BUILDING ON NEW CONSTRUCTIVIST IDEAS AND CMAPTOOLS TO CREATE A NEW MODEL FOR EDUCATION[1]

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There is today almost universal agreement that every learner must construct her/his own knowledge structure, or cognitive structure, through her/his own efforts. The commitment to building a powerful knowledge structure must be the learner's commitment. There is less universal recognition that knowledge structures are built primarily through *meaningful learning*, and by contrast, rote learning or simply memorizing information contributes little to building a person's knowledge structure. Nevertheless, we believe that Ausubel's theory (1963; 2000) provides a strong foundation on which to improve teaching and learning. We shall seek to illustrate this through efforts that employ constructivist epistemology and constructivist cognitive psychology, together with the use of the Internet and CmapTools, a software toolkit to aid in the construction of concept maps.

1 Introduction

Concept maps have been used in all facets of education and training. Within the fundamental goal of fostering learning (Novak & Gowin, 1984), they have been identified to be an effective tool for –and we don't pretend to provide an exhaustive list– evaluation, displaying students' prior knowledge, summarizing what has been learned, note taking, aiding study, planning, scaffolding for understanding, consolidating educational experiences, improving affective conditions for learning, teaching critical thinking, supporting cooperation and collaboration, and organizing content (Coffey et al., 2003). Aware that *new* technologies have failed to deliver on the false expectation of being the solution to education's problems, we propose that good use of the appropriate technology can increase the benefits of using concept maps in education.

In this paper we first explore the power of CmapTools and how it can support concept mapping, and then discuss how these tools and new ideas can lead to a New Model of Education.

2 The Power of CmapTools

For the past dozen years, the Institute for Human and Machine Cognition (IHMC) has been developing CmapTools (Cañas et al., 2004) a client-server software environment that greatly facilitates the construction and sharing of concept maps. The software is used extensively throughout the world by users of all ages and for a large variety of applications. Describing the complete functionality of the program is beyond the scope of this paper, so we will present some key features that will provide an idea of how the software supports concept mapping.

CmapTools has been designed with the objective of supporting collaboration and sharing. The client-server architecture, together with a collection of Public Places (CmapServers) where any Internet user can create a folder and construct, copy or publish their concept maps, facilitates the sharing of concept maps and the collaboration during concept map construction (Cañas, Hill, Granados, Pérez, & Pérez, 2003). Additionally, a CmapServer (Place) can easily be installed in a classroom or school to facilitate collaboration locally. Collaboration is supported at several levels. If two or more users attempt to edit the same concept map at the same time, the program will –with the consent of the users– establish a synchronous collaboration session where the users can concurrently modify the map and communicate via a chat window. Peer review and collaboration are facilitated through Annotations (post-it notes) that can be added to map after selecting the portion of the map to be annotated, and through Discussion Threads that can be added to a node (concept or linking phrase). When a user creates a folder in a Public Place (server) he/she becomes the Administrator of that folder, and can determine which users receive "annotation" (can comment on a map but cannot modify it, appropriate for peer review), write (can modify the maps, appropriate for teamwork and collaboration) or read-only permissions (appropriate for publishing). In addition, the Knowledge

