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Meaningful Learning: The Essential Factor for Conceptual Change in Limited or Inappropriate Propositional Hierarchies Leading to Empowerment of Learners

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ABSTRACT: The construction and reconstruction of meanings by learners requires that they actively seek to integrate new knowledge with knowledge already in their cognitive structure. Ausubel's assimilation theory of cognitive learning has been shown to be effective in guiding research and instructional design to facilitate meaningful learning (Ausubel, The psychology of meaningful verbal learning, New York: Grune and Stratton, 1963; Educational psychology: A cognitive view, New York: Holt, Rinehart and Winston, 1968; The acquisition and retention of knowledge, Dordrecht: Kluwer, 2000). Gowin's Vee heuristic has been employed effectively to aid teachers and students in understanding the constructed nature of knowledge (Gowin, Educating, Ithaca, NY: Cornell University Press, 1981). "Situated learning" occurs when learning is by rote or at a lower level of meaningful learning. Concept mapping has been used effectively to aid meaningful learning with resulting modification of student's knowledge structures. When these knowledge structures are limited or faulty in some way, they may be referred to as Limited or Inappropriate Propositional Hierarchies (LIPH's). Conceptual change, or more accurately conceptual reconstrution, requires meaningful learning to modify LIPH's. Collaborative group learning facilitates meaningful

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learning and new knowledge construction. World-wide economic changes are forcing major changes in business and industry placing a premium on the power and value of knowledge and new knowledge production. These changes require changes in school and university education that centers on the nature and power of meaningful learning. New computer tools are available to facilitate teaching activities targeted at modifying LIPH's, and aiding meaningful learning in general. © 2002 Wiley Periodicals, Inc. *Sci Ed* **86:**548–571, 2002; Published online in Wiley Interscience (www.interscience.wiley.com). DOI 10.1002/sce.10032

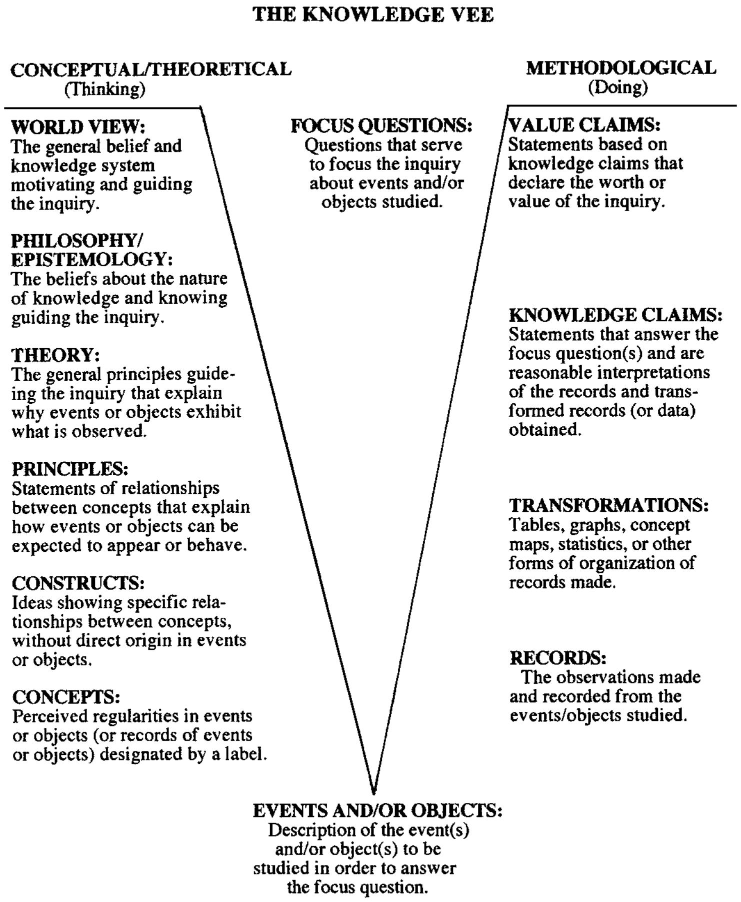
THE CONSTRUCTION OF MEANINGS

It is now almost universally accepted among those who study human learning that humans begin construction of meanings at birth and rapidly accelerate the process as they gain the capacity to use language to code meanings for events and objects around them. It is also almost universally accepted that some of the meanings constructed are faulty or limited and this can distort or impede new meaning construction (see for example Bransford, Brown, & Cocking, 1999). What is not agreed upon is *why* these faulty constructions arise, and *how* we can facilitate the construction of valid meanings and the reconstruction of faulty or invalid meanings. There have been four international seminars at Cornell University where several hundred research studies were presented on student misconceptions and instructional strategies that failed, and some that have succeeded in remediating student misconceptions. The proceedings for these seminars are available electronically (www.mlrg.org).

We must pause to address the question: What are meanings? Since 1964, my graduate students and myself, and many scholars around the world who have been receptive to our work, have built upon the ideas of David Ausubel. In his *The Psychology of Meaningful Verbal Learning* (1963) and later *Educational Psychology: A Cognitive View* (1968, 1978), and in his recent *The Acquisition and Retention of Knowledge* (2000), Ausubel has made the clear distinction between *rote* learning where new knowledge is arbitrarily and non-substantively incorporated into cognitive structure (or we might say now, into long term memory, LTM), and *meaningful* learning where the learner chooses conscientiously to *integrate* new knowledge to knowledge that the learner already possesses (Novak, 1994). Young (preschool) children are marvelously adept at meaningful learning, but upon entering formal schooling, too often with overwhelming emphasis on rote memorization and verbatim recall of answers for tests, most learners move to predominantly patterns of rote learning. Most Cornell University students achieve their high grade point averages by rote learning—which they do very well. Unfortunately, most of this "knowledge" soon becomes irretrievable from long-term memory, and even if recalled, seldom can the learner utilize the knowledge in new contexts, as in novel problem solving. This inability to transfer knowledge is sometimes referred to as "situated learning." Thus much of this high "achievement" is really fraudulant or inauthentic (Edmondson & Novak, 1992).

THE CONSTRUCTION OF KNOWLEDGE

If meaningful learning involves substantive, nonarbitrary incorporation of concepts and propositions into cognitive structure, we must ask: What is a *concept*, what is a *proposition*, and what is *cognitive structure*? Here we must move from psychology to epistemology, the study of knowledge and new knowledge production. Our research group has relied strongly upon the work of Gowin (1981), who has devoted his career to the study of epistemology in the context of education. Gowin has devised a marvelous heuristic shaped as a V. The shape is arbitrary but it serves to give emphasis and distinction to a number of important epistemological elements that are involved in the construction of new knowledge, or new meanings. Figure 1 shows the general form of Gowin's Knowledge Vee, with definitions



THE KNOWLEDGE VEE

CONCEPTUAL/THEORETICAL
(Thinking)

METHODOLOGICAL
(Doing)

WORLD VIEW:
The general belief and knowledge system motivating and guiding the inquiry.

PHILOSOPHY/ EPISTEMOLOGY:
The beliefs about the nature of knowledge and knowing guiding the inquiry.

THEORY:
The general principles guiding the inquiry that explain why events or objects exhibit what is observed.

PRINCIPLES:
Statements of relationships between concepts that explain how events or objects can be expected to appear or behave.

CONSTRUCTS:
Ideas showing specific relationships between concepts, without direct origin in events or objects.

CONCEPTS:
Perceived regularities in events or objects (or records of events or objects) designated by a label.

FOCUS QUESTIONS:
Questions that serve to focus the inquiry about events and/or objects studied.

VALUE CLAIMS:
Statements based on knowledge claims that declare the worth or value of the inquiry.

KNOWLEDGE CLAIMS:
Statements that answer the focus question(s) and are reasonable interpretations of the records and transformed records (or data) obtained.

TRANSFORMATIONS:
Tables, graphs, concept maps, statistics, or other forms of organization of records made.

RECORDS:
The observations made and recorded from the events/objects studied.

EVENTS AND/OR OBJECTS:
Description of the event(s) and/or object(s) to be studied in order to answer the focus question.

Figure 1. Gowin's Vee showing 12 epistemological elements operating in the construction of knowledge or in an analysis of a unit of knowledge. All elements interact with one another and the process of knowledge construction can be initiated from any element, but most commonly from the focus question and event(s) or object(s) of interest. The Vee heuristic can serve as a metacognitive tool.

of the 12 epistemological elements and Figure 2 shows an example of a math problem as depicted through the Vee.

