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RE-EXAMINING THE FOUNDATIONS FOR EFFECTIVE USE OF CONCEPT MAPS

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Abstract. The use of concept maps continues to grow worldwide, and users are consistently finding new applications and uses for the tool. However, we continue to observe difficulties in the use of the tool that seem to be consistent throughout countries and domains of use. Among them, we cite the difficulty in the construction and structure of propositions, the lack of a focus question to guide the construction of the map, and the tendency to construct descriptive as opposed to explanatory concept maps. In this paper we examine how an understanding of the foundations of concept mapping and the ability to ask good questions can aid in addressing these problems, resulting in a more effective use of concept maps.

1 Introduction

There are today many different applications for what we call concept maps, and many of these applications are substantially different from the uses when this tool was first developed in 1972. Moreover, the advance of computer technology and the development of the Internet have conferred new capabilities for the use of this tool. We thought it would be useful to re-examine the foundations for this tool and to discuss implications for current and future applications. Many of the difficulties we observe with the use of concept maps derive at least in part from inappropriate use of the tool, lack of adequate training for users and trainers, and a general failure to recognize the importance of the theoretical foundations for the tool. We shall begin with a discussion of some of the difficulties we see in the use of concept maps, review of important theoretical ideas and then move to a discussion of various applications, illustrating how the concept mapping tool might be used more effectively.

2 Difficulties

Even though concept mapping today is used in ways and in domains that we would not have been able to predict years ago, the main purpose of the concept map continues to be the same: it is a tool that allows one or more persons to represent explicitly their understanding of a domain of knowledge; and the theoretical foundations of concept mapping haven't changed.

However, as we see the use of the tool in different places, some difficulties seem to be pervasive.

1. The construction and structure of propositions seems to be a problem that many concept mappers have.
2. The lack of a (good) focus question that 'focuses' the construction of the concept map;
3. Concept maps tend to be mostly descriptive as opposed to explanatory, with many of them being classificatory.

We believe that some of these issues can be addressed by (a) a clear understanding of the foundations, and (b) asking good questions, including the focus question that triggers the construction of map, the questions that teachers use to prompt the students to improve their maps, the questions that map constructors ask themselves while building the maps (which lead to refining and expanding the map and construction of other maps), the questions that students ask each other when collaborating, or the questions that knowledge engineers ask experts while eliciting knowledge. We first re-examine the theoretical foundations and later discuss the topic of questions.

3 Re-examining the Foundations

Concept mapping, as we use this term, derived from a research project where first and second grade children were taught basic science concepts, and interviewed periodically over the twelve-year span of their schooling to determine how this early instruction influenced later learning of science (Novak, 2005; Novak & Musonda, 1991). Novak and his team tried various assessment strategies to monitor children's learning, including the use of modified

Piagetian clinical interviews (Pines & Novak, 1978). While the interviews did reveal striking differences in children's understanding of the science they were being taught, it was difficult to track specific changes in each child's concepts of matter, energy, and other concepts that were taught. Novak's team reviewed in depth the Ausubelian learning principles and also the constructivist epistemological ideas underlying their work. The latter theoretical works also were foundations for the audio-tutorial science lessons developed and interviewing strategies that were employed.

Briefly, the key epistemological ideas considered were: (1) The universe consists of objects and events, and energy exchanges during events. (2) Concepts are constructed by humans and are perceived regularities or patterns in events of objects, or records of events or objects, designated by a label, usually a word. (3) Two or more concepts can be linked with appropriate words to form a meaningful statement or proposition. (4) Concepts and propositions are the building blocks of knowledge in all fields. The key learning principles that were considered, based on Ausubel's (1963; 1968) cognitive psychology were: (1) *Meaningful learning* (as contrasted with *rote* learning) is necessary for development of conceptual understanding. Meaningful learning is sometimes characterized as *deep* or *dynamic* learning, (in contrast with *surface* or *static* learning). (2) New learning must build on relevant prior concepts and propositions held by the learner. (3) The learner must be encouraged to choose to learn meaningfully. (4) Appropriate concrete props are needed to learn abstract concepts, together with appropriate didactic instruction. (5) Learning is highly idiosyncratic and progresses over time. (6) High quality meaningful learning leads to construction of well integrated concept and propositional structures (i.e. cognitive structures) that better facilitate new learning and creative problem solving. Given these foundational ideas, Novak's groups sought to represent knowledge as a hierarchical structure of concepts and propositions, a form they called a concept map.