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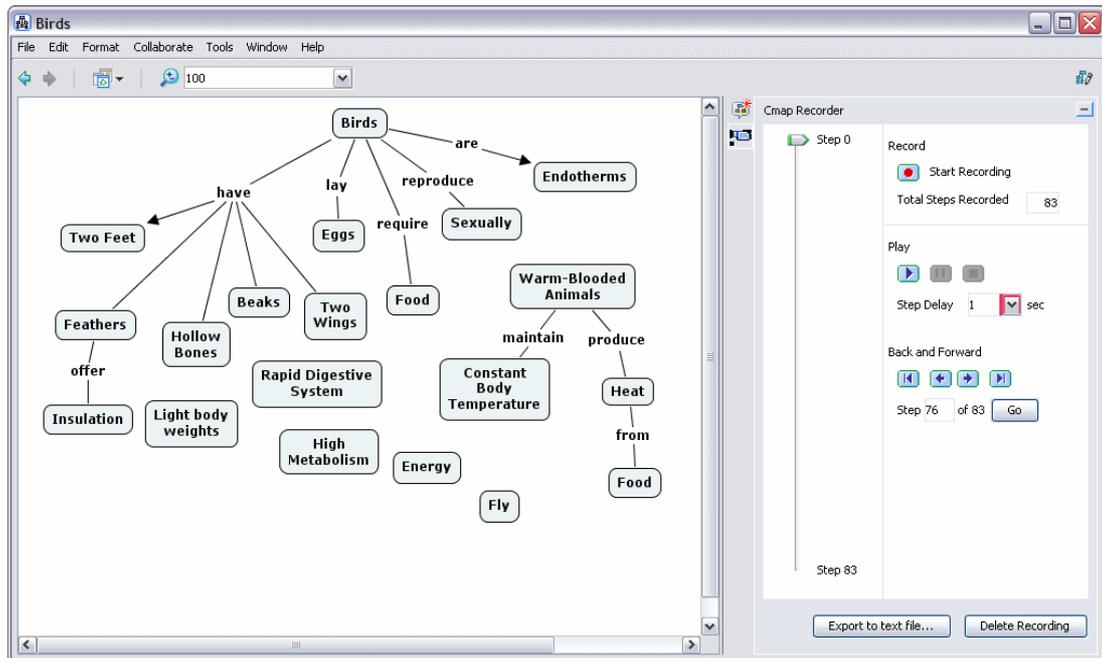[1] Based in part on earlier papers, Novak (2004), and Novak (In press).

Figure 1. The Recorder feature of CmapTools allows the graphical playback of the steps in the construction of a concept map.

Soups enable collaboration at the proposition or knowledge level (Cañas, Ford, Brennan, Reichherzer, & Hayes, 1995; Cañas et al., 2001)

CmapTools supports the construction of "knowledge models": sets of concept maps and associated resources about a particular topic (Cañas, Hill, & Lott, 2003). Through simple drag-and-drop operations students can link all types of media (images, videos, text, web pages, documents, presentations, etc.) and concept maps, whether theirs or constructed by others, to their maps. These resources can be located anywhere on the Internet.

Novak and Gowin (1984, Chapter 2) have depicted the act of mapping as a creative activity, in which the learner must exert effort to clarify meanings, by identifying important concepts, relationships, and structure within a specified domain of knowledge. Educators have acknowledged that it is the "process" of creating a concept map that is important, not the final product. However, in many cases the teacher can not accompany the students during the process of concept mapping, whether it's because there are too many students, the student is doing the work at home, or the learning is taking place at a distance. CmapTools provides the capability of "recording" the process of constructing a concept map, allowing for a graphical "playback" at a later time, controlling the speed and moving forward or backwards as needed. Figure 1 shows at the right pane that allows the user to control the recording. In this example, the student has taken 83 steps to reach this point in the map construction, and pressing on the playback button will start showing step by step the complete process of map construction. The recording is saved with the concept map, so if it is copied or moved the recording is not lost. The playback also identifies which user performed each step, which is essential to support collaborative work. We expect that this feature will also provide the capability for researchers to investigate the process followed by different users when constructing concept maps.

Despite the free-style format that concept maps can take, specific characteristics of well-constructed concept maps (structure, semantics, context, etc.) provide an abundance of information on which to develop smart tools that aid the user in the process of constructing concept maps (Cañas & Carvalho, 2004). One such tool allows the user to select a concept in a map and search the web and Places (CmapServers) for information (including concept maps) that is related to the concepts selected, taking into account the context of the concept map itself (Carvalho, Hewett, & Cañas, 2001). That is, the program tries to determine "what the concept map is about" and performs a query accordingly. Researching a topic can begin by constructing a small map and using the search to locate information

related to the map. The information retrieved can then be used to improve the map, and the cycle continues. By linking relevant resources found to the map itself, concept the map becomes the centerpiece of the research endeavor.