At the "point" of the Vee are the events or objects we are trying to understand. On the left side are those epistemological elements we bring to the study (our conceptual/theoretical framework) and on the right side are the procedural activities we do guided by our conceptual/theoretical framework. In the center is(are) the focus question(s) that frame the inquiry and guide the interplay of all 12 elements as the inquiry proceeds. Meaning making proceeds when a new regularity is perceived in events or objects, or records of events or objects, leading to concept formation and/or the construction of new propositions. With young children, concept formation is a relatively autonomous event, albeit adults and older children may help to focus the child's attention on key criterial attributes of some regularity and supply language labels for the regularity (the concept label). By age three, children can use language to construct new meanings of regularities observed and to acquire new concepts, even relatively abstract concepts such as hot, slow, and love (Macnamara, 1982). Of course, all concepts are an abstraction, a representation of reality in our minds, not the reality itself. We define concepts as *perceived regularities in events or objects, or records of events or objects designated by a label* (usually a word). The universe is comprised of events and objects and we observe events or objects in our private universe directly or through

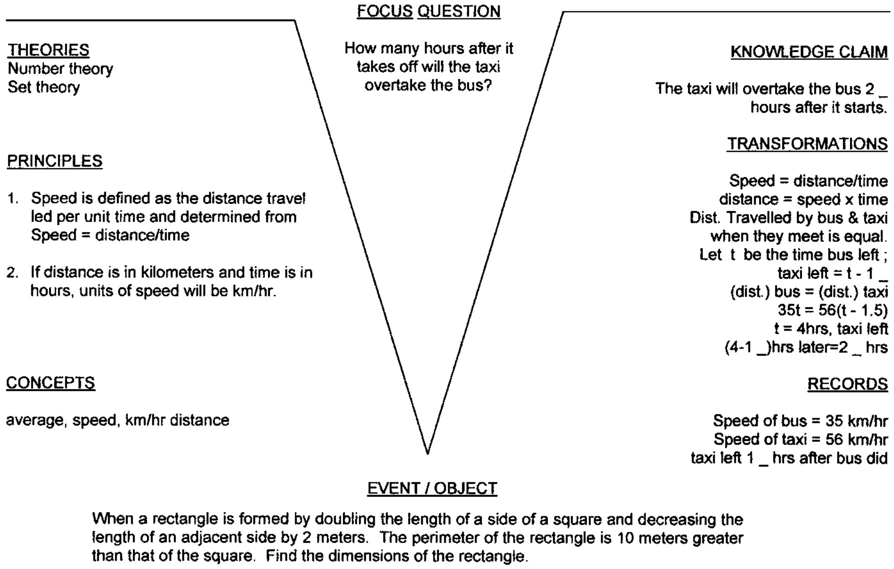


Figure 2. An example of Gowin's Vee drawn by a secondary school student to represent a textbook problem (from Fuata'i, 1998, p. 69). Students were not asked to include philosophy or world view or value claims.

the use of record-making instruments. What we *perceive* as the regularity in these events, objects, or records depends on what we already know, our observational strategies, and the emotional, physical, and social state we are in. Thus concept acquisition is an idiosyncratic process, but mediated socially to allow for some degree of meaning sharing (Macnamara, 1982; Ryder, Leach, & Driver, 1999).

THE CONSTRUCTION OF CONCEPT/PROPOSITIONAL FRAMEWORKS

Concepts are combined to form statements or *propositions*. Knowledge stored in our brain consists of networks of concepts and propositions. As meaningful learning proceeds, new concept meanings are integrated into our cognitive structure to a greater or lesser extent, depending on how much effort we make to seek this integration, and on the quantity and quality of our existing, relevant cognitive structure. If we learn strickly by rote, essentially no integration of new concept meanings occurs, and existing cognitive structure is not elaborated or reconstructed. Because individuals vary in the extent of their existing relevant cognitive structure, and also the effort they make to incorporate new concept meanings, there is a continuum in learning from extreme rote learning to highly meaningful learning. This is shown in Figure 3. The *meaning* of concepts derives from the *totality* of propositions linked to any given concept, plus emotional connotations associated with these concepts, derivative in part from the experiences, and context of learning during which the concepts were acquired. This complex of meanings and feelings leads to learning that is to a greater or lesser extent constratined by the context in which it occurs, sometimes referred to as situated learning (Kirshner & Whitson, 1998). Vygotsky (1962) suggested that construction of new meanings takes place in a "zone of proximal development," or that area of cognitive structure that is prepared to accept new or altered ideas. This may account in part for the effectiveness of group learning, since students tend to be closely matched in their "zones of proximal development" and useful negotiation of meanings can occur between them (Jones, Rua, & Carter, 1998; Towns & Grant, 1997). The extent and complexity of meanings we hold in any domain are dependent on the quality and quantity of meaningful learning we

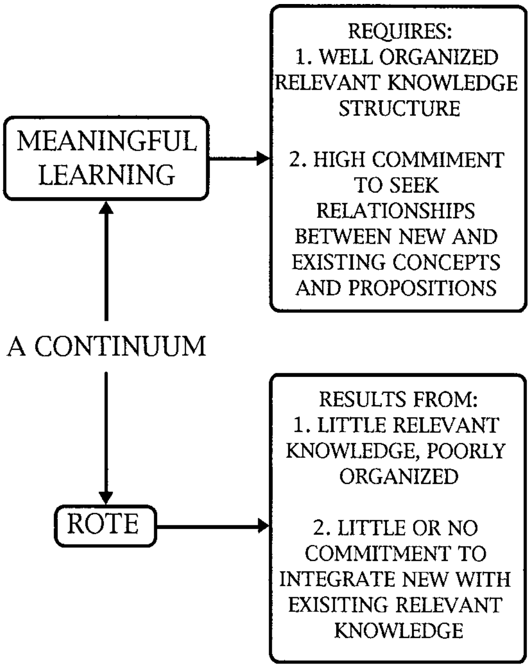


Figure 3. Meaningful learning occurs on a continuum, depending on the quantity and quality of relevant knowledge possessed by the learner and the degree of her/his effort to integrate new knowledge with existing relevant knowledge.

have pursued in that knowledge domain. In turn, the quantity and quality of the knowledge structures we build will determine our ability to transfer this knowledge for use in new contexts (Alexapolou & Driver, 1996; Basconas & Novak, 1985).

Unfortunately, so much of school learning is near the rote end of the spectrum, and this accounts for what some authors call *situated cognition* (Brown, Collins, & Duguid, 1989). What is commonly observed is that learners often cannot transfer what is learned in one context or setting to another context or setting, and hence learning is *situated* in the original learning context. However, these authors fail to emphasize that the fundamental problem leading to high situativity is the predominance of near rote mode learning, or seriously deficient meaningful learning. The prevalence of misconceptions may exacerbate the situativity, because these faulty knowledge structures are not modified by rote or near rote learning and trap the person into limited or faulty transfer of knowledge.

Piaget popularized the clinical interview as a means to probe children's cognitive processes that they use to interpret events. We adapted his approach to serve a significantly different purpose, namely to identify the concept and propositional frameworks that people use to explain events. Working with almost 200 students in our 12-year longitudinal study, and interviewing these students several times during the first year of the study, we were soon overwhelmed with interview transcripts. Moreover, we found it difficult to observe specific changes that were occurring in the children's understanding of science concepts. We had to find a better way to represent the children's knowledge and their changing understanding of concepts. From these interviews we devised the technique of *concept mapping* to represent the interviewee's knowledge (Novak & Gowin, 1984, Chapter 7; Novak & Musonda, 1991). Figure 4 shows a concept map of my ideas on the nature of concept maps. Unlike so many "concept maps" appearing in the literature. what our team developed was a knowledge representation tool showing concepts and explicit prepositions forming a hierarchical structure. So-called concept maps that do not specify the links between "nodes" fail

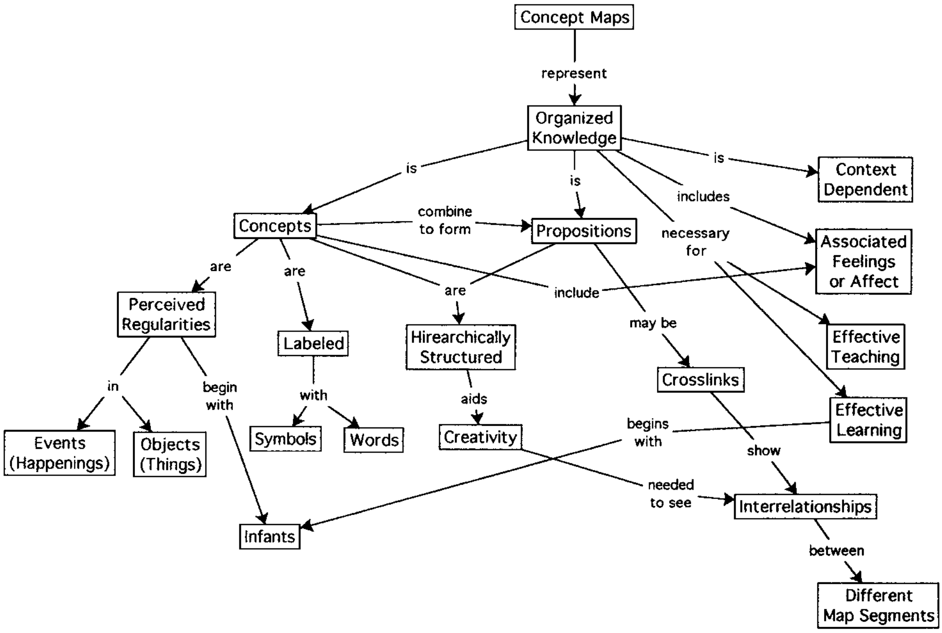


Figure 4. My concept map showing the nature and structure of concept maps.

to construct propositions which we see as the essential elements in representing meanings. The lack of hierarchy fails to indicate what concepts are most inclusive, or most salient for a given context to which the knowledge structure is to be applied.

