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The Theory Underlying Concept Maps and How To Construct Them

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Concept maps are tools for organizing and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts or propositions, indicated by a connecting line between two concepts. Words on the line specify the relationship between the two concepts. We define *concept as a perceived regularity in events or objects, or records of events or objects, designated by a label.* The label for most concepts is a word, although sometimes we use symbols such as + or %. *Propositions are statements about some object or event in the universe, either naturally occurring or constructed. Propositions contain two or more concepts connected with other words to form a meaningful statement.* Sometimes these are called semantic units,or units of meaning. Figure 1 shows an example of a concept map that describes the structure of concept maps and illustrates the above characteristics.

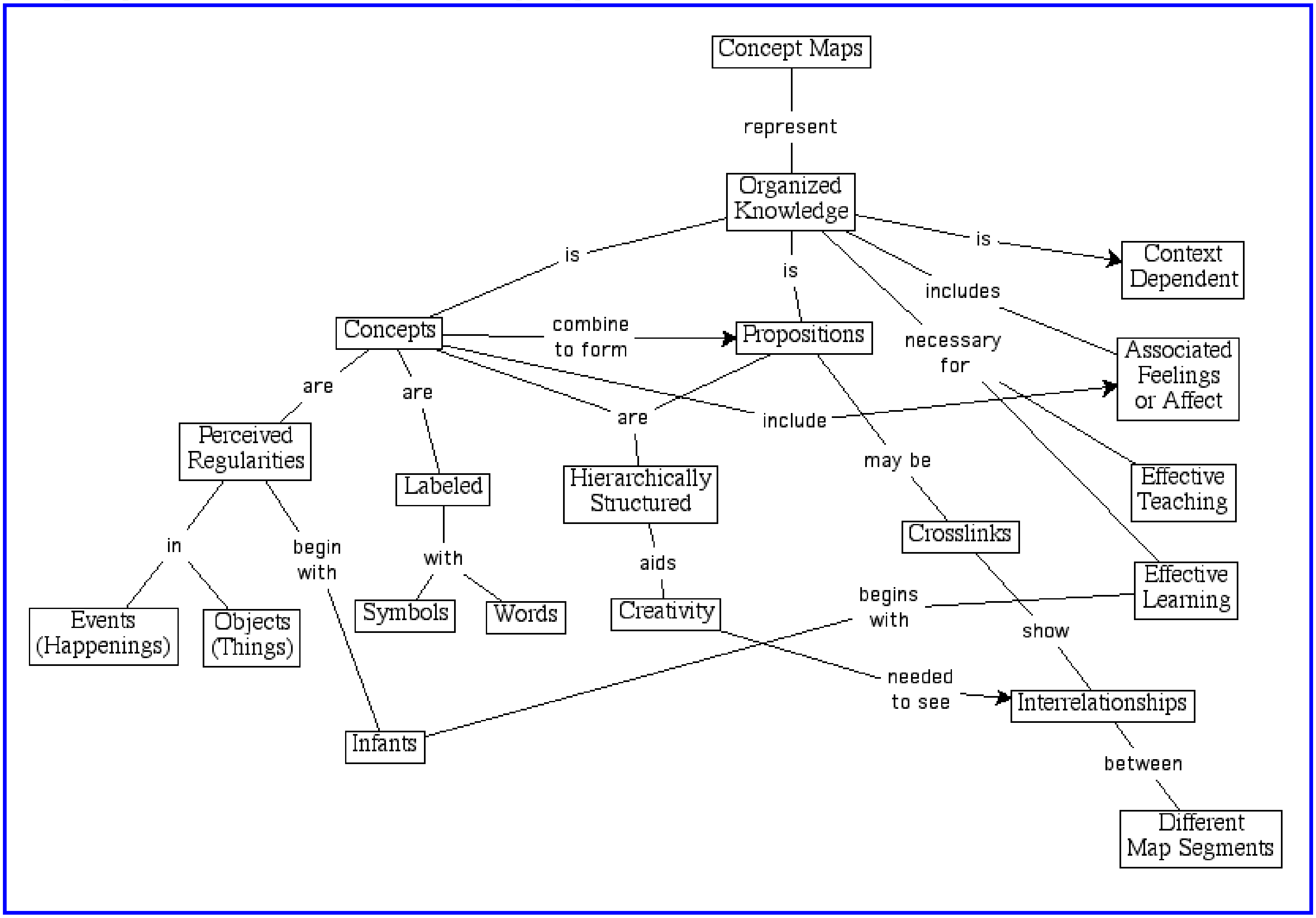

Figure 1

Another characteristic of concept maps is that the concepts are represented in a hierarchical fashion with the most inclusive, most general concepts at the top of the map and the more specific, less general concepts arranged hierarchically below. The hierarchical structure for a particular domain of knowledge also depends on the context in which that knowledge is being applied or considered. Therefore, it is best to construct concept maps with reference to some particular question we seek to answer or some situation or event that we are trying to understand through the organization of knowledge in the form of a concept map.

Another important characteristic of concept maps is the inclusion of "cross-links." These are relationships (propositions) between concepts in different domains of the concept map. Cross-links help us to see how some domains of knowledge represented on the map are related to each other.Inthe creation of new knowledge, cross-links often represent creative leaps on the part of the knowledge producer. There are two features of concept maps that are important in the facilitation of creative thinking: the hierarchical structure that is represented in a good map and the ability to search for and characterize cross-links.A final features that may be added to concept maps are specific examples of events or objects that help to clarify the meaning of a given concept.