The program contains other features that support the user, whether a student, teacher, or instructor, in the use of concept mapping in an educational environment, such as a map-comparison module and automatic generation of an HTML version of the concept map when it is stored in a Place. For the purpose of supporting the ideas presented in this paper, we consider that the combination of the collaboration tools, the knowledge model construction features, and the search mechanism provide a strong foundation on which to build the "expert skeleton" map scaffolding ideas in the New Model for Education described in the following sections.

3   Using "Expert skeleton" Concept Maps to "Scaffold" Student and Teacher Learning

During the first author's last 20 years teaching at Cornell University he taught a course called "Learning to Learn". The book, Learning How to Learn (Novak & Gowin, 1984), derived in large part from experiences teaching the course. One of the techniques Novak found most helpful to students was to prepare concept maps showing key ideas and their relationships. These were not complete maps, just the key concepts and relationships. Students were asked to add concepts to the professor's maps and restructure the map in ways that would make the most sense to them. The exams in this course typically provided the students with a list of 20-25 concepts, and they were asked to build a concept map using these concepts and at least 20 additional concepts they wished to add. Students were also asked to select a "learning partner", since considerable research supports the value of cooperative learning (Qin, Johnson, & Johnson, 1995). It was impractical in terms of student schedules to form learning groups larger than two, although sometimes the students took the initiative to meet in groups of 4-6, usually comprising 2-3 learning partner teams. Course evaluations repeatedly commented on the value of the learning partner arrangement, and in fact a few of these led to later marriage of the learning partners. Examples of the kind of concept maps that were used with students can be seen on the CmapTools Network[2].

Novak's experiences in using concept maps to help guide student learning were highly positive. They were supported by Vygotsky's (1928, 1978) ideas of the importance of social exchanges in learning. Another idea that was supported is Vygotsky's concept of "Zone of Proximal Development" (ZPD). Vygotsky's studies showed that there was a level of cognitive development that allowed a learner to advance in understanding of a given domain of knowledge without coaching, and a higher level of understanding beyond which the learner cannot advance without coaching. He called this range of understanding the Zone of proximal Development. One advantage of cooperative learning approaches is that students tend to be at about the same ZPD, hence they can better communicate ideas to each other, and when assisted by "expert skeleton" concept maps, they can progress even further. In general, the literature on "coaching" students using various approaches shows significant facilitation of learning (Bransford, Brown, & Cocking, 1999). Given the learning facilitation now possible using CmapTools, we believe that even greater advantage of Vygotsky's ideas and ideas from the literature on coaching can be incorporated into instruction.

While there needs to be much more research done on how best to devise "expert skeleton" concept maps and how to best employ them in teaching and learning, our experience provides some guidance. For young children, or even older learners, it would be best to begin with very simple expert maps, perhaps not more than five of six concepts. This will be illustrated below in the section on The World of Science Project. The important thing is that the learner must be *active* in acquiring new concepts and building new propositions. CmapTools allows one to access information that is pertinent to the map, but the learner must identify the concepts and construct the new propositions. For younger learners, finding pertinent material that they can understand and can use to select new concepts to incorporate into their map will take patience and guidance. While anyone can drag a new resource onto a concept and "attach" resources to concepts from the Internet or other sources, it takes thinking and new meaning building to isolate the pertinent concepts and construct valid new propositions. This is the central purpose of using "expert" concept maps to scaffold learning. The use of the expert map as a "skeleton" or starting point is important, since it gets the learning off to a valid starting point and serves as a base for selecting new concepts and constructing new propositions. As the learner puts "conceptual meat" on the bones of the skeleton, they are more likely to build a

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[2] Place: IHMC Public Cmaps (2), Folder: JDN'sLCKKnowledge.