Figure 1 shows an example of a concept map that illustrates the key ideas described above. Note that objects or things are key building blocks of the universe, and they are also key building block of knowledge. We use words, usually nouns, to label objects. *Events* are the other key building blocks of the universe, and also for knowledge. When we focus on events, we are usually asking how something happens, and concept maps emphasizing events, using verbs, and they tend to be richer in explanations, whereas concept maps focused on objects tend to be more

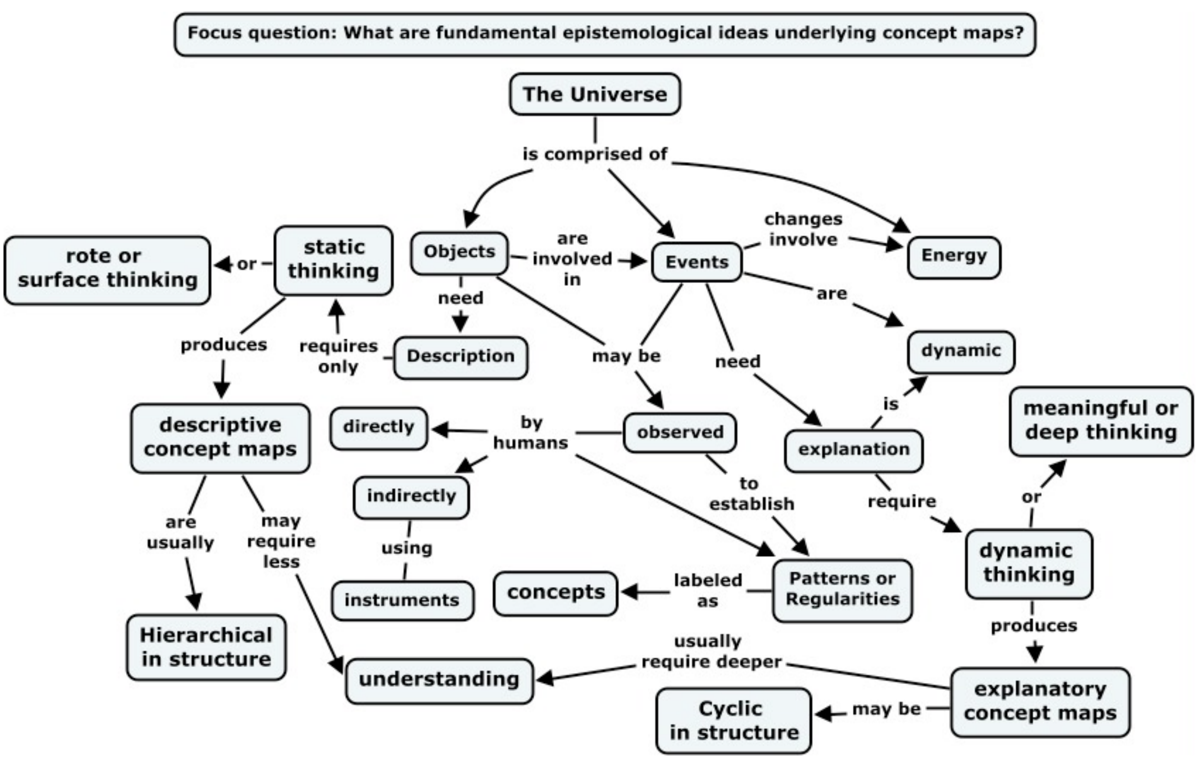

Figure 1. A concept map showing the key theoretical ideas underlying construction and use of concept maps.

descriptive. In general, concept maps showing explanations require more deep or dynamic thinking. We have observed, however, that most concept maps deal with objects, not with events, and propose that through the proper focus question, and through questioning in general, we could move towards the dynamic thinking that is required to build concept maps showing explanations.

