Concept Maps: Theory, Methodology, Technology
Proc. of the First Int. Conference on Concept Mapping
Pamplona, Spain 2004

A SCIENCE EDUCATION RESEARCH PROGRAM THAT LED TO THE DEVELOPMENT OF THE CONCEPT MAPPING TOOL AND A NEW MODEL FOR EDUCATION[1]

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1 Introduction

When I began my graduate studies in 1952 at the University of Minnesota, the only psychology of learning presented was *behavioral psychology*, based largely on research with rats, cats and other animals. The only philosophy of knowledge, or epistemology, I was taught was *logical positivism*, for which the Philosophy Department at Minnesota was world famous. I did not see much value in behavioral psychology as a theory to guide research on human problem solving and ways to enhance this ability, which was the subject of my PhD thesis. Nor did I see value in a view of knowledge creation that centered on proving axioms and logically deriving new knowledge from basic premises, a view that did not appear to apply to the work I was doing in laboratory research in the Botany Department.

Although there was the work of Bartlett (1932) theorizing on how cognitive learning takes place, and the extensive work of Piaget beginning in 1926 describing how children's cognitive operations advance over time, I was taught none of this. I did, however discover the writing of Conant (1947) and his ideas on how the science create new knowledge. Later his protégé, Kuhn (1962) would expand Conant's ideas in his enormously polpular, *The Structure of Scientific Revolutions*. Lacking a psychology of learning that made sense to me, I chose to base my research on Wiener's (1948) *cybernetic* ideas, and we continued with these ideas until our research data failed to fit the theory. Most fortunately Ausubel's (1963) *cognitive* psychology of learning was published about this time, and we embraced this as a foundation from 1963 onward. Today cognitive learning theories have essentially replaced behavioral theories, although much school learning still proceeds on behavioral learning principles, such as repetition and reinforcement.

One of the issues debated in the early 1960's was the extent to which children could profit from instruction on abstract, basic science concepts such as the nature of matter and energy. The dominant thinking in science education and developmental psychology was centered on the work of Jean Piaget (1926), particularly his ideas about cognitive operational stages. Piaget had devised some ingenious interviews administered to children, the results of which could be interpreted to support his theory of stages of cognitive operational development. It was widely assumed that children could not profit from instruction in such abstract concepts as the nature of matter and energy before they reached the formal operational stage of thinking at ages 11 or older.

The fundamental questions that concerned me and my research group were:

1. Are these claimed cognitive operational limitations of children the result of brain development, or are they at least partly an artifact of the kind of schooling and socialization characteristic of Piaget's subjects, and those commonly tested in US and other schools?
2. With appropriate instruction in basic science concepts such as the nature of matter and energy, can six to eight year-old children develop sufficient understanding to influence later learning?
3. Can the development of children's understanding of science concepts be observed as specific changes in their concepts and propositions resulting from the early instruction and from later science instruction?
4. Will the findings in a longitudinal study support the fundamental ideas in Ausubel's (1963) assimilation theory of learning?

Answers to these questions could only be obtained by first designing systematic instruction in basic science concepts for 6-8 year-old children, and then following the same children's understanding of these concepts as they progressed through school, including later grades when formal science courses were taken. This was the instructional development and research project we set out to do.

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

Development of instructional materials in our longitudinal study was by means of audio-tutorial lessons, in which children learned from audiotapes that we had developed and that were supplemented with film clips and equipment. The audio-tutorial lessons were based on ideas in the National Science Teachers Association report, *Importance of conceptual schemes for science teaching* (Novak, 1964), and an elementary science textbook series, *The World of Science* (Novak, Meister, Knox and Sullivan, 1966).

Figure 1. A six-year old child working with an audio-tutorial lesson dealing with plant growth.

Twenty-eight lessons were developed that dealt with the particulate nature of matter, energy types and energy transformations, energy utilization in living things, and other related ideas. For the most part, these kinds of concepts are rarely presented to elementary school children, especially to 6-8 year olds in grades one and two. Figure 1 shows an example of an early lesson on plant growth. All lessons provided audio-guidance through manipulation of materials in the carrel and other observations, including occasional “loop films” showing animations or time-lapse photography.

