits of Short-Term or working memory, where all new meaning-making must occur, is one reason why many students suffer when their knowledge is limited or organized into tiny "chunks."

Figure 5.A simple concept map used to introduce some major concepts and concept relationships in my courses. The most useful maps with students' learning a new discipline or sub-discipline are simple maps.

Figure 6.A complex concept map I use to review and summarize some of the major concepts and principles I teach in my courses. An useful strategy is to have students work in pairs to construct questions about the map or to suggest modifications.

Figure 7.A Vee constructed from a class "experiment" involving several short-term learning events. Here the concept map represents key concepts and principles needed to understand and to interpret the data obtained. Philosophy and world view are not shown on the left side.

FOOTNOTES********************************

{1}A modified version of a paper presented as the opening address of the Third Congress on Research and Teaching of Science and Mathematics, Santiago de Compostela, Spain, September 20, 1989. In 1990, this paper was selected for an award by the Association for the Education of Teachers of Science.

{2}   We are currently working to accomplish this for secondary school biology in New York.