4 The Importance of Questions

Unfortunately, concept maps are frequently used only as an assessment tool. As a result, students have 'one shot' at getting the concept map right, either in a test or as an assignment. In our New Model of Education (Novak & Cañas, 2004) we propose a concept-map centered learning environment (Cañas & Novak, 2005) where the concept map is used from the beginning of a unit to determine how much a student knew beforehand, through the unit as a means for researching and linking resources found or created by the student, until the map shows at the end how much the student has learned about the topic. Within this environment, the concept map evolves as the student learns, reflecting his/her increased understanding, and its through questions from the teacher, from colleagues, or questions that the student asks him/herself that the student pursues a deeper understanding that is reflected in the map.

4.1 The Focus Question(s)

A good way to define the context for a concept map is to construct a *Focus Question*, that is a question that clearly specifies the problem or issue the concept map should help to resolve. Every concept map responds to a focus question, and a good focus question can lead to a much richer concept map, as will be examined later. When learning to construct concept maps, learners tend to deviate from the focus question and build a concept map that may be related to the domain, but which does not answer the question. This is fine in the sense that the map built probably answers another focus question, and so the focus question of the map should be changed to reflect this (CmapTools provides a field for the focus question as part of the information that is stored with a Cmap, and the focus question is displayed in the header of the window when a map is displayed, making the focus question explicit to the viewer). In the case of a school-learning environment, it may be important to have the learner go back and construct a concept map that responds the original focus question. However, its important to clarify that starting with a single focus question does not imply that the 'job is done' when that question is answered. Fagundes and Dutra (2006) emphasize in their work with teachers and students the importance of questioning each individual concept in a concept map (do I understand what this concept really means and its relationship with its linked concepts?) This leads to research and searching, and to the generation of focus questions for other concept maps that will end up linked to the original map.

4.2 Asking Students Questions

As a student is building a concept map, the teacher should probe the student to (a) find out how much the student knows about the topic, and (b) help the student improve, refine or expand the concept map. Unfortunately, there is little research on question-asking during concept map construction. Chacón (2006) has reported on the "pedagogical question" and its use as a mediating instrument during concept map construction. She refers to three moments during the construction of concept maps (a) defining the context, where she proposes that questions be asked that help determine the context, such as "Why are we addressing this problem?", "Why use concept maps to solve this problem?", "Where do we find information?" among others; (b) development of the concept map, where the focus question is constructed, inquiry questions such as 'where? what? who?' help establish what the student(s) already know (see the section below on Interviewing), verification questions are used to verify whether propositions in the concept map are true or not and if they are coherent or not, amplifying questions to find out if information is missing or concepts need to be expanded and cross links added; (c) reviewing purpose, where through questions the student can take cognizance over how he/she is building his/her Cmap. Not coincidentally, Chacón (2004) has done a large portion of her work with pre-school children, and it's in papers on the use of concept mapping in pre-school where the authors, including Chacón, have reported the questions-answer dialogues that have lead to the construction of concept maps by children (see for example, Beirute, Brenes, Cortés, García, & Meza, 2006; Cassata & French, 2006; Mancinelli, 2006; Mancinelli, Gentili, Priori, & Valitutti, 2004). Authors working with preschool children all emphasize the importance of teachers asking questions instead of providing the students the 'right' answers. We could all benefit from paying attention to the way these teachers lead their students in the process of improving their concept map construction through careful questioning. Learning to ask question requires training, and we have found that one way to learn how to ask questions is through learning how to interview, as is described below.

4.3 Learning to Ask Questions: the Interviewing Experience

Learning to interview requires that one listen carefully to what the interviewee is saying. Teachers are notoriously poor at this and tend to steer students to answers, or just give them answers, rather than probe the child's mind and listen carefully to what they are saying. Concept mapping the interview plays an important role in the process.

During the process of developing the concept mapping tool, there was a constant interplay between the structuring of interviews, transcribing interviews, and creation of concept maps from the interviews. This interplay is critically important to understanding and constructing good concept maps. Therefore we recommend that all users of this tool engage early in their practice to conduct several interviews and proceed to construct concept maps from these interviews. Detailed procedures for this can be found in Novak and Gowin (1984, Chapter 7). It should be recognized that we are trying to probe into a person's cognitive structure and ascertain what concepts and propositions that person has relevant to a particular topic and how are these integrated and organized? This is a profoundly challenging task, and yet it is fundamental to improving teaching and learning in any field. It is also essential for the capture and archiving of expert knowledge, an application of concept mapping that is growing rapidly. We will illustrate the process using two interviews with children dealing with plants in our lecture. The interviews were conducted as part of the planning for an elementary school program dealing with plants with the acronym LEAP (LEarning About Plants). The program was developed by staff of Cornell University Plantations.