In the past 30 years, there has been increasing interest in the problem of representing knowledge. Ryle (1949) suggested that knowledge can be classified as *declarative* or *procedural. Declarative* knowledge (sometimes called conceptual knowledge) is knowledge where we *know that* about something, whereas *procedural* knowledge is where we *know how* something works. Rummelhart and Ortony (1977) claim that declarative knowledge is characterized as organized into schemas. Jonassen, Beissner, and Yacci (1993) described *structural knowledge* which they see as the awareness and understanding of one's own cognitive structure. They describe various kinds of methods for representing knowledge structures and tools used to do this. The American Association for Advancement of Science (AAAS) has recently published an Atlas of conceptual maps (AAAS, 2001), albeit these differ from what I call concept maps. From my perspective the fundamental building blocks of knowledge are concepts and propositions as described above, and discussed further elsewhere (Novak, 1977, 1993a, 1993b). Interest in knowledge representation and knowledge elicitation has grown exponentially in the past decade and a new literature is emerging on this topic.

Since 1972, we have used concept maps to represent knowledge and changes in knowledge of individuals. Figures 5 and 6 show concept maps drawn from interviews with two second grade school students and interviews with the same students 10 years later. Note the great differences in development of their development of understanding of the particulate nature of matter. These students were part of a 12-year longitudinal study of science concept development, further discussed below.

Early concept learning tends to be context imbedded and highly meaningful. By contrast, much school learning involves the rote learning of concept definitions or statements of principles without opportunities to observe the relevant events or objects, and without careful integration of new concept and proposition meanings into their existing knowledge frameworks. This rote, arbitrary acquisition of knowledge is encouraged by poor evaluation

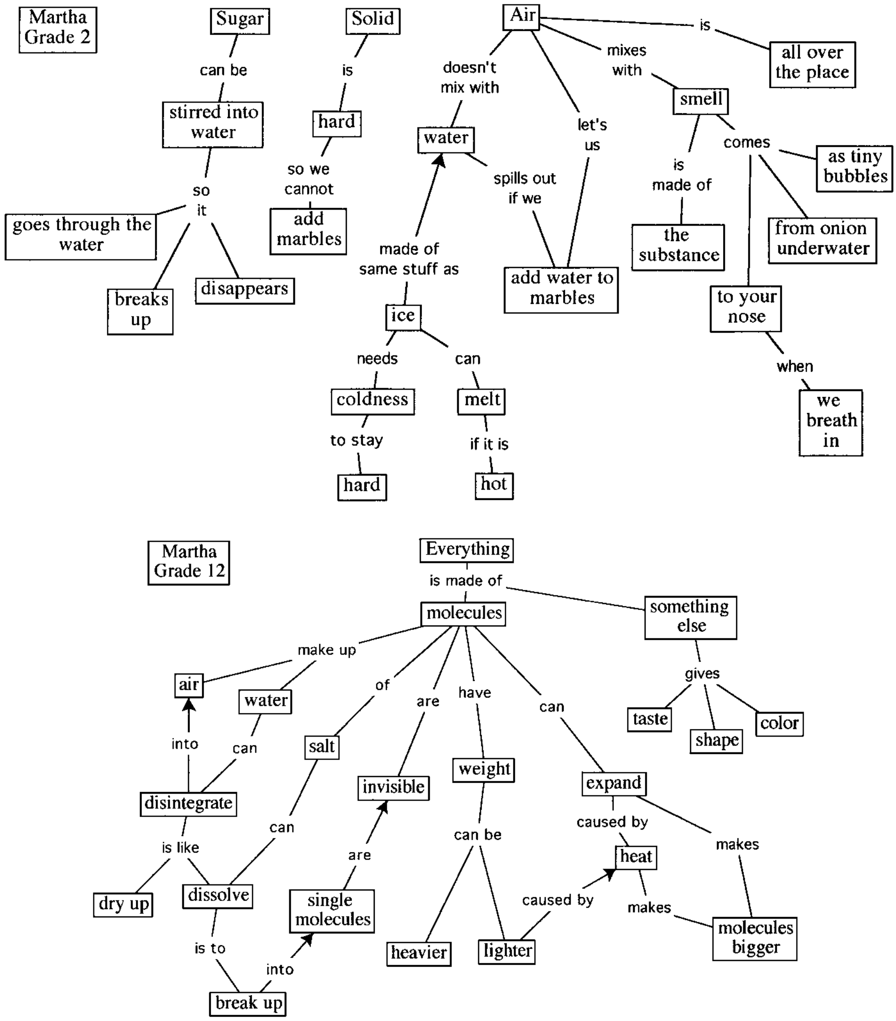


Figure 5. Concept maps drawn from interviews with Martha in grade 2 and grade 12. Note that Martha's knowledge structure about the nature of matter shows little increase over-all and more faulty conceptions and limited conceptions in grade 12 than in grade 2 (modified from Novak & Musonda, 1991).

practices as well as instruction strategies where teacher rewards quick answers to questions that have little or no relevance to direct experiences with pertinent objects or events. But "hands on" experience is not enough; we also need "minds on" experiences (Hassard, 1992). The problem also exists in mathematics, as Schmittau (1994) observed in her study of ways that students conceptualize mathematics. Figure 7 shows an example of a concept map drawn by one of her subjects who sees no relevance of algebra and geometry to everyday life and few connections with multiplication that is relevant to everyday life.

THE PROBLEM OF FAULTY CONCEPTUAL FRAMEWORKS

Even when classroom learning experiences involve hands-on activities to illustrate concepts and principles, many students fail to construct concept and propositional frameworks that are congruent with what scientists or mathematicians currently believe. Examples of this will be given below.

One could argue that inadequate maturity, low innate intelligence, and/or the quality of the instructional program are the reasons for the lack of appropriate knowledge acquisition. Our research and the research of others indicate that while the latter factors are in many cases significant factors influencing achievement, they are probably not the most important factors (Carey, 1985; Donaldson, 1978; Metz, 1997). For example, in a study with Ph.D. students in chemistry at Cornell University, the number and variety of misconceptions after carefully designed lectures on gas chromatography was similar to that evidenced before the lectures (Pendley, Bretz, & Novak, 1994). After carefully designed and executed eighth grade science lessons on the particulate nature of matter, students evidenced a greater number and variety of misconceptions than scientifically accepted conceptions (Bartow, 1981).

What is clearly evident from the studies cited above and hundreds of other studies such as those reported at our International Seminars on misconceptions (proceedings available at www.mlrg.org) is that facilitating student's acquisition of powerful and valid conceptual frameworks is not easy. There are innumerable ways to go wrong and no set of traditional instructional strategies that are foolproof. This, of course, is to be expected because we know that meaning building is an idiosyncratic event, involving not only unique concept and propositional frameworks of the learners, but also varying approaches to learning and varying emotional predispositions. The challenge is how to help teachers, directly or vicariously, help students construct and reconstruct their individual conceptual frameworks and their attitudes toward science and mathematics in ways that will lead to increasing cognitive competence.

There was much discussion at the 1983 International Seminar (Helm & Novak, 1983) on the proper label to apply to these cognitive problems researchers have called misconceptions, alternative conceptions, naive notions, prescientific notions, etc. Each of these labels has merit, but each also is limited in its description of the origin of the problem, the historical antecedents of the conception and/or the role these conceptions play in the thinking of the individual or the society that holds the belief. I proposed then (Novak, 1983) that we consider an acronym LIPH as a fresh label for these conceptions, representing the idea that problems arise from the Limited or Inappropriate Propositional Hierarchies (LIPH's) possessed by the individual. Now, two decades later and hundreds of relevant research studies later, I

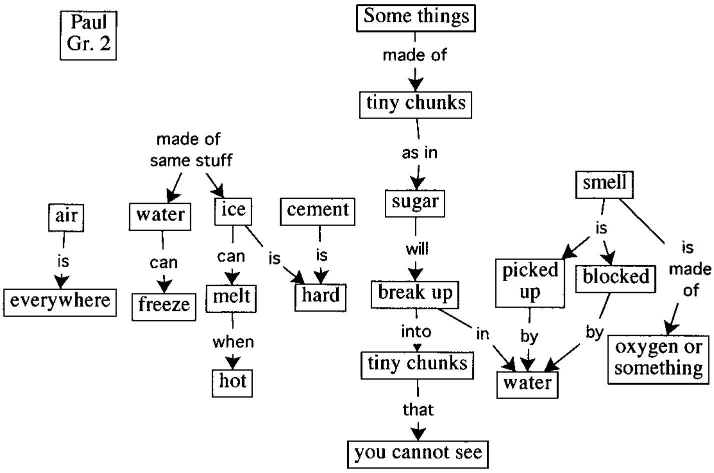


Figure 6. Concept maps drawn from interviews with Paul in grade 2 (Map A) and in grade 12 (Map B). Note the enormous growth and refinement of Paul's concept/propositional knowledge of the particulate nature of matter (modified from Novak & Musonda, 1991).