Concept maps were developed in the course of our research program where we sought to follow and understand changes in childrenÕs know ledge of science. This program was based on the learning psychology of David Ausubel (1963, 1968, 1978). The fundamental idea in Ausubel's cognitive psychology is that learning takes place by the assimilation of new concepts and propositions into existing concept propositional frameworks held by the learner. The question sometimes arises as to the origin of the first concepts; these are acquired by children during the ages of birth to three years, when they recognize regularities in the world around them and begin to identify language labels or symbols for these regularities (Macnamara, 1982). This is a phenomenal ability that is part of the evolutionary heritage of all normal human beings. After age 3, new concept and propositional learning is mediated heavily by language, and takes place primarily by a **reception learning** process where new meanings are obtained by asking questions and getting clarification of relationships between old concepts and propositions and new concepts and propositions. This acquisition is mediated in a very important way when concrete experiences or props are available; hence the importance of "hands-on" activity for science learning with young children, but this is also true with learners of any age and in any subject matter domain. In addition to the distinction between the discovery learning process, where the attributes of concepts are identified autonomously by the learner, and the reception learning process, where attributes of concepts are described using language and transmitted to the learner, Ausubel made the very important distinction between rote learning and meaningful learning. Meaningful learning requires three conditions:

- The material to be learned must be conceptually clear and presented with language and examples relatable to the learner's prior knowledge. Concept maps can be helpful to meet this condition, both by identifying large general concepts prior to instruction in more specific concepts, and by assisting in the sequencing of learning tasks though progressively more explicit knowledge that can be anchored into developing conceptual frameworks.
- The learner must possess relevant prior knowledge. This condition is easily met after age 3 for virtually any domain of subject matter, but it is necessary to be careful and explicit in building concept frameworks if one hopes to present detailed specific knowledge in any field in subsequent lessons. We see, therefore, that conditions (1) and (2) are interrelated and both are important.
- The learner must choose to learn meaningfully. The one condition over which the teacher or mentor has only indirect control is the motivation of students to choose to learn by attempting to incorporate new meanings into their prior knowledge, rather than simply memorizing concept definitions or propositional statements or computational procedures. The control over this choice is primarily in the evaluation strategies used, and typical objective tests seldom require more than rote learning (Holden, 1992). In fact, the worst forms of objective tests, or short-answers tests, require verbatim recall of statements and this may be impeded by meaningful learning where new knowledge is assimilated into existing frameworks, making it difficult to recall specific, verbatim definitions or descriptions. This kind of problem was recognized years ago in Hoffman's (1962), *The Tyranny of Testing*.

One of the powerful uses of concept maps is not only as a learning tool but also as an evaluation tool, thus encouraging students to use meaningful-mode learning patterns (Novak & Gowin, 1984; Novak, 1990, Mintzes, Wandersee and Novak, 2000). Concept maps are also effective in identifying both valid and invalid ideas held by students. They can be as effective as more time-consuming clinical interviews (Edwards & Fraser, 1983).

Another important advance in our understanding of learning is that the human memory is not a single "vessel" to be filled, but rather a complex set of interrelated memory systems. Figure 2 illustrates the three memory systems of the human mind.