Planning an interview begins with identifying one or a few Focus Questions that will be the main interest of the interviews. Then a concept map should be prepared that anticipates the kind of knowledge that might be revealed and organizes the ideas for the interview. In general, this concept map will be more comprehensive than that drawn from interviews, since the interviewer has to be prepared for all possible answers. The objective is to understand what prior knowledge children typical of this age group will bring to the lessons to help with planning the lessons. It should be noted that this concept map used to guide interviews might need to be modified as interviewing progresses, and also the interview may need to be modified until it can be "standardized". This is an iterative process, but our experience has been that two or three cycles of prepare map-interview-map student-revise interview are sufficient for a given target audience on a given topic.

We will show brief video clips of two children being interviewed, one a third grader and the other a fourth grader. These interviews began with questions about "what is a seed", and then moved to "what do seeds and plants need to grow"? It is common with interviews that one may begin with a given Focus Question, and as the interview proceeds, another focus question may emerge. The interviews done some years ago by one of Novak's graduate students will illustrate good interviewing techniques, including position of the interviewer, sufficient "wait time" after a question is asked, and neutral feedback that does not steer the interviewee's answers. We found that both children are not aware of the role of carbon dioxide in plant growth, do not know that seeds are formed in the ripened ovaries of flowers, and in general appear to have little or no understanding of photosynthesis. However, both have significant knowledge about seeds and how they grow into plants, so there is a good conceptual foundation for building their understanding further with appropriate instruction. Interestingly, the younger child actually has an important concept the fourth grade child lacks, namely the idea that sun is needed for plants to grow. Both children correctly indicate that plants need minerals from the soil to grow. The interviews and the concept maps we prepared identify explicitly new concepts that need to be learned, such as the fact that the sun is a source of energy and energy is needed to make food from water and carbon dioxide. However, the missing concepts also suggest that these children lack an understanding of the concepts of energy, atoms, molecules, gas, and liquid. Some level of development of these concepts would be needed for the children to understand the process of photosynthesis. The latter concepts were developed in some depth in The World of Science Program (Novak, Meister, Knox, & Sullivan, 1966).

It is to be expected that any given interview protocol will lead to new questions to be explored. For example, the above interview suggested that students had a pretty fuzzy knowledge of how plants use sun to produce food. This could lead to another interview on this focus question. It is likely that the new interview would show that students do not understand the nature of gases such as oxygen and carbon dioxide, and an interview on this subject would likely show that they also lack an understanding of the particulate nature of matter, including the nature of atoms and molecules. We found this to be the case in our work as we planned our 12-year longitudinal study, and for this reason, the lessons we prepared for grades one and two placed heavy emphasis on developing these concepts. Contrary to popular opinion in the 1970's, we were able to show that students could at least begin to understand these concepts and that this influenced future science learning.

Becoming skilled at probing into learner's cognitive structure is a profoundly challenging task, and yet it is fundamental for understanding how learners learn. It also helps build skills in asking good questions and guiding the students to ask good questions. Developing interviewing skills and skill in concept mapping interviews should be part of every teacher-training program. A typical problem teachers have is that they do not wait long enough for students to respond after they ask a question. Rowe (1974) and others have found that on average teachers wait only 0.7 second before they answer the question, ask a different question, or move to another student for a response. This short wait time does not permit the deep cognitive processing that is needed for a learner to generate a good response. Interviewing can help a teacher to see that the "wait-time" after asking a question might need to be 10-30 seconds or more to obtain thoughtful responses from the student. Longer wait-times are especially needed when questions are asked that require explanation, rather than simply naming an object or event.

One of the uses of CmapTools that is growing in importance is the capture and archiving of expert knowledge. For corporations, knowledge is in most cases the principal asset of the company, and too often when workers retire or leave, much of this asset is lost. Another problem is that precious corporate knowledge was archived in various company reports, consisting primarily of texts and data tables. Such knowledge is notoriously difficult to retrieve by others, who might benefit from this knowledge, and most corporations find that current or new employees seldom read these archived reports. Capturing expert knowledge from people is fundamentally a process of becoming skillful in interviewing corporate workers. At IHMC, we have been involved in a series of projects to train workers in the use of concept maps for capturing and archiving knowledge.