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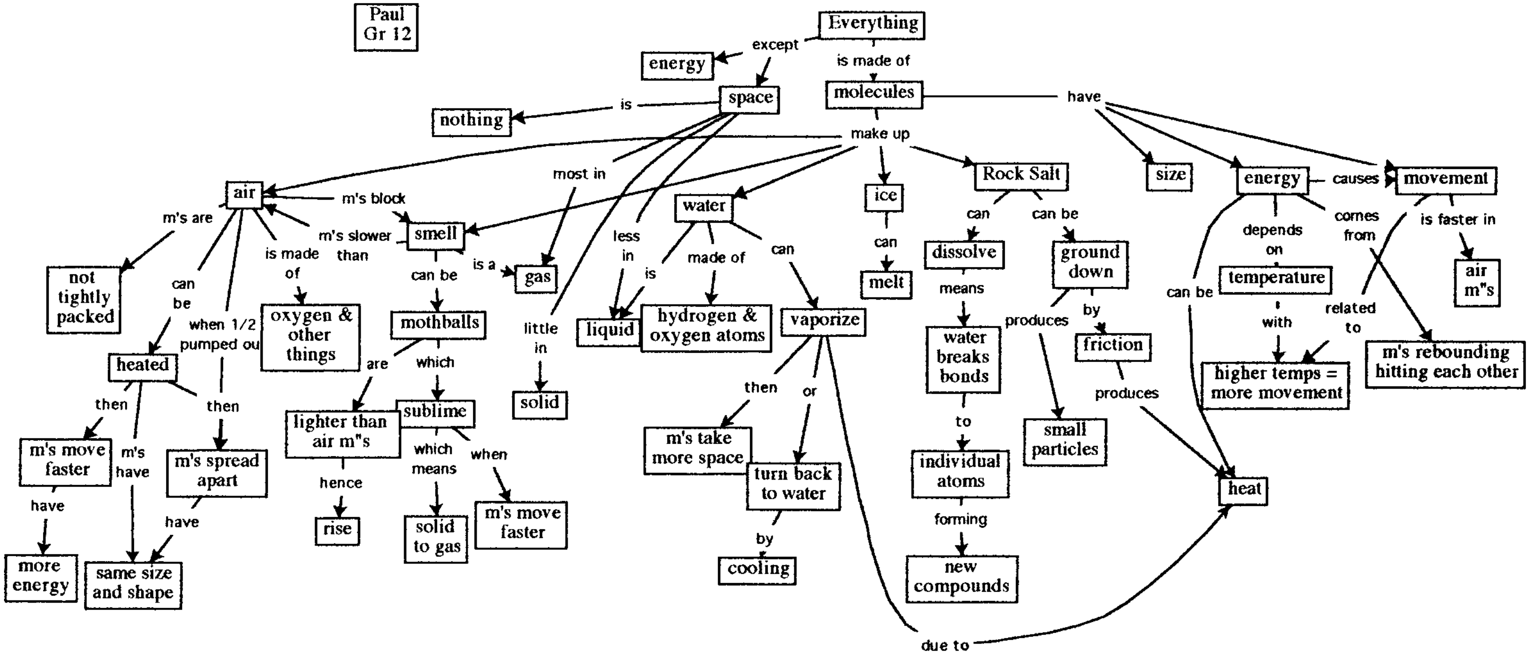

Figure 6. *(Continued)*

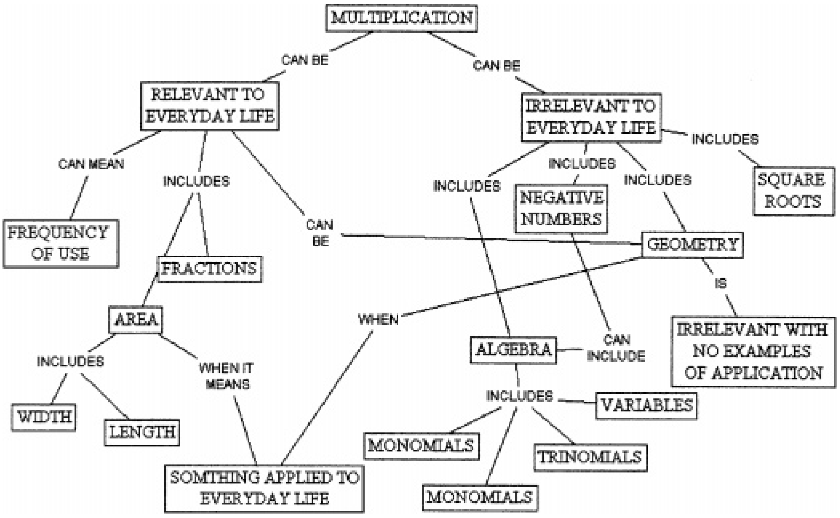

Figure 7. A concept map drawn by a college student showing her conception of multiplication. She does not have an integration of ideas from geometry with multiplication concepts (from Schmittau, 1991).

am even more persuaded that the LIPH label is appropriate and powerful. It recognizes that we cannot simply ask learners to expunge a faulty concept meaning they have in their mind and substitute the currently valid label and description. It recognizes that rote learning is ineffective in reconstructing cognitive frameworks, thus "removing" misconceptions and supplanting them with valid conceptions. It also recognizes that only the learner can choose to learn meaningfully and to consciously and deliberately reconstruct his/her cognitive framework. What is required is often the reconstruction of a significant segment of the learner's concept and propositional framework, and we see in some of the above figures that this does not occur easily even with meticulous instructional effort. Caravita and Hallden (1994, p. 90) describe this well

> We suggest a view of learning not as an event of mere replacement of old ideas by new ones, but as a process which occurs in a system where conceptions of specific phenomena are only one of the components, Organization, refinement and differentiation among contexts are other important and observable aspects which continuously enlarge the power of the system to perceive and interpret reality.

There is one advantage to rote learning: because new information is not integrated with existing concepts and propositions in the learner's cognitive structure, misconceptions the learner holds do not operate to distort the new learning. Hence the learner can respond to oral or written questions that are "correct," at least for the few days or weeks that information learned by rote is retained in cognitive structure. This can be satisfying to both teachers and students. However, no constructive modification of LIPH's can occur—and no ability to transfer the learning to new contexts results. The literature on misconceptions research is replete with examples of this kind.

WHY MEANINGFUL LEARNING IS ESSENTIAL TO REMEDIATE LIPH'S AND EMPOWER LEARNERS

As indicated earlier, the construction of new meanings requires that an individual seeks to integrate new knowledge with existing relevant concepts and propositions in their cognitive structure. Only the learner can choose to do this, so one of the obstacles to alterations of misconceptions or LIPH's is that learners who *choose* to learn by rote will not modify their existing knowledge structures regardless of the efforts of the text or instructor. Thus a precondition for remediating a given LIPH is that learners must choose meaningful learning, at least to some degree. Furthermore, high levels of meaningful learning require that the learner already possess a relatively sophisticated relevant knowledge structure, so in most cases, remediation of LIPHs will be an iterative process where the learner gradually builds relevant knowledge structures and refines these over time. This is also supported by research by Sadler (2000). Working with large samples of high school students, his research has shown a number of examples of responses on tests specifically designed to include common misconceptions as choices. His data show a decrease in performance for average students and then a move toward near perfect performance for the best students as a result of instruction. What happens, and my colleagues and I have seen this in our research also (Feldsine, 1987; Pines & Novak, 1985), is that as less able learners attempt to integrate new learning into a faulty knowledge structure, the misconception is elaborated or strengthened at first; whereas for the more able students, as their relevant cognitive framework builds, new integrations are possible that lead to a more powerful, accurate knowledge structure and the misconceptions are remediated. Similar problems are observed with preservice elementary school teachers (Schoon & Boone, 1998).

DiSessa (2001) also observes that intuitive ideas developed in childhood are not necessarily a liability, "Intuitive ideas are frequently effective, even if not 'correct'. In fact, in most usual circumstances, they work perfectly well" (p. 97). He goes on to say, "The most disturbing thing I uncovered in a study of bright, motivated, and successful MIT undergraduates years ago was that, although they did very well in high school physics and got high marks, almost none felt they really understood the material" (p. 107). DiSessa goes on to explain that that without the "committed learning" that is characteristic of much out-of-school childhood learning, bright students essentially play the "school game" and achieve little in building powerful knowledge structures. Looking at DiSessa's ideas through the lens of assimilation theory, we concur that without commitment to a high level of meaningful learning, much of what occurs in school science learning does little to build powerful and useful knowledge structures.