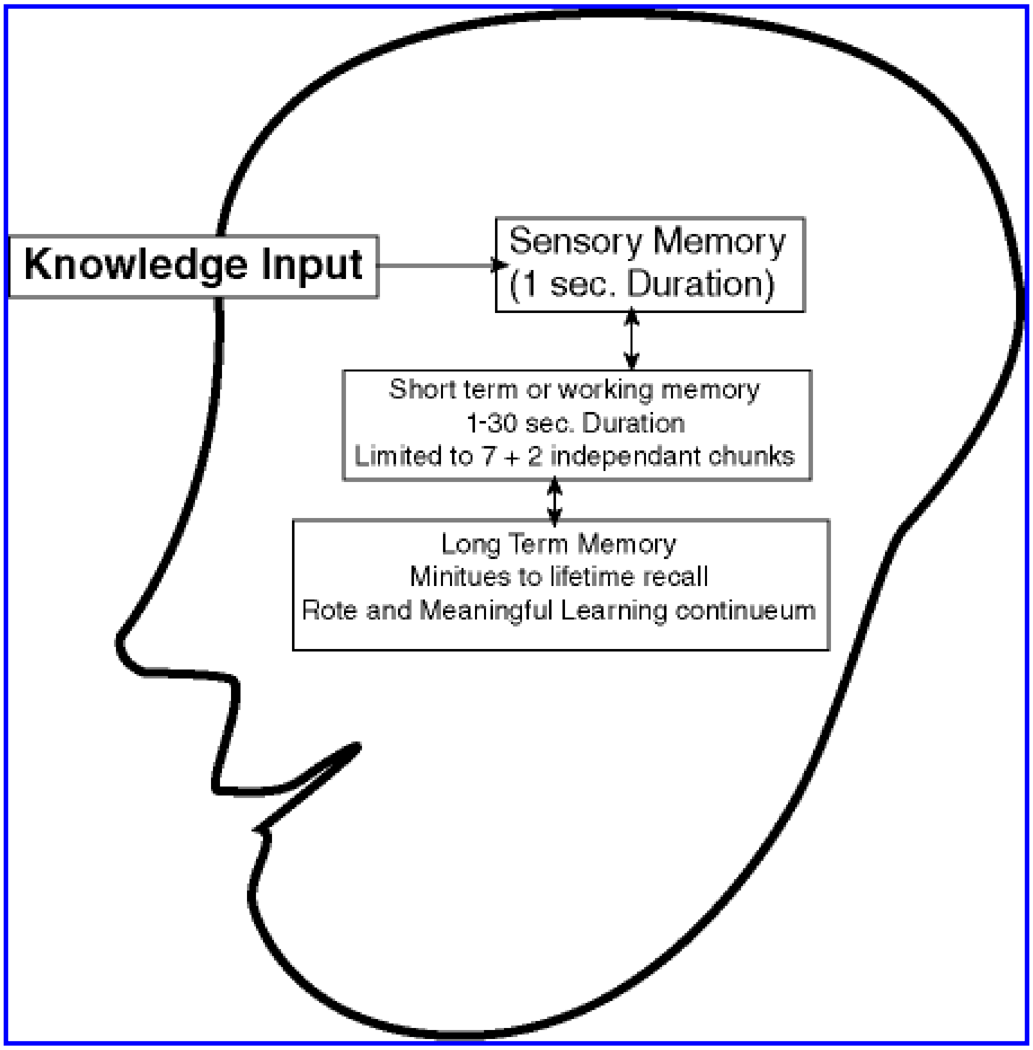

Figure 2

While all memory systems are interdependent (and have information going in both directions), the most critical memory system for incorporating knowledge into long-term memory is the short-term or "working memory." All incoming information is organized and processed in the working memory by interaction with knowledge in long-term memory. The limiting feature here is that working memory can process only a relatively small number (five to nine) of psychological units at any one moment. This means that relationships among two or three concepts are about the limit of working memory processing capacity. Therefore, to structure large bodies of knowledge requires an orderly sequence of iterations between working memory and long-term memory as new knowledge is being received (Anderson, 1991). We believe one of the reasons concept mapping is so powerful for the facilitation of meaningful learning is that it serves as a kind of template to help to organize knowledge and to structure it, even though the structure must be built up piece by piece with small units of interacting concept and propositional frameworks. Many learners and teachers are surprised to see how this simple tool facilitates meaningful learning and the creation of powerful knowledge frameworks that not only permit utilization of the knowledge in new contexts, but also retention of the knowledge for long periods of time (Novak, 1990; Novak & Wandersee, 1991). There is still relatively little known about memory processes and how knowledge finally gets incorporated into our brain, but it seems evident from diverse sources of research that our brain works to organize knowledge in hierarchical frameworks and that learning approaches that facilitate this process significantly enhance the learning capability of all learners.

While it is true that some students have more difficulty building concept maps and using these, at least early in their experience, this appears to result primarily from years of rote-mode learning practice in school settings rather than as a result of brain structure differences per se. Socalled "learning style" differences are, to a large extent, differences in the patterns of learning that students have employed varying from high commitment to continuous rote-mode learning to almost exclusive commitment to meaningful mode learning. It is not easy to help students in the former condition move to patterns of learning of the latter type. While concept maps can help, students also need to be taught something about brain mechanisms and knowledge organization,and this instruction should accompany the use of concept maps.

Epistemological Foundations

As indicated earlier, we defined concepts as perceived regularities in events or objects, or records of events or objects, designated by labels. What is coming to be generally recognized now is that the meaningful learning processes described above are the same processes used by scientists and mathematicians to construct new knowledge. In fact, I have argued that knowledge construction is nothing other than a relatively high level of meaningful learning (Novak, 1977; Novak, 1988).

As defined above, conepts and propositons are the building blocks for knowledge in any domain. We can use the analogy that concepts are like the atoms of matter and propositions are like the molecules of matter. There are now about 460,000 words in the English language, and these can be comibined to form an infinite number of propositions; albeit most combinations of words might be nonsense, there is still the possibility of creating an infinite number of valid propositions. We shall never run out of opportunities to create new knowledge! As people create and observe new or exisiting objects or events, the creative people will continue to create new knowledge.

While there is value in studying more extensively with the process of knowledge construction, and the nature of knowledge, this is beyond the scope of this document.

Constructing Good Concept Maps

In learning to construct a concept map, it is important to begin with a domain of knowledge that is very familiar to the person constructing the map. Since concept map structures are dependent on the context in which they will be used, it is best to identify a segment of a text, a laboratory activity, or a particular problem or question that one is trying to understand. This creates a context that will help to determine the hierarchical structure of the concept map. It is also helpful to select a limited domain of knowledge for the first concept maps.

Once a domain has been selected, the next step is to identify the key concepts that apply to this domain. These could be listed, and then from this list a rank order should be established from the most general, most inclusive concept, for this particular problem or situation, to the most specific, least general concept. Although this rank order may be only approximate, it helps to begin the process of map construction.