The Universe — contains → Matter, Energy

Matter — transformed where E=mc2 → Energy

Matter — is → Particulate; is → Usually Conserved; has → Mass; may be → Organized

Energy — is → Usually Conserved; can be → Stored; comes in → Forms

Forms — may be → Heat, Light, Chemical, Electrical, Nuclear, from Mass

Particulate — such as → Atoms

Atoms — vary in → Mass; combine to form → Molecules; which are → Elements; are separated by → Space

Organized — into → Molecules; used to make things

Molecules — may form → Gases, Liquids, Solids

Gases, Liquids, Solids — are → States of Matter

Space — is greater in → Gases

Elements — such as → Carbon, Oxygen

Heat — increases motion of → Molecules; is a major determinant of → States of Matter

Chemical, Electrical, Nuclear — may be → Transformed one to another

Transformed one to another — requires → Time

from Mass — may be in → Motion, Higher Positions

Motion — is → Kinetic Energy

Higher Positions — is → Potential Energy

Figure 2. A "global" concept map presenting the major concepts needed to understand most areas of science

solid, valid body of knowledge. This will require hard work and encouragement form the teacher, as well as from peers in a collaboration group.

Our plans are to begin developing "expert skeleton" concept maps in the area of science, since science is universal and it is also a subject poorly taught, especially at the elementary school level. The same could be said for mathematics, and this might be the second area to be developed. We estimate that the project would require some 300 expert concept maps to provide reasonable coverage of all areas of science for grades one through twelve, or ages 6 through 18. There are many scientists who have already prepared concept maps for specific disciplines, so this would be an easy starting point, although many of the maps might need some revisions to make a better fit with the project. Also, we would need to prepare some "global" concept maps to give broad conceptual overview of science or sub-domains of science. Figure 2 is an example of one such "global' concept map. Figure 3 shows a concept map dealing with the kind of energy transformation we call photosynthesis, and could represent a sub-map for Figure 2. Ideally, a map like this would be built by a group of cooperating students, and they could also attach pertinent resources to the map. A map of this complexity might be appropriate for 12-15 year old students, although we might expect to see equally complex maps developed by much younger students as they become more expert in the process.

Pérez et al. (Pérez, Suero, Montanero, & Fernández, 2000) report on using concept maps to scaffold university and high school student's learning of physics for more than a decade. Although their students did not use computer software, their feedback indicated better understanding of physics concepts with the use of concept maps. They are now moving towards leveraging on the use of CmapTools and technology (Pérez, Suero, Montanero, & Pardo, 2004). O'Donell, Dansereau, & Hall (2002) report on a study where a kind of concept mapping was used successfully to scaffold learning. A number of other school and university teachers have reported on using scaffolding approaches with concept maps, but little empirical data is available at this time. Therefore, we proceed with this approach with the support of underlying theoretical ideas, and indirect empirical support such as can be found in some of our research (Bascones & Novak, 1985; Novak & Musonda, 1991). The Bascones and Novak
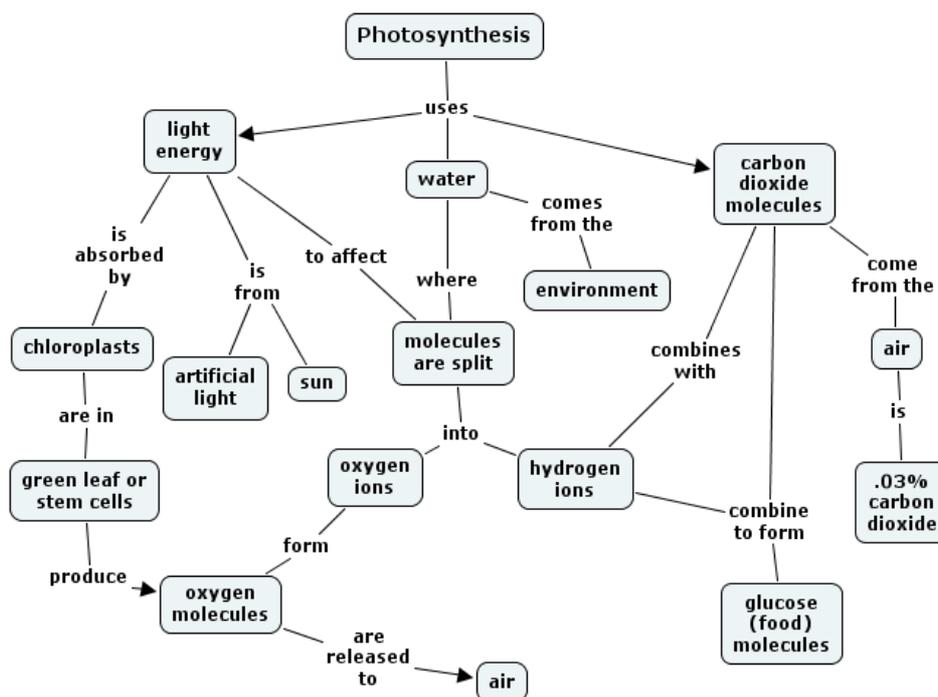
Figure 3. An example of a sub-concept map for Figure 2, dealing with photosynthesis