During the course of remediation of LIPHs, four cognitive processes described by Ausubel may be necessary. (1) *Progressive differentiation* of existing concept and propositional meanings may occur through the process of (2) *subsumption*. In subsumption new exemplars of concepts or proposition are linked with existing concepts and propositions thus refining and elaborating the meaning of these. For example, elaboration of the concept of fish may entail study of additional representatives of this concept, perhaps including some examples of non-fish such as dolphins. Another process occurs more rarely, where several concepts are recognized as subconcepts of some more inclusive concept or proposition, and this is known as (3) *superordinate* learning. For example, fishes, birds and mammals may be recognized all as types of *vertebrates* with bony backbones. Superordinate concepts are relatively few in number in any knowledge domain, so most learning in usually subsumptive learning. Superordinate learning normally contributes significantly to development of cognitive structure, and this characterizes the knowledge of experts (Chi, Feltovich, & Glaser, 1981; Novak & Iuli, 1995; Pendley, Bretz, & Novak, 1994). Finally, (4) *integrative reconciliation* may be required, or the form of meaningful learning where concepts or propositions in two somewhat different knowledge domains are seen as clearly similar and related, or clearly different and unrelated. Following along the lines of the above examples, when dolphins and sea lions are recognized as similar to and related to other mammals, and different from and not closely related to fishes, a form of integrative reconciliation occurs. Another example that often causes trouble in physics is the confusion of the meaning of *work* in everyday usage with the meaning of *work* in physics. A man holding up a heavy ceiling beam is doing no work in physics, but to the lay person he appears to be working very hard! These two meanings of work need to be reconciled by the physics student.

Because the meaning for any concept is framed by the set of propositions in which that concept is embedded, and also the stability and affective connotations of that set, the entire relevant cognitive framework for a given concept or proposition must undergo some restructuring. This may require repeated incidents of some or all of the above described forms of meaningful learning. The more elaborated and persistent LIPHs require more effort to remediate, and this may account for the tendency for younger students to correct LIPHs more quickly than older students (Sneider & Ohadi, 1998). It is no wonder, then, why misconceptions or LIPHs are so difficult to remediate with conventional instruction, and why some of these persist for the life of a person.

The above four cognitive processes all function in meaningful learning and play a role in the remediation of misconceptions. These cognitive processes are consistent with ideas described by Bransford and others in *How People Learn* (Bransford, Brown, & Cocking, 1999, pp. 163–170), although the latter book does not clearly identify a theory of learning or specific processes involved. In addition, Ausubel also described the instructional strategy of *advance organizers*, or preliminary learning tasks that help to activate relevant aspects of the learner's existing cognitive structure and guide their observation of specific aspects of relevant events or objects. Using advance organizers provide a kind of *scaffolding* or *coaching* that is recommended in *How People Learn* and other works. These scaffolding, coaching, or advance organizer tasks provide the opportunity for the learner to see new regularities in events or objects, or records of events or objects, and to recast the meanings for the concept words or symbols and to form new meaningful propositions with existing relevant elements of their cognitive structure. The principal difference in the view I am presenting here is that by building on Ausubelian learning theory and the derivative knowledge representation tool of concept maps, we can observe *explicitly* what concept and prepositional frameworks are being changed. Moreover, when concept maps are used to facilitate learning, they not only aid coaching and scaffolding student learning, they serve also as metacognitive tools (see below) improving student learning over time.

This is illustrated in the data shown in Figure 8 (from Basconas & Novak, 1985). In this study, students in high school classes using a traditional sequence of physics topics and textbook problems (the Traditional group) were compared on problem solving tests that required some transfer of knowledge to novel settings with students using concept maps and a topic sequence more congruent with Ausubelian principles (the Concept Mapping group). Raven's Progressive Matrices test of ability were given and students were divided into three ability groups base on these test scores. The data in Figure 8 show that, while the Concept Mapping group outperformed the traditional group at the end of the first study unit, the superiority of their performance increased continuously as the school year progressed. Figure 8 also shows that while there was some improvement in performance on unit tests over the school year for the traditional group, the improvement did not continue. Since ANOVA showed highly significant gains when Concept Mapping groups were compared with Traditional groups ($F = 480$) and a significant interaction between study units and methods ($F = 12.4$) it is reasonable to conclude that students in the Concept Mapping group were not only learning physics better, they were building metacognitive skills that further fostered the continuing improvement in achievement. Of interest too is that student ability as measured had no significant effect on problems solving scores, indicating that the Concept Mapping method was effective for all ability groups.

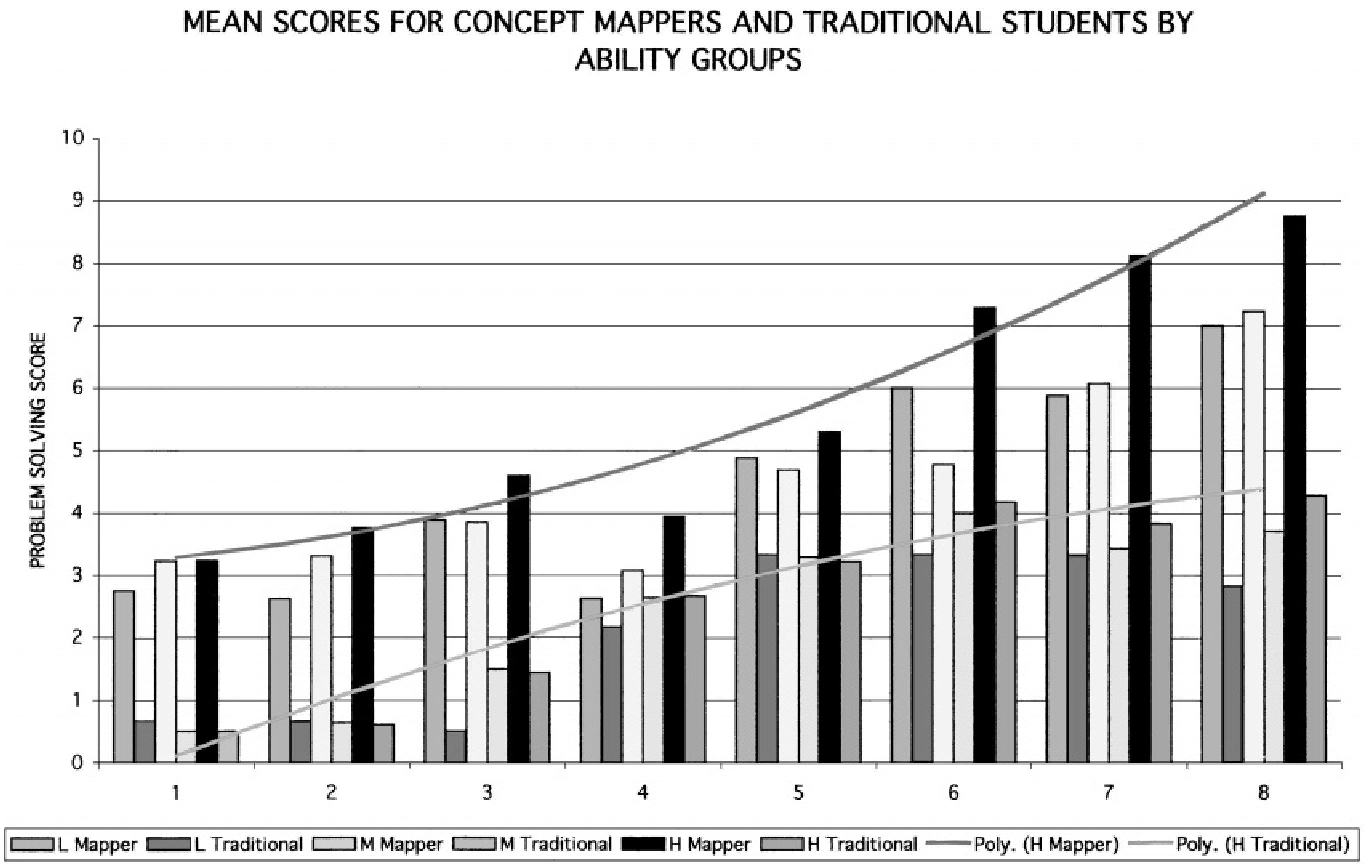

Figure 8. Results from a study with high school physics students showing that those groups that made concept maps and had a modified sequence of physics topics performed better than those groups that had tradition physics instruction on problem solving tests requiring trasfer of knowledge. The data also show that over the 8 study units of the school year, (1) the concept mapping students continued to improve, and (2) differences in ability as measured had little effect on achievement (data from Basconas & Novak, 1985).

HELPING STUDENTS TO LEARN MEANINGFULLY

For more than three decades, we have been developing ways to apply the concept map tool to help teachers help students "learn how to learn." For almost three decades we have also employed the Vee heuristic to help students and teachers understand better how to "unpack" knowledge in documents in biology (Waterman & Rissler, 1982) and mathematics (Fuata'i, 1998), and to construct knowledge (Novak, 1979; Novak & Gowin, 1984). Our research and the research of others have shown that these tools can be effective in facilitation of meaningful learning (Gonzales & Novak, 1993; Mintzes, Wandersee, & Novak, 1998; Mintzes, Wandersee, & Novak, 2000; Novak, 1990; Novak & Wandersee, 1990). These studies have shown that it is not easy to move science and mathematics instruction from the traditional approaches emphasizing rote memorization to patterns where meaningful learning predominates. The tools are no panacea or "magic bullet," but they can be effective. Concept maps are now appearing in many science books and Vee diagrams are beginning to appear. Mathematics instruction has moved much more slowly toward the use of cocept mapping and Vee heuristic tools, but they can be effective in this field as well (Fuata'i, 1985, 1998). Figure 9 shows a concept map prepared by a secondary school math student in Western Samoa. The real test of the effectiveness of these tools would require school settings where the tools are used in multiple subjects and for a succession of years, but to date I am not aware of any schools or colleges where this is being done. Indeed, it is a rare school where the overwhelming and explicit commitment of teachers and administrators is to meaningful learning. Most schools remain a mix of traditional rote learning activities and various efforts by enlightened teachers to emphasize meaningful learning.