The principal principle of the Ausubelian learning theory we considered in the design of our lessons comes from the epigraph to his 1968 book:

> *If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.*

As my graduate students and I developed an idea for a new lesson, we would interview 6-8 primary grade children in an open ended interview, usually using some of the “props” we were planning to use to teach the central concepts of the lesson, such as pictures, materials to be manipulated, loop films or apparatus we were considering. These interviews gave us some idea of what anchoring concepts most of the children already had, and also gave some preliminary feedback on how they were interpreting or using the props. This process was often repeated several times, and again after lesson prototypes were developed. On average, each lesson underwent 6-8 revisions before it was deemed ready to use in classrooms. We also considered Ausubel’s ideas of *progressive differentiation* and *integrative reconciliation* in designing the lessons and lesson sequences (see the section on concept mapping for further discussion of these ideas). The idea of progressive differentiation requires that students build upon their prior relevant concepts, and elaborate concepts in earlier audio-tutorial lessons in a sequence as they study later related lessons. This required that some students needed to experience earlier lessons in a sequence before we could use these students to help develop later lessons. Furthermore, many concepts were revisited in later lessons, but with different examples or props to effect greater differentiation of concepts introduced earlier, and thus also to achieve integrative reconciliation of concepts that may have been initially confusing to a child or where meanings acquired may have been somewhat distorted. Photos and loop films were selected or constructed in many cases to serve as *advance organizers*. That is, we would use things that were familiar to the students, and we would build on the familiar to point them to see new aspects or dimensions of the new materials observed, much of this through the audio guidance.

2 Methodology of the 12-year Study

Ithaca Public Schools had 13 elementary schools, and for logistic reasons we chose to work with first grade teachers in five schools that were representative of the school district. A carrel unit was set up in the corner of the classroom of each of the participating teachers and 191 students in all took turns doing the lessons. These were our experimental or “Instructed” students, so called since very little science is taught in primary grades in Ithaca schools. In the second year of the study, we began to interview 48 students in the same classrooms and with the same teachers as the previous year, but these students did not receive the lessons. This was our control or “Uninstructed” sample. The timeline in Figure 2 shows the sequence of various events in the study that began in 1965 with the development of audio-tutorial lessons and was completed with the publication of the study results in 1991 (Novak and Musonda, 1991).

The lessons were placed in carrel units, usually in a corner of the classroom. The class teacher determined the time provided for student involvement with the lessons, but most often this was during “seat-work” times, or when the teacher was working with small reading groups. Students, one at a time, could take turns doing the audio-tutorial lesson. Some students observed others doing the lessons, and many students repeated lessons one or more times, often during recess, lunchtime, or other free time. Each lesson required approximately 20 minutes for a student to complete; thus the 28 lessons provided some 10-20 hours in carefully designed instruction over the two-year span of the instruction. Those teachers who included science in their instruction (a minority) usually dealt with topics such as seasons, clouds, and plant growth, but only in a descriptive manner and not including the basic science concepts such as energy transformations and the particulate nature of matter.

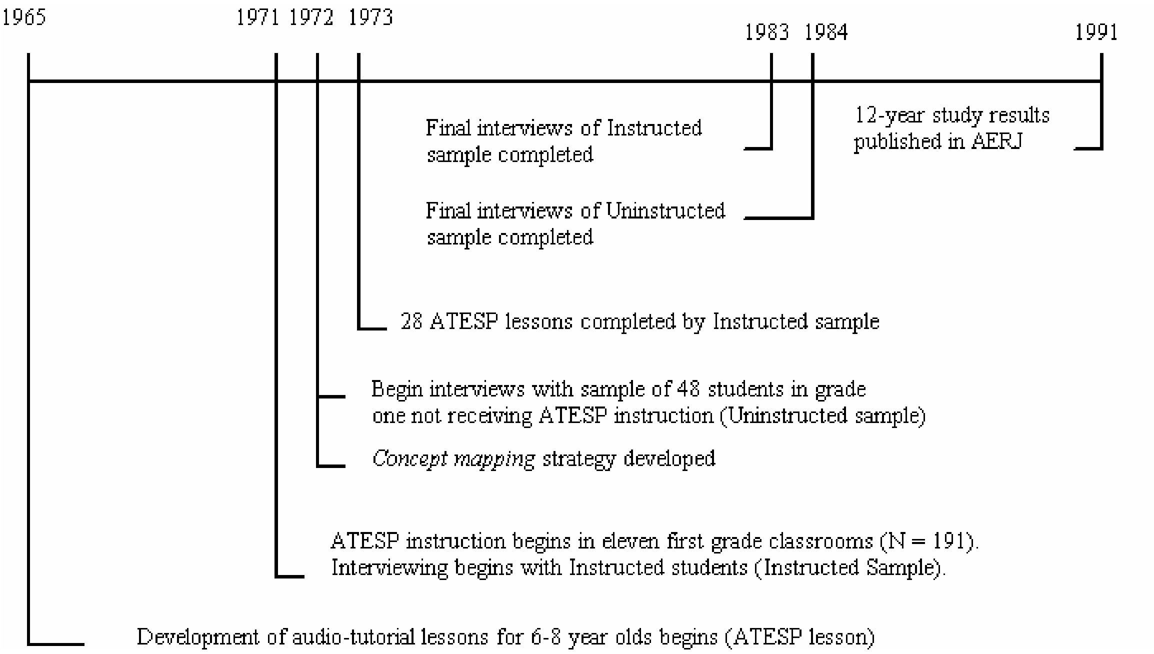

Figure 2: Timeline for the project.
*ATESP: Audio Tutorial Elementary Science Program