study showed approximately 100% greater improvement in problem solving scores for high school physics students using concept mapping, compared with students doing traditional exercises. The Novak and Musonda study showed that students taught with audio-tutorial methods in grades one and two achieved 100% or more improvement in understanding of molecular kinetic concepts when compared over twelve school years with students who did not receive this early science instruction. The latter study illustrates in part that technologically mediated instruction can be very effective. The two studies and other similar research show the huge unattained learning improvement potentials that currently exist for the improvement of teaching and learning. No study has looked at the learning improvement that could be attained by applying the best technology and the best pedagogy over the 12-year span of schooling, but the studies that exist suggest that such learning augmentation can approach an order of magnitude greater over a period of years than that now commonly observed.

4   The World of Science Project

During the early 1960's Novak worked on a series of elementary science books that had first been published by Bobbs-Merrill as The Wonderworld of Science, which was a fairly traditional elementary science book series. Most elementary school science textbooks cover many, many topics of science very superficially. None of these books present basic concepts of atoms and molecules and the nature and transformation of energy. Without introducing these concepts, it is essentially impossible to provide explanations of why things in the universe behave as they do. Wonderworld was an apt name for the early Bobbs-Merrill books as well as all other 28 elementary science series that were on the market in the 1960's, and indeed remains the case today! The problem of superficial coverage of science topics was also recognized by the Curriculum Committee of the National Science Teachers Association and their plan to build science instruction on "basic conceptual schemes" (Novak, 1964). Ausubel's cognitive learning theory was published in 1963, and this became a foundation for final writing in the books for The World of Science (Ausubel, 1963, 1968). Novak sought to take many of the good illustrations, activities and ideas in the Wonderworld of Science books and to rewrite the books to include information and activities that would illustrate the particulate nature of matter, energy and energy transformations, and the interplay of energy and matter in living and non-living systems. After 4 years of writing and editing, the *World of Science* was published in 1966. Unfortunately, Bobbs-Merrill was sold to another company in 1968 and this company decided to not market the World of Science books, Nevertheless, the books began to enjoy some success in elementary school classrooms in the USA, and later served as the primary foundation for audio-tutorial lessons designed for our 12-year longitudinal study (Novak, 2004;

Novak & Musonda, 1991). All of these books have now been scanned and we hope to make them publicly available soon at the IHMC web site (www.ihmc.us).