The next step is to construct a preliminary concept map. This can be done by writing all of the concepts on Post-its, or preferably by using this computer software program. Post-its allow a group to work on a whiteboard or butcher paper and to move concepts around easily This is necessary as one begins to struggle with the process of building a good hierarchical organization. Computer software programs are even better in that they allow moving of concepts together with linking statements and also the moving of groups of concepts and links to restructure the map. They also permit a computer printout, producing a nice product that can be e-mailed or in other ways easily shared with collaborators or pother interested parties.

Figure 3 shows a list of concepts for making a concept map to address the question, "What is a plant?" What is shown is only one of many possible maps. Simple as this map is, it may contain some propositions that are new to the reader.

It is important to recognize that a concept map is never finished. After a preliminary map is constructed, it is always necessary to revise this map. Good maps usually undergo three to many revisions. This is one reason why computer software is helpful.

After a preliminary map is constructed, cross-links should be sought. These are links between different domains of knowledge on the map that help to illustrate how these domains are related to one another. Finally, the map should be revised, concepts positioned in ways that lend to clarity, and a "final" map prepared.

When computer software is used, one can go back and change the size and font style to "dress up" the concept map.

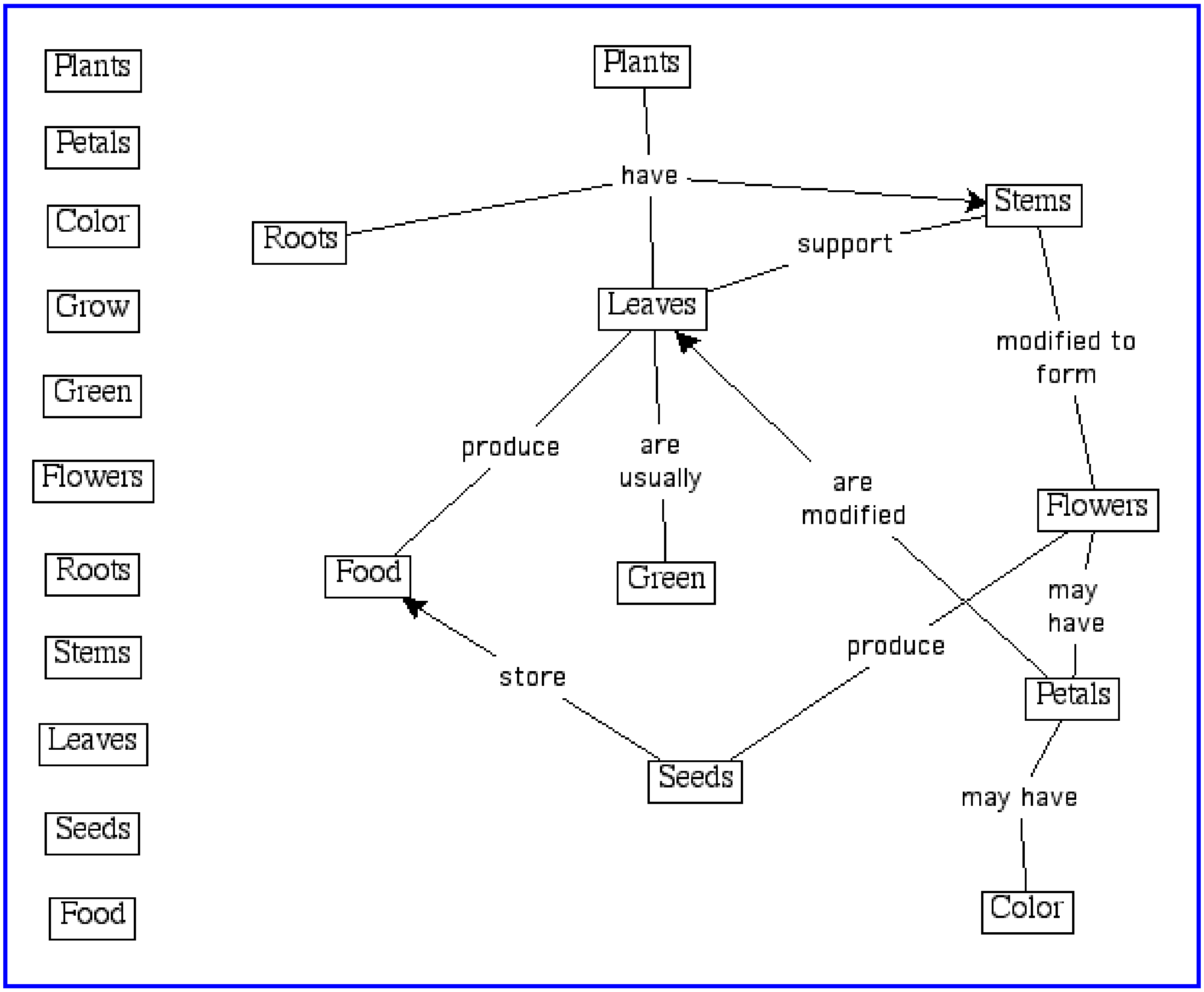

Figure 3

It is important to help students recognize that all concepts are in some way related to one another. Therefore, it is necessary to be selective in identifying cross-links, and to be as precise as possible in identifying linking words that connect concepts. In addition, one should avoid "sentences in the boxes" since this usually indicates that a whole subsection of the map could be constructed from the statement in the box. "String maps" illustrate either poor understanding of the material or an inadequate restructuring of the map. Figure 4 shows an example of a string map.