4.4 Questions among Students: Collaboration

CmapTools was designed with the purpose of facilitating collaboration (Cañas *et al.*, 2004). Within this collaboration framework, the software provides for students to easily collaborate in building a concept map. They can either work on a given map at the same time, i.e., synchronously, or at different times as their schedules permit (asynchronous collaboration). Vygotsky (1978) stressed the importance of social exchange in learning, especially with learners who are at about the same Zone of Proximal Development (ZPD). That is, students who are at about the same level of cognitive development (same ZPD) on a given topic will enhance each other's learning if they engage in active exchange of ideas. Using the collaboration tools in CmapTools can facilitate this exchange.

The software includes features that allow teachers and/or students to ask each other questions. The "Annotation tool" is a 'post-it note'-type of annotation by which students can post short comments or questions on other students' concept maps. CmapTools provides for an 'annotate permission' on servers that allow students to annotate each other's concept maps without having the permission to modify them. Discussion threads (DTs) provide threaded discussions that can be attached to any concept or linking phrases. Through DTs students and teachers can get involved in more in-depth discussions than in an Annotation. CmapTools also provides the possibility of collaborating at the knowledge level through Knowledge Soups (Cañas *et al.*, 2001), whereby collaborating students publish propositions (called 'claims' in this environment) to a Soup, and in return are displayed claims from other students that are similar to the ones they published (see Figure 2). However, students can question each others' claims by attaching a discussion thread to them (as shown in Figure 2), and students are expected to defend the claims they published (Cañas, Ford, Brennan, Reichherzer, & Hayes, 1995).

In a previous research effort the Knowledge Soups had a 'Giant[1]' (Reichherzer, Cañas, Ford, & Hayes, 1998, August). This tool took propositions from the Soup and generated questions and propositions of its own that it presented to the student. For example, if a proposition published by one student was "green plants make food" and another claim was "plants use sunlight to make food", The Giant might ask, "do green plants use sunlight?". Students would teach the Giant by telling him whether the question was true, false or silly. If The Giant asked, "does