CONCEPTUAL CHANGE

The issue of how individuals change their conceptual ideas has been much discussed in the past decade. Posner et al. (1982) proposed a theory of conceptual change that has been widely quoted. Instructional strategies and evaluation studies based on this theory have generally shown mixed success. This has led Strike and Posner (1992) to critique their original theory and to propose revisions. Their theory derives from epistemological foundations, especially the work of Kuhn (1970) and Toulmin (1972), drawing parallels from

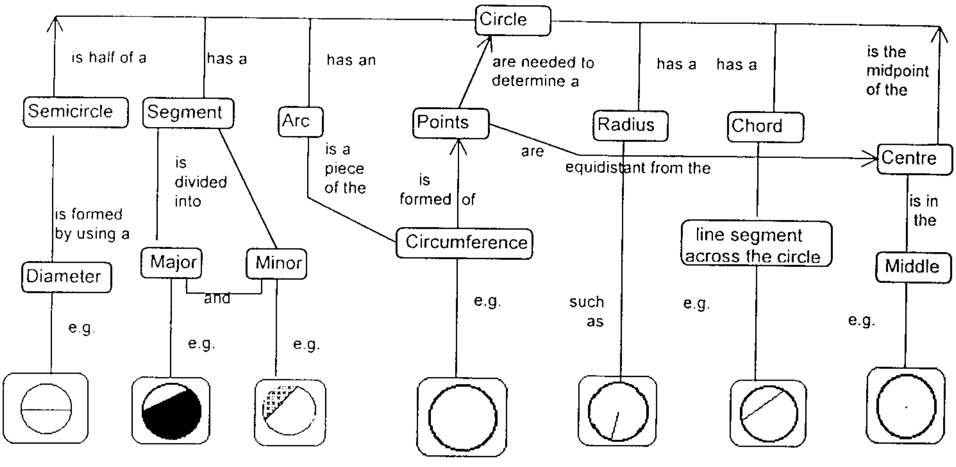

Figure 9. One of the best concept maps prepared by a student from the textbook section dealing with circles (from Fuata'i, 1998, p. 68).

conceptual (or paradigm) change to changes in an individual's "conceptual ecology." Chi (1994) has developed another model to explain problems in acquisition of valid concepts that emphasizes that a specific class of *constructs*, namely those that are invented by scientists and involve dynamic interactions of several underlying components. She sees "electrical current" and "evolution" as examples of these constructs.

From my perspective, the more fundamental issue is how an individual acquires knowledge and I see the epistemology of knowledge construction more parsimoniously explained by Ausubel's assimilation theory of learning, as described above (Novak, 1993b; 1998). Obviously, all knowledge constructed in a discipline is first constructed in some individual's cognitive structure. To understand how knowledge is constructed in any field, it is therefore essential to understand how individual human beings construct knowledge. To understand how an individual constructs his or her conceptual frameworks, we need to understand the psychology underlying human meaning making.

What becomes central to "conceptual change" from my perspective is the necessity for *meaningful learning* to occur. This is in principle a simple task, but in practice it may be profoundly difficult. When one is dealing with secondary or tertiary students who have had years of experience with science and mathematics instruction and evaluation that encourages rote memorization of definitions or problem-solving algorithms, it is not easy to get these students to reconsider and revise their learning to meaningful learning strategies. The learning processes that must occur were described in the previous sections. In fact, this task is typically so difficult that I believe the research evidence suggests the use of learning tools such as concept maps and Vee diagrams are *essential* to achieve high levels of meaningful learning by a high percentage of students. The fundamental challenge to "conceptual change teaching" is therefore to help learner's understand how they must choose to modify their concept and propositional hierarchies and to provide instruction that is "conceptually transparent" to the learners (Novak, 1992). Changing their "conceptual ecology" requires that the learner recognize explicit ways where their concept/propositional frameworks are limited, inappropriate or poorly organized into hierarchies. When this is done, a few learning episodes, using concept maps prepared by the learner, can result in restructuring of a student's LIPH's and stable alteration of the conceptual framework (Feldsine, 1983; Marin, Mintzes, & Clavin, 2000; Pearsall, Skipper, & Mintzes, 1997). Reconstruction of LIPH's requires negotiation of meanings between students and teachers. It is a social as well as a personal reconstruction process.

In our 12-year longitudinal study of concept development, we observed cases (e.g., Paul in Figure 6) where enormous improvements occurred in the student's understanding of the particulate nature of matter, and other cases (e.g., Martha in Figure 5) where from grade 2 to grade 12, an increased number of LIPHs was evidenced even though the students took similar numbers of subsequent science courses and obtained similar grades. Based on the nature of Paul's responses to the interviews, he was obviously committed to meaningful learning in science, whereas Martha was obviously a rote learner, memorizing as best she could and recalling bits and pieces of knowledge, but not forming a well-organized conceptual framework. Notice how she added the concept of *dissolve* to her knowledge structure, but it was not properly integrated with other related concepts. She also now thinks that matter is made of something else besides molecules, probably confusing atoms and not integrating this concept with molecules. Furthermore, she thinks molecules expand with heat and become bigger and lighter. Her failure meaningfully to integrate new concepts presented in her science classes with her earlier knowledge has resulted in more misconceptions or LIPH's than she had in grade two, and no greater over-all cognitive complexity.

The long-term impact on learning science when high quality, audio-tutorial, science lessons were provided in only grades one and two was remarkable (Novak & Musonda, 1991). Figure 10 shows the differences in valid and invalid conceptions evidenced in interviews over the span of school years for those students who engaged in the audio-tutorial lessons in grades one and two (experimental or Instructed group) compared with those who had only ordinary school science experiences (the control or uninstructed group). These kinds of data suggest a very optimistic picture regarding the potential effectiveness of science instruction when deliberate and explicit efforts are made to provide instruction that has clear and explicit linkage between the events students are manipulating and observing and instruction in the conceptual ideas necessary to construct the concept and propositional hierarchies necessary for valid scientific understanding of these events. Schmittau (1994) has shown that similar results can be obtained in mathematics.

In recent years, the Private Universe Project (PUP, 1989), based at Harvard University, has prepared a number of video tapes showing how graduates of Harvard, MIT, and other leading institutions have many of the same science misconceptions observed with children. The powerful videotape created earlier by PUP, showing 21 out of 23 Harvard graduates, alumni and faculty could not explain why we have seasons, has already been seen by thousands of teachers and lay persons, illustrating the failure of most current science instruction, even with Harvard graduates. The new videotapes developed by the PUP also contribute to an

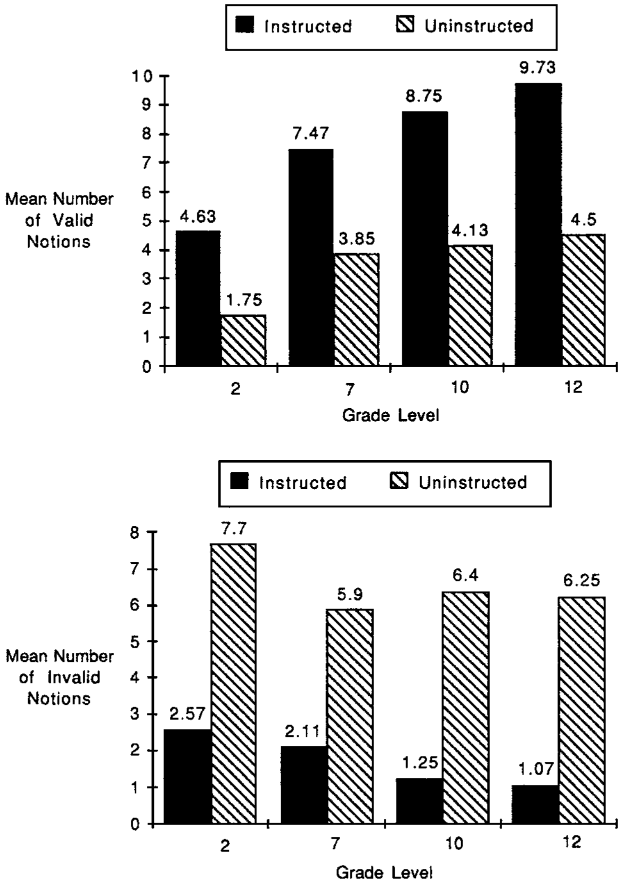

Figure 10. Students receiving audio-tutorial instruction in basic science concepts in grade 1 and 2 (ages 6–8), show more valid notions and fewer invalid notions throughout their school years, compared with students who did not receive this early instruction (see Novak & Musonda, 1991; Novak, 1998, Figure 7.8).

awareness of the conceptual problems that arise as a result of ineffective science education. In interviews with MIT graduates, they found that none of the 21 students interviewed knew that most of the weight of an oak log came from carbon dioxide in the air, and they later evidenced skepticism when they were told that this is the case. Their answers were similar to those given by fourth grade students. Macbeth (2000) has challenged the interpretations given in some of the PUP videotapes, but acknowledges their professional preparation and their value for elicitation of student conceptions.