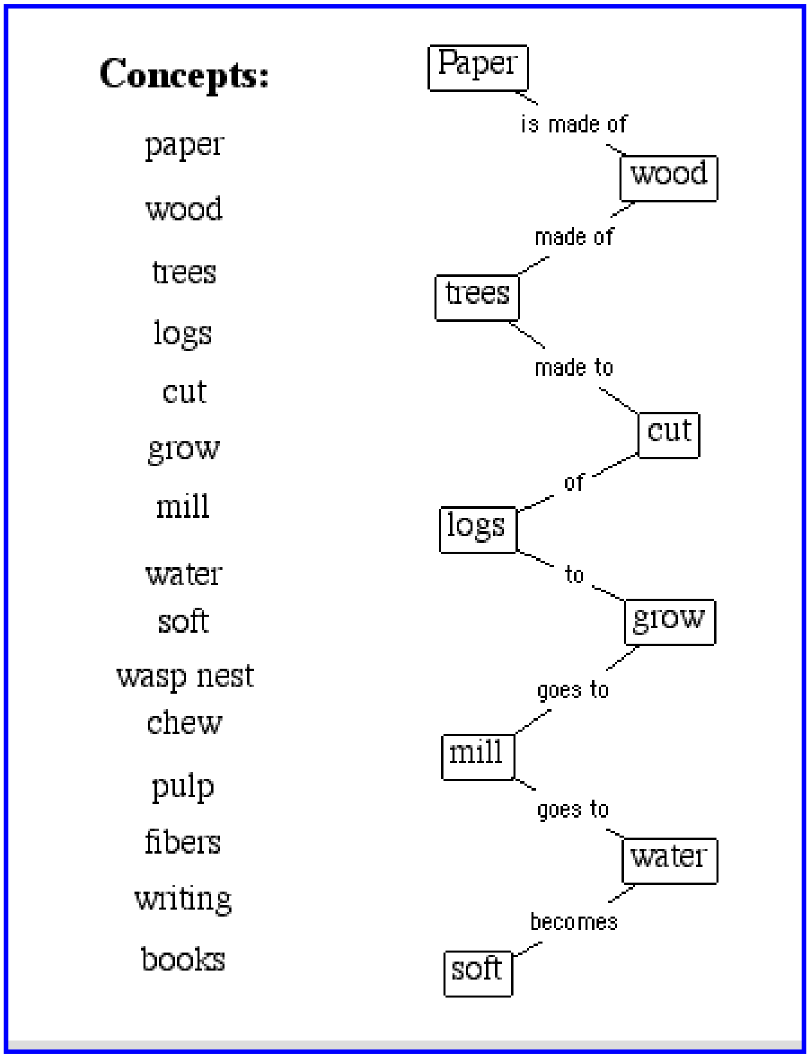

Figure 4

Students often comment that it is hard to add linking words onto their concept map. This is because they only poorly understand the relationship between the concepts and it is the linking words that specify this relationship. Once students begin to focus in on good linking words, and also identification of good cross-links, they can see that every concept could be related to every other concept. This also produces some frustration, and they must choose to identify the most prominent and most useful cross-links. This process involves what Bloom (1956) identified as high levels of cognitive performance, namely evaluation and synthesis of knowledge. Concept mapping is an easy way to achieve very high levels of cognitive performance, when the process is done well. This is one reason concept mapping can be a very powerful evaluation tool.

Macro and Micro Concept Maps

In curriculum planning, concept maps can be enormously useful. They present in a highly concise manner the key concepts and principles to be taught. The hierarchical organization of concept maps suggests more optimal sequencing of instructional material. Since the fundamental characteristic of meaningful learning is integration of new knowledge with the learners' previous concept and propositional frameworks, proceeding from the more general, more inclusive concepts to the more specific information usually serves to encourage and enhance meaningful learning. Thus, in curriculum planning, we need to construct a global "macro map" showing the major ideas we plan to present in the whole course, or in a whole curriculum, and also more specific "micro maps" to show the knowledge structure for a very specific segment of the instructional program. Figure 5 shows a macro map constructed for this CD-ROM and gives a "global view" of all the content of the CD. Figure 6 shows a "micro map" map expanding on ideas for which the concept "Human Exploration" is shown in the "macro map". In turn, one could click on the map icons in figure 6 and see further detailed knowledge about MARS.