1 CmapTools does not currently incorporate an implementation of the Giant.

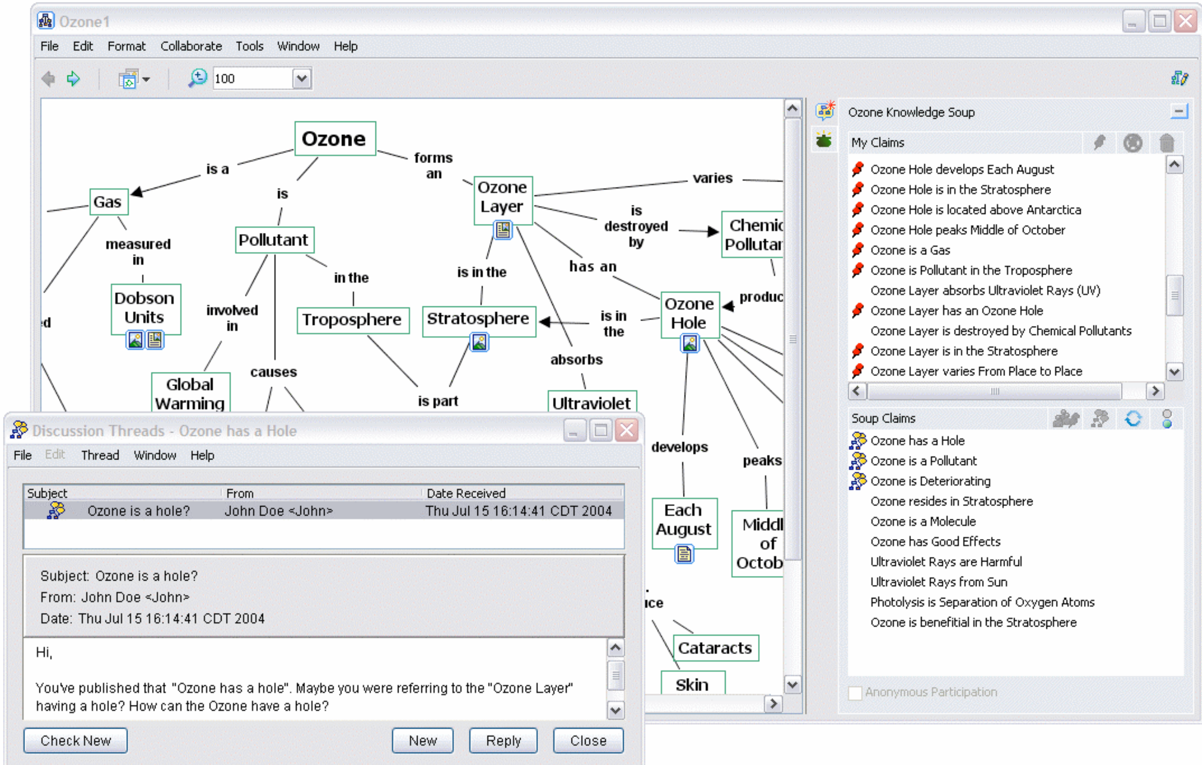

Figure 2: Students collaborate through a Knowledge Soup on the Ozone and question each other through Discussion Threads in CmapTools.

sunlight make green plants?", this would be marked as silly. The Giant was not an intelligent tool, and therefore the recombination of concepts and propositions made by the Giant were often nonsense. Nevertheless, the questions asked often stimulated enhancement of the concept maps and some good discussion among collaborating students.

5 Dynamic Verses Static Knowledge

Earlier in this paper we commented on the need to move towards the dynamic thinking that is required to build concept maps showing explanations, that is, concept maps that deal with *events* as opposed to *objects*. Cause and effect diagrams (also known as Ishikawa, fishbone, or characteristic diagrams) and causal maps are specialized graphs that depict the factors that contribute to or affect a given situation: all the causes, that is, that lead to a certain effect. However, these maps suffer from the same representation restriction as mind maps, having no linking phrases that clearly and explicitly explain the relationship between the events, or in other instances have been formalized to the point that they are no longer amenable to be used by children but are meant for computers to understand.

In a series of studies, Safayeni, Derbentseva and Cañas (2005) have found that the structure of concept maps can be indicative of the level of thinking expressed in the map. For example, concept maps modeled with a circular structure (see Figures 3 and 4) lead to significantly more instances of meaningful or dynamic propositions when compared with concept maps modeled with a tree-like structure. In work presented at the Concept Mapping conferences (Derbentseva, Safayeni, & Cañas, 2004, 2006) they further report on experiments comparing two strategies to encourage the construction of more dynamic relationships: the use of quantifiers on the root concept of a concept map and a dynamic focus question. Interestingly, although a more dynamic focus question has an effect on the nature of the propositions generated, it is adding a "quantifier" to the root map that has the greatest impact. Although the results of the experiments are preliminary, they report on three methods by which more dynamic thinking can be encouraged: cyclic maps, a dynamic focus question and a quantified root concept.

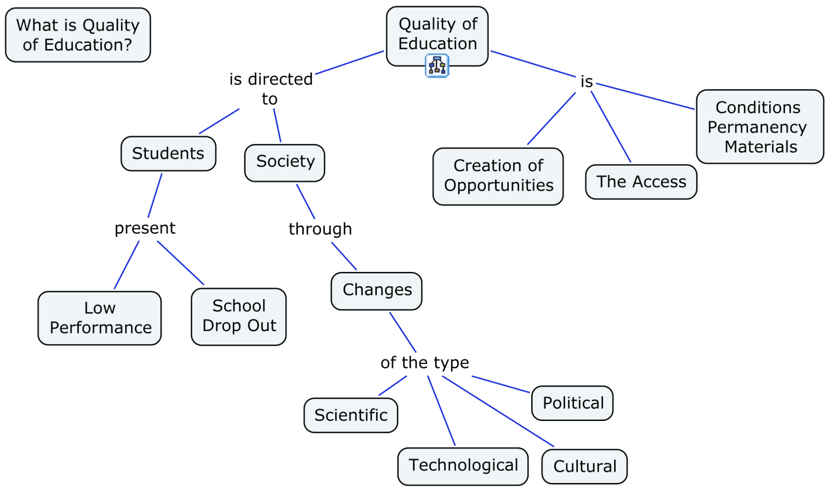

Figure 3. Tree-structure concept map generated from a static focus question.