Working with a skillful 7th grade science teacher, PUP staff interviewed Jon before and after a 2-week instructional unit on photosynthesis that included several experiments and much class discussion. Figure 11 shows two concept maps drawn from interviews with Jon before and after instruction on photosynthesis. In spite of the fact that Jon learned that carbon dioxide was used in photosynthesis, he failed to understand that this was the major source of the weight in an oak log. Although Jon's relevant knowledge structure increased in size and complexity, his original misconception that the weight came from water and minerals in the soil persisted. Jon knew that carbon dioxide was part of air, but he continued to believe that air has no weight, and hence would not account for the weight of the log. This

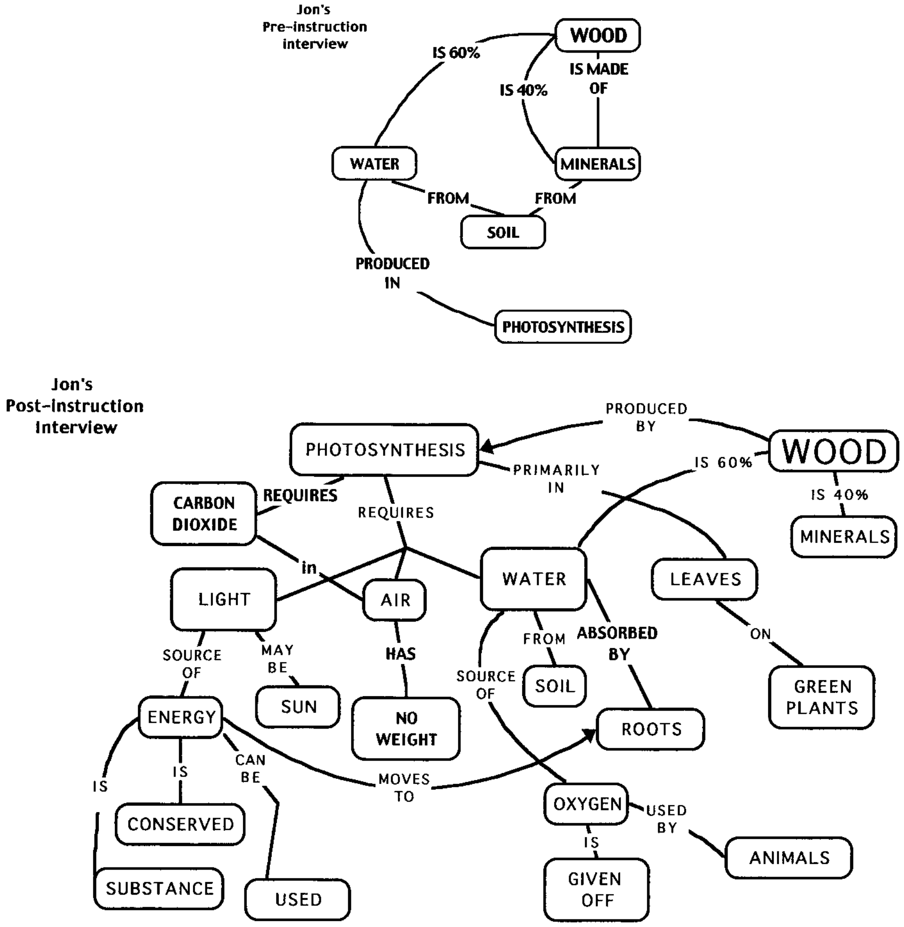

Figure 11. Concept map drawn from interviews with Jon before and after instruction on photosynthesis in 7th grade science. Note that even after instruction, he still believes most of the weight of wood comes from the soil minerals and from water, not from the carbon dioxide in air, which he thinks has no weight.

faulty conception was not remediated under standard instruction with a very good teacher and considerable "hands on" experience in the study unit. The interviews suggested that Jon was oriented toward meaningful learning, but this was not sufficient to correct his faulty conceptions. In a longitudinal study of students following them from junior high school to high school, Hellden (2001) and Shymanski et al. (1997) have found similar persisting misconceptions.

METACOGNITIVE LEARNING

Psychologists and educators have recognized for many years that in addition to learning subject matter knowledge, learners can also acquire knowledge about learning or the nature of knowledge. Flavel (1973) coined the term *metacognition* to label learning about learning, for example, learning to plan, monitor success, correct errors, recognize unsuccessful problem approaches, etc. DiSessa (2001) describes meta-representation as a kind of metacognitive learning, where learners gain facility in representing knowledge in new forms, leading to new insights. Using his software, Boxer, students have been successful in inventing graphic representations, and many forms of multivisual examples of knowledge representation. The Boxer software facilitates this kind of learning, and DiSessa shows that elementary school and older learners can be highly successful in acquire skill in using the software and in meta-representation.

In our work, we also see metaknowledge learning as a form of metacognition, where learners acquire and understanding of the nature of concepts and concept formation and the processes of knowledge creation. Concept maps and the Vee heuristic when understood and mastered illustrate powerful metaknowledge tools as well as metacognitive tools (Novak, 1985; 1990). In general, most psychology books do not deal with metaknowledge learning, because they fail to recognize the important relationship between epistemological foundations and psychological foundations for construction of meanings. It is common to see psychologist espouse a contructivist view of learning and yet manifest epistemological ideas that are inherently positivistic in nature. Von Glasersfeld (1984) labeled such persons *trivial* constuctivists in contrast to *radical* constructivists that recognize both the psychological process by which each individual creates her/his own meanings, and also the epistemological process where new concepts in a discipline are constructed, subject to all the human frailties we see in concept and propositional learning. The very human nature of knowledge construction could be a powerful metacognitive understanding, but this seldom plays an important role in school leaerning (Novak, 1993b). As tools to facilitate remediation of misconceptions, metacognitive and metaknowledge tools should play an important role.

THE PROMISE OF NEW TECHNOLOGY

When we first began making concept maps in the early 1970's, our only available technology was paper and pens. Though this was at times tedious, it nevertheless allowed us to refine methods for using this tool both in research and in teaching. Later Minnesota Mining and Manufacturing corporation's "Post-Its" helped in that they allowed us to place concepts and/or linking words on Post-Its and to move these around relatively easily as maps were structured and refined. We still use Post-Its in group or individual work when other technology is not available, or for simple ease of use. However, we now have very good computer software to use for map construction and also some beta stage software for sharing maps and propositions in maps. This software was developed the Institute for Human and Machine Cognition (IHMC) at the University of West Florida and can be downloaded free for nonprofit use at http://cmap.coginst.uwf.edu.

Figure 12 shows a concept map we have done in cooperation with NASA-Ames Research Center utilizing the IHMC software. Note that this map contains icons that can be clicked to obtain other resources including subconcept maps giving greater details. Figure 13 shows a subconcept map for Space Missions, which in turn has icons for other resources such as texts, photos, videos, URL's, or any other resources that can be stored or transmitted electronically. These concept maps are used as the indexing structure for a new CD-ROM released by NASA (available at http://cmex.arc.nasa.gov/CMEX/index). Excellent free software for making concept maps is available at www.coginst.uwf.edu. The NASA CD may help to show how learning tools can be incorporated into instructional materials to facilitate meaningful learning. Also illustrated by the CD is what could be done by teams of students who work collaboratively to build concept maps for topics of study or research projects, and gradually populate these concept maps with a wide range of pertinent resources. Using Cmap software with its associated tools for collaborative learning, students can work with colleagues in the same classroom or anywhere in the world (Canas et al., 2001).

The IHMC had previously developed software that allows students to share propositions in their concept maps using an electronic "knowledge soup." Once a student submits one or more propositions to the "soup," she/he can see all related propositions in the soup and may choose to add some of these to her/his concept maps. The propositions remain anonymous, but they can be challenged by any student, leading to a lively dialog about the validity of a whole family of related propositions on any subject matter. The software was used successfully in seven Latin American countries, and many of the schools in the original project continue to use the software. New, improved software for concept mapping is now available, and an improved "knowledge soup" software should be available soon from IHMC. These tools are ideally suited to distance education programs. Such programs are now growing exponentially and will probably become the dominant mode of adult education in the future. This is especially true for programs produced by for profit corporations, and I would not be surprised to see such programs become the dominant mode of instruction for college education. Increasingly, we are likely to see such programs prevalent in public and private schools as well.