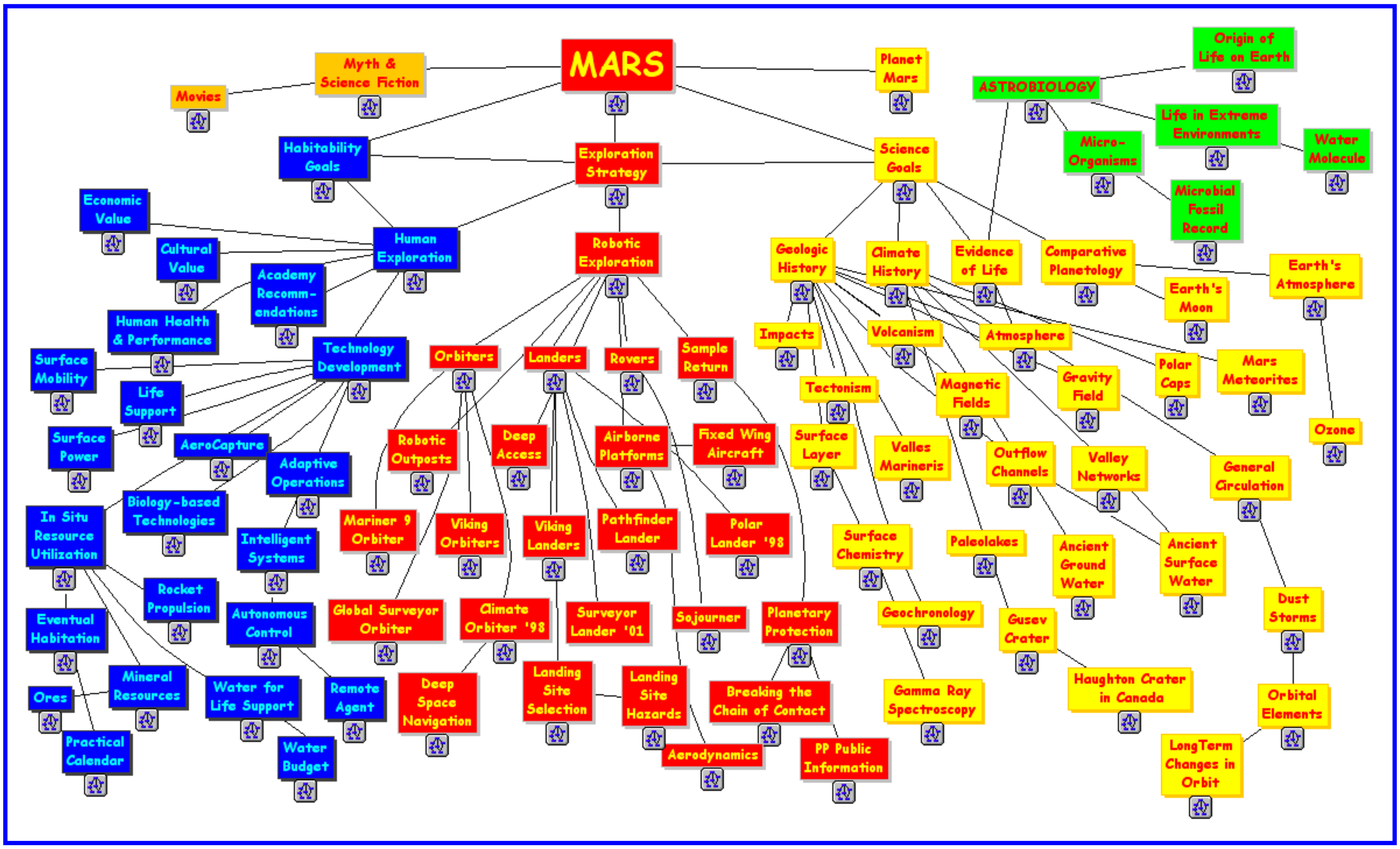

Figure 5

Using concept maps in planning a curriculum or instruction on a specific topic helps to make the instruction "conceptually transparent" to students. Many students have difficulty identifying and constructing powerful concept and propositional frameworks, leading them to see science learning as a blur of myriad facts or equations to be memorized. If concept maps are used in planning instruction and students are required to construct concept maps as they are learning, previously unsuccessful students can become successful in making sense out of science and acquiring a feeling of control over the subject matter (Bascones & Novak, 1985; Novak, 1991; Novak, 1998).