Our plan is to use The World of Science books as a starting point for a demonstration project for A New Model of Education. To begin, concept maps have been prepared for all sections of the grade two book of the World of Science entitled The Exciting World of Science. The concept maps would serve as a starting point for students and teachers for each section illustrated in the book, and then students would use these Cmaps together with CmapTools to search the internet for pertinent resources and ideas. Figure 4 illustrates two of these concept maps dealing with the first sections of the Grade 2 book, pages 6-11 and 12-17, and shows the beginning of how these concept maps might be elaborated by a student, or preferably students working in teams and sharing ideas. All concept maps are publicly available on the CmapTools Network[3]. The science books provide many suggested activities, and it would be important for the teacher to help students perform these activities, and similar related activities, some of which might by suggested in Internet resources. Obviously, it would be a very deficient science program that did nothing more that to have students copy and do some building on the concept maps provided for grade two, or for any other grade. Students need concrete, hands on experiences with real things and to observe real phenomena to put meaning into the concept labels provided in the concept maps and other resources (Novak, In Press). Figure 5 shows concept map showing some of the key features of Novak's New Model of Education. When online, clicking on the icons on
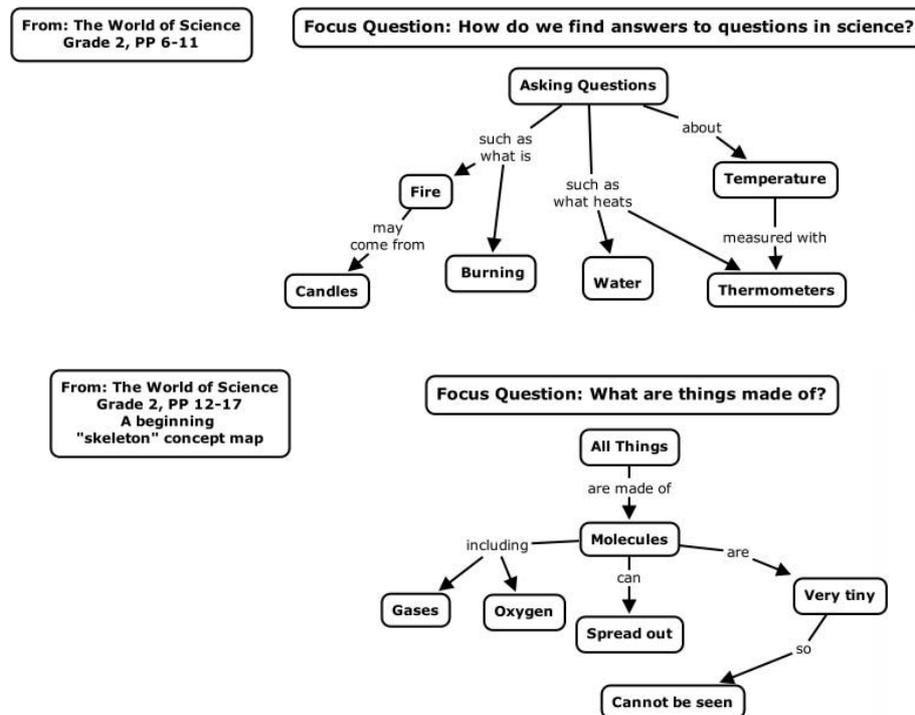

Figure 4. Two sample "skeleton" concept maps for the first sections of Grade 2, The World of Science, pages 6-11 and 12-17.

concepts provides additional information. Other concept maps for the New Model of Education can be found at the CmapTools Network[4].