We have started applying these ideas in our work with concept mappers, and have found that although a more dynamic focus question can generate a more dynamic map, concept mappers often ignore the question's nature and construct a declarative concept map. Adding a "quantifier" to the root concept, as reported above, tends to force the mapper to generate a more dynamic set of propositions. This is shown in two concept maps on the topic "Quality of Education" constructed by teachers during workshops, where the concept map in Figure 3 was constructed from the focus question "What is Quality of Education?" and was not given a root concept, resulting in a declarative type map, and Figure 4 was constructed from the Focus Question "What are the Effects of an Increase on the Quality of Education?" and a root concept of "Increase in Quality of Education" (an event), resulting in an interesting cyclic map based on dynamic propositions.

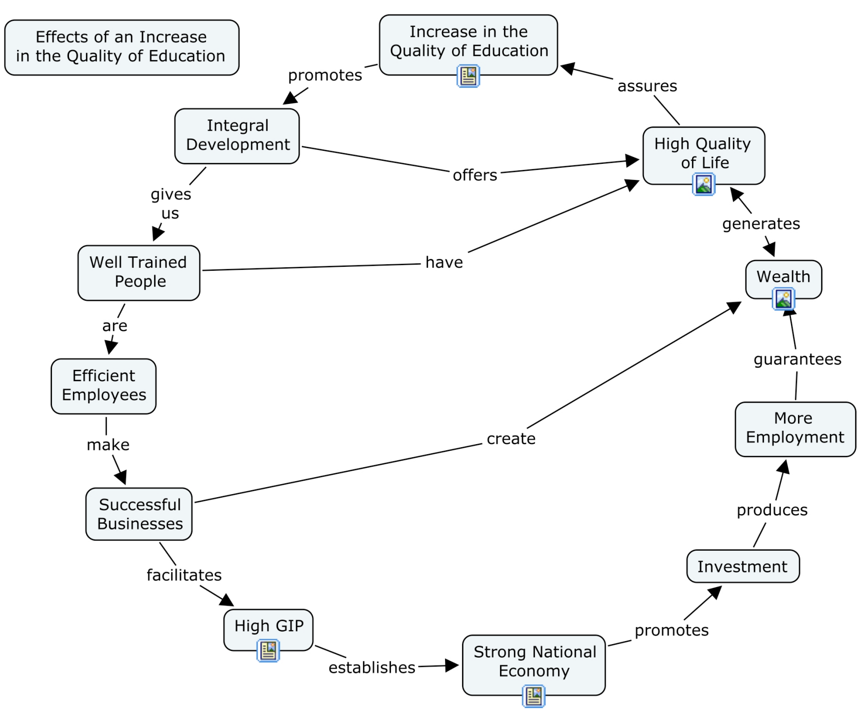

Figure 4. Cyclic concept map generated from a dynamic focus question and a quantified root concept.

The studies by Safayeni and colleagues serve to illustrate how much we have yet to learn about strategies for optimizing the use of concept maps for the encouragement of high levels of dynamic or meaningful learning. Their work also serves to illustrate the importance of constructing and using good focus questions. This has long been recognized, and it is one reason why CmapTools calls for the inclusion of a Focus question whenever a concept map is saved. Unfortunately, we often see that concept mappers fail to construct a focus question in advance of building a concept map, or they simply ignore the question as their map construction progresses.

6 Conclusions

Effective education programs provide for a wide range of learning activities including selected readings, Internet searches, project work, report preparation and presentation, drawings, video presentations, collaborative research, and other activities. With CmapTools, it is possible to develop a general concept map to serve as a framework for guiding these studies and as a tool to integrate all other learning activities into one highly organized *knowledge model*. These knowledge models can be shared with others, stored on a server, and used as an “archive”, that can serve as a starting point for future studies. In this concept map-centered environment, the concept map evolves from an initial ‘assessment’ of what students know about the topic being studied to a knowledge model reflecting the students’ progress. The extent to which the constructing concept maps help the student improve their understanding depends, to a large extent, on the quality and type of maps they build. Good questions, whether they come from the teacher, other students, or the concept mapper questioning him/herself, lead to better maps, a more dynamic thinking, and a deeper understanding. We would like to see more systematic research on this issue and encourage participants at this Conference to include research questions dealing with the nature and quality of questions and their effects on map properties and value for learning.

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