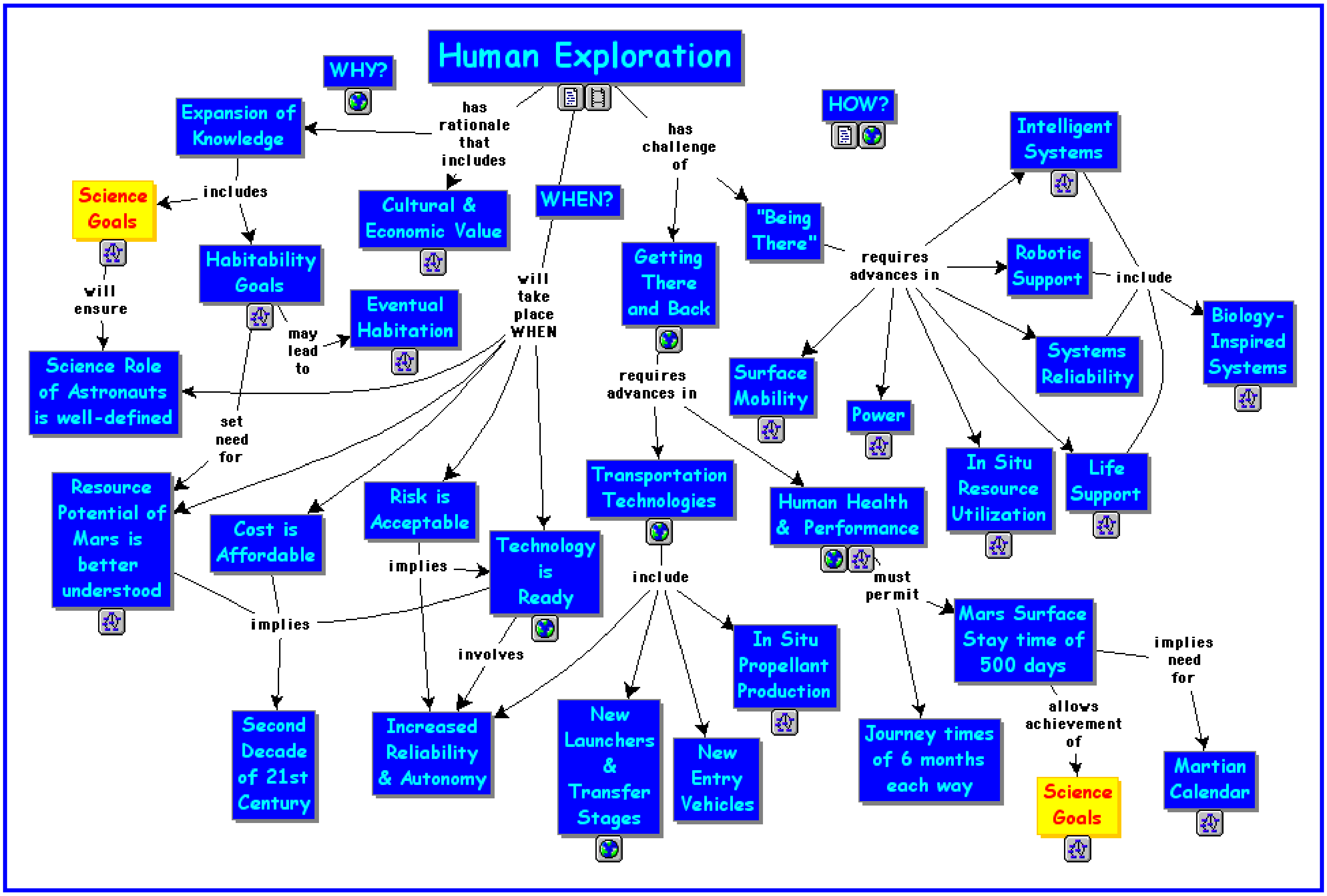

Figure 6

Facilitating Cooperative Learning

There is a growing body of research that shows that when students work in small groups and cooperate in striving to learn subject matter, positive cognitive and affective outcomes result (Johnson et al., 1981). In our work with both teachers and students, small groups working cooperatively to construct concept maps have proven to be useful in many contexts. For example, the concept maps shown in Figure 7 was constructed by faculty working together to plan instruction in veterinary medicine at Cornell University. In my own classes, and in classes taught by my students, small groups of students working collectively to construct concept maps can produce some remarkably good maps. In a variety of educational settings, concept mapping in small groups has served us well in tasks as diverse as understanding ideas in assimilation theory to clarifying job conflicts for conflict resolution in profit and non-profit corporations. Concept maps are now beginning to be used in corporations to help teams clarify and articulate the knowledge needed to solve problems ranging from the design of new products to marketing to administrative problem resolution.