Pilot program efforts are already in progress in Italy, where Giuseppe Valitutti (2004) is now working to translate The World of Science books into Italian, and Alfredo Tifi and colleagues have started collecting "expert skeleton" maps[5]. We expect a number of elementary school teams to begin working with the World of Science

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[3] Place: IHMC Public Cmaps (2), Folder: The World of Science.
[4] Place: IHMC Public Cmaps (2), Folder: Novak's New Model of Education.
[5] CmapTools Network, Place: IHMC Public Cmaps, Folder: LE_PAROLE_DELLA_SCIENZA/ALFREDO.

concept maps and other resources during the next school year, and the feedback should help us to rapidly refine concept maps, techniques and approaches for improving practice of the New Model of Education. The CmapTools
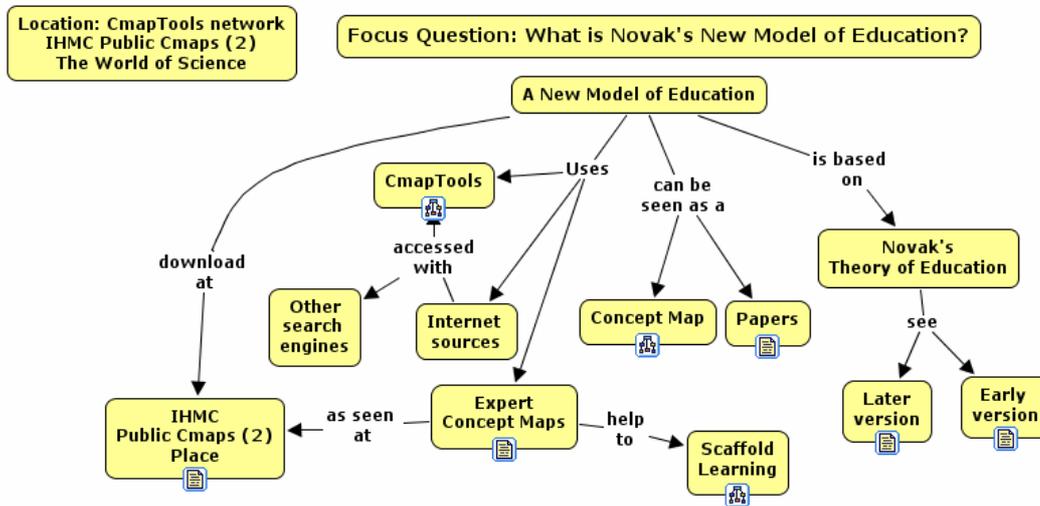

Figure 5. A concept map showing some of the key features of Novak's New Model of Education. When online, the icons below concepts lead to additional information.

Network may serve as a clearing house for some of these efforts, through its Public servers in Italy and other countries. We anticipate that an abundance of both anecdotal and empirical data will flow from these efforts in a few years. Based on the solid theoretical and related research findings now available, there is every reason to be optimistic that these innovative efforts will be successful.

5   Problems of Implementation

The greatest challenge we may expect is to change the school situational factors in the direction of teacher as coach and learner from the prevailing model of teachers as disseminator of information. We know that we need to engage teachers and administrators in training programs that can model the new educational approaches, and we also need to seek their counsel on ways to improve on the New Educational Model. There is also the challenge of changing assessment practices that now rely primarily on multiple-choice tests that measure mainly rote recall of information, to tests that require students to demonstrate that they understand basic concepts and can use these concepts in novel problems solving, and that they can use Internet resources to grow and modify their concepts and learn new concepts. There remains in the New Model plenty of room for acquisition of specific facts and procedures, but now these should be in learned within the context of powerful conceptual frameworks. Research (Bransford et al., 1999) has shown that factual information acquired in a context of meaningful learning is not only retained longer, but they can be used much more successfully to solve new problems.

Even with the current state of technology and pedagogical understandings, it is possible for schools, states or countries to mount a New Model of Education. As technology continues to advance, we should expect that what is relatively expensive and difficult today will become an order of magnitude less costly and more effective in a few years. Furthermore, research on teaching and learning is improving, and this too will contribute to greater effectiveness. The rate and kind of new technological advances is difficult to predict, but the history of the past few decades can serve as a model of where we might expect to be in 10 or 20 years, if we begin to exploit more fully the technologies and ideas available today.

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