Many other educators point to the need to increase our use of technology. Linn and Hsi (1999) describe the use of computers as "learning partners," and illustrate the kind of learning successes that can accrue when students, teachers, and computers are integrated into collaborative efforts to learn better. DiSessa (2001) and his associates have developed a computer software called "Boxer" that provides and his colleagues have developed a software that permits easy construction of knowledge representation in the form of boxes embedded in boxes. Almost any kind of learning resource can be included in the boxes by students. In this respect, Boxer is somewhat like CMap, except the latter provides for a highly explicit concept and prepositional framework, arranged higherarchially. This allows a kind of "auto-coaching" as students work with CMap to build their own knowledge structures.

We all have experienced the ego assault that comes with the recognition that we cannot grasp the meaning of some idea or illustration. This kind of disempowerment now occurs too often when students move from classroom to real world problem settings. The tragedy is that it occurs not because of innate limitations in intelligence or perseverance, but most often from educational failure that might be prevented or at least ameliorated. We now know how to help students "learn how to learn," and to empower them to be better and better learners, and more confident and committed contributors to society. The challenge is to change the educational institutions that continue to dwell on rote mode learning and assessment that reinforces such learning, and fail to help learners build powerful cognitive structures.

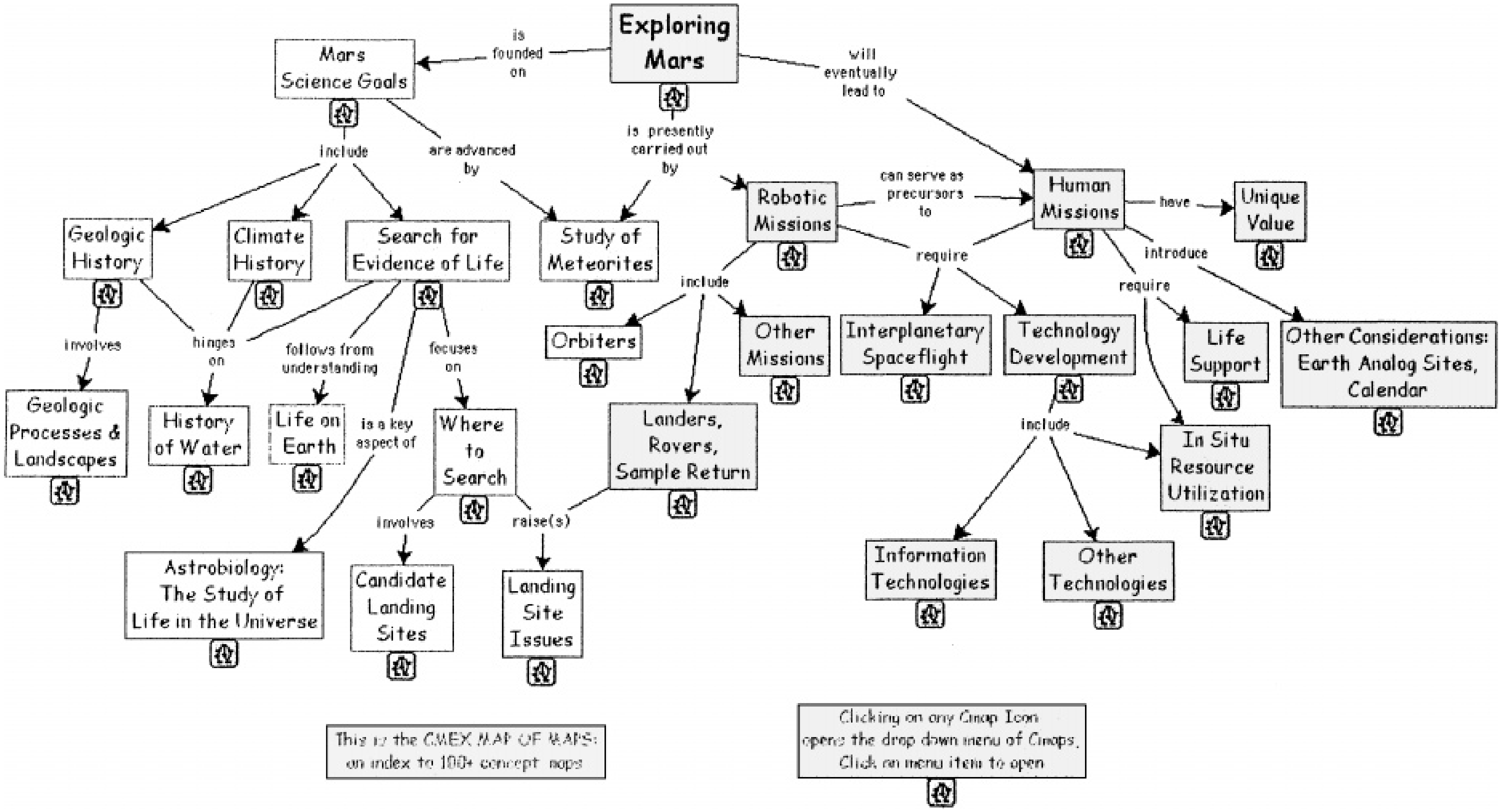

Figure 12. A concept map used to route users through the new CD-ROM on Mars 2000. This is the "home page" that not only shows and overview of the content of the CD but also shows how concepts presented are related. The icons on the bottom of concepts can be clicked to access other information, including subordinate concept maps, such as shown in Figure 13.

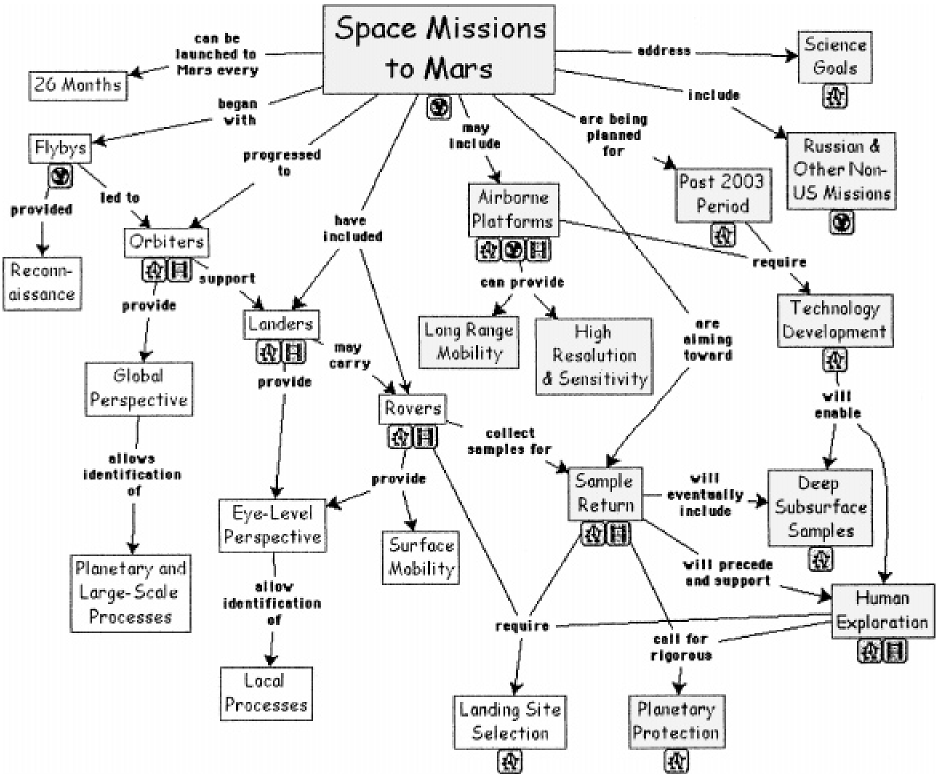

Figure 13. A subordinate map that can be accessed from the map in Figure 12. The icons on the bottom of concepts can be clicked to access other information, including further subordinate concept maps, text, photos, videos, and URL's.

There is also coming on line now new devices that permit high speed data transfer over conventional phone lines at very low cost. We are currently planning projects that will make the IHMC software available to students and teachers in large geographic areas, creating the possibility for knowledge sharing by students and teachers in any disciplines, both in individual classrooms and over large geographic areas.

The enormous advantages of using software and Internet access to knowledge at almost no cost to the users can fuel the kind of dramatic educational change that has never been possible before. It could also be feasible for third world countries that could never afford the kind of expensive, but limited in effectiveness, educational practices we now see dominant in the developed countries. As we move forward in this twenty-first century, we may finally begin to see the promise of technology, so long little more than a dream, slowly but surely becoming a reality.

It may be audacious to say this, but I think we know in principle *why* learning in sciences and mathematics is so ineffectual for most students and how to remediate this problem. What we lack is the commitment, resources, and the political strategies to change schooling in the direction that requires uncompromising commitment to meaningful learning for all students in all subjects. It is difficult to see this happening soon in the United States, with some 15,000 independent school districts. Perhaps a smaller country with strong leadership from their Ministry of Education (see for example Ministry of Education and Science, 1989) will be the first to mobilize their political and educational resources to effect the changes needed to achieve meaningful learning for all students at all ages.

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