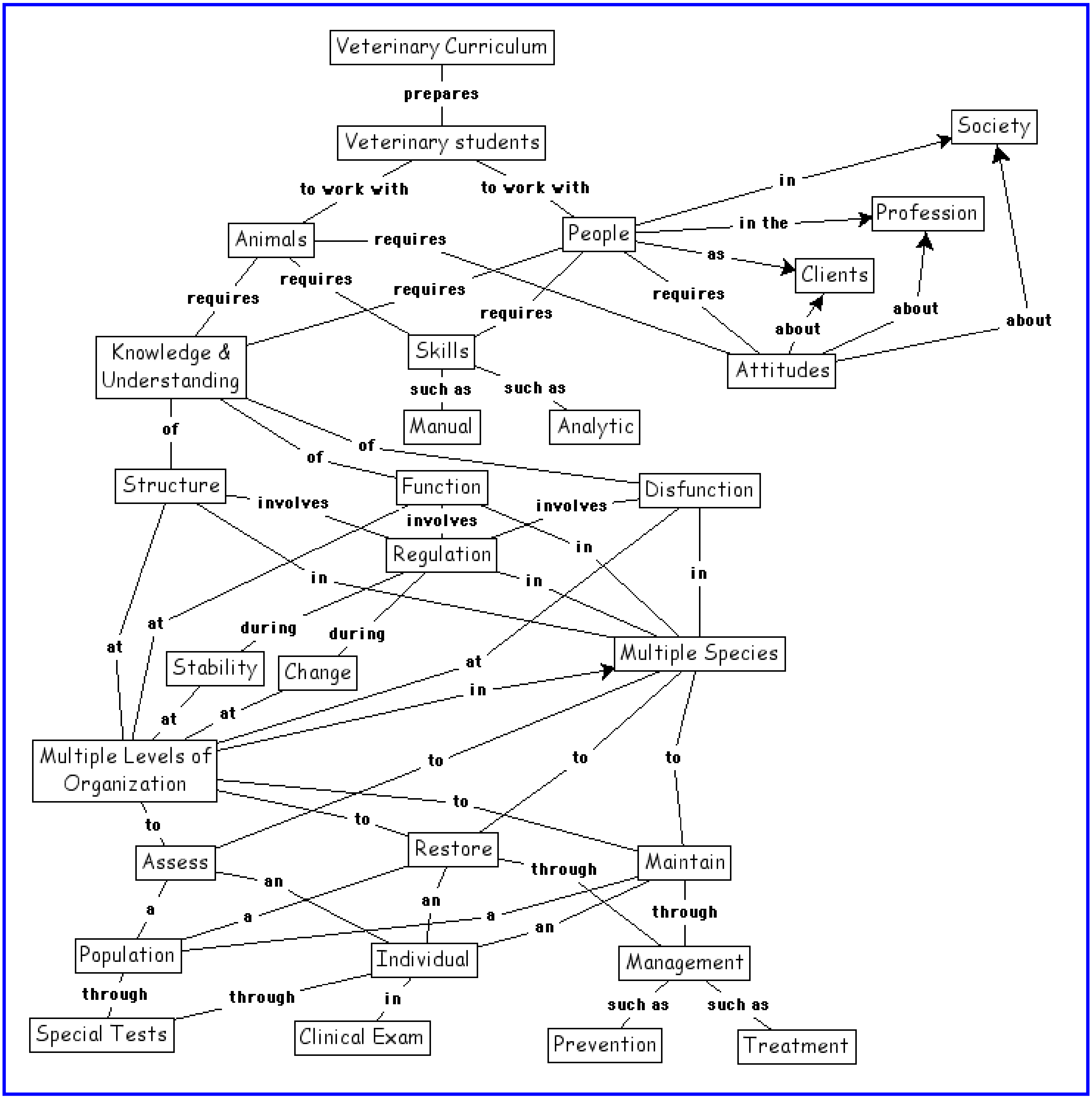

Figure 7

Concept Maps for Evaluation

We are now beginning to see in many science textbooks the inclusion of concept mapping as one way to summarize understandings acquired by students after they study a unit or chapter. Change in school practices is always slow, but it is likely that the use of concept maps in school instruction will increase substantially in the next decade or two. When concept maps are used in instruction, they can also be used for evaluation. There is nothing written in stone that says multiple choice tests must be used from grade school through university, and perhaps in time even national achievement exams will utilize concept mapping as a powerful evaluation tool. This is a chicken-and-egg problem because concept maps cannot be required on national achievement tests, if most students have not been given opportunities to learn to use this knowledge representation tool. On the other hand, if state, regional, and national achievement exams will utilize concept mapping as a powerful evaluation tool. This is a chicken-and-egg problem because concept maps cannot be required on national achievement tests, if most students have not been given opportunities to learn to use this knowledge representation tool. On the other hand, if state, regional, and national exams would begin to include concept maps as a segment of the exam, there would be a great incentive for teachers to teach students how to use this tool. Hopefully, by the year 2061, this will come to pass.

References

- Anderson, O. R. (1992). Some interrelationships between constructivist models of learning and current neurobiological theory, with implications for science education. *Journal of Research in Science Teaching*, 29(10), 1037-1058.
- Ausubel, D. P. (1963). *The Psychology of Meaningful Verbal Learning*. New York: Grune and Stratton.
- Ausubel, D. P. (1968). *Educational Psychology: A Cognitive View*. New York: Holt, Rinehart and Winston.
- Ausubel, D. P., J. D. Novak, and H. Hanesian. (1978). *Educational Psychology: A Cognitive View*, 2nd ed. New York: Holt, Rinehart and Winston. Reprinted, New York: Warbel & Peck, 1986.
- Bascones, J., & J. D. Novak. (1985). Alternative instructional systems and the development of problem-solving skills in physics. *European Journal of Science Education*, 7(3), 253-261.
- Bloom, B. S. (1956). *Taxonomy of Educational Objectives--The Classification of Educational Goals*. New York: David McKay.
- Edwards, J., and K. Fraser. (1983). Concept maps as reflectors of conceptual understanding. *Research in Science Education*, 13, 19-26.
- Hoffman, B. (1962). *The Tyranny of Testing*. New York: Corwell-Collier.
- Holden, C. (1992). Study flunks science and math tests. *Science*, 26, 541.
- Johnson, D., G. Maruyama, R. Johnson, D. Nelson, and L. Skon. (1981). The effects of cooperative, competitive and individualistic goal structure on achievement: A meta-analysis. *Psychological Bulletin*, 89, 47-62.
- Macnamara, J. (1982). *Names for Things: A Study of Human Learning*. Cambridge, MA: M.I.T. Press.
- Mintzes, J., Wandersee, J. and Novak, J. (1998) *Teaching Science For Understanding*. San Diego: Academic Press.
- Mintzes, J., Wandersee, J. and Novak, J. (2000) *Assessing Science Understanding*. San Diego: Academic Press
- Novak, J. D. (1977). *A Theory of Education*. Ithaca, NY: Cornell University Press.
- Novak, J. D. (1990). Concept maps and Vee diagrams: Two metacognitive tools for science and mathematics education. *Instructional Science*, 19, 29-52.
- Novak, J. D. (1991). Clarify with concept maps. *The Science Teacher*, 58(7):45-49.
- Novak, J. D., & D. B. Gowin. (1984). *Learning How to Learn*. New York and Cambridge, UK: Cambridge University Press.
- Novak, J. D., & D. Musonda. (1991). A twelve-year longitudinal study of science concept learning. *American Educational Research Journal*, 28(1), 117-153.
- Novak, J. D., & J. Wandersee, 1991. Coeditors, Special Issue on Concept Mapping of Journal of *Research in Science Teaching*, 28, 10.