Each teacher we worked with reported excellent student response to the audio-tutorial lessons, and some of the teachers also noted their value for their own learning. None asked to be dropped from the study and most wanted to continue to use the lessons in future years.

Early in the study we developed various forms of paper and pencil tests, including tests with pictures that students marked with crayons following oral questions. We found in subsequent interviews with children that these paper and pencil tests were not valid indicators of the conceptual understanding of students. We subsequently chose to use modified Piagetian interviews as primary evaluation tools, with procedures as described elsewhere (Novak and Gowin, 1984, Ch. 7).

We designed interviews to use some of the materials that were in the lessons and other materials that were different but illustrated the same concepts. We prepared interview kits, and these were used by a number of different graduate students, with some instruction on how to do the interviews. Interviews were done with the Instructed students several times during the first year, including interviews on topics other than the nature of matter and energy. However, we found we did not have the staff resources to continue interviewing all Instructed and Uninstructed students on several domains of science, and chose to interview students only on concepts of matter, energy, and energy transformations. The same interview kits were used as the students progressed through school, and over the years. We also did not have staff to interview all students each year, and we had to choose a random sample from the Instructed and Uninstructed groups for later years of the study. All interviews were tape-recorded and some were also video-recorded. Ithaca has two junior high schools (grades 7-9) and one high school (grades 10-12). This made it easier to do follow-up interviews, especially in their high school years. We made a concerted effort to interview all students remaining in both the Instructed and the Uninstructed samples during their senior year and succeeded in interviewing 85 of the 87 students remaining in high school. Many children have parents who are students at Cornell or Ithaca College, and they leave Ithaca when their parents complete school. With the high attrition rate, we were perhaps a bit lucky that the remaining Instructed and Uninstructed students had almost identical SAT scores, indicating we could consider these samples to be comparable in general ability.

A single investigator could not carry out the large number of interviews, so throughout the project I was assisted by my graduate students. Graduate students do not, however, stay forever. The long period of time meant that over the 13 years of the study (counting the final year of data gathering from the Uninstructed students), 24 different graduate students and staff persons participated in the interviews and interview interpretations. This feature of the study may be unique. I patterned my research group after the models I had come to know as a teaching and research assistant in the Botany Department at the University of Minnesota. Our research group worked with a common, explicit theoretical foundation, we held seminars regularly to discuss out research, our instructional development efforts in several projects in addition to the work reported here, and where we found difficulties in or new insights in our work. This teamwork was essential to maintain the momentum and consistency in methodologies as our work progressed.

3 The Invention of *Concept Mapping*

As we continued interviewing children is our study, we were accumulating hundreds of interview tapes. When we transcribed the tapes, we could observe that propositions used by students would usually improve in relevance, number, and quality, but it was still difficult to observe specifically how their cognitive structures were changing. Our research team considered various alternatives we might explore, and we also reviewed again Ausubel’s ideas regarding cognitive development. Three ideas from Ausubel’s Assimilation Theory emerged as central to our thinking. First, Ausubel sees the development of new meanings as building on prior relevant concepts and propositions. Second, he sees cognitive structure as organized hierarchically, with more general, more inclusive concepts occupying higher levels in the hierarchy and more specific, less inclusive concepts subsumed under the more general concepts. Third, when meaningful learning occurs, relationships between concepts become more explicit, more precise, and better integrated with other concepts and propositions. The latter involves what Ausubel calls *progressive differentiation* of conceptual and propositional meanings, resulting in more precise and/or more elaborate ideas, and *integrative reconciliation*, or resolution of conflicting or ambiguous meanings or concepts and propositions. In our discussions, the idea developed to translate interview transcripts into a hierarchical structure of concepts and relationships between concepts, i.e., propositions. The ideas developed into the invention of a tool we now call the *concept map*. We now see the development of organized frameworks of knowledge not only the product of meaningful learning, but also the basis for creative thinking and the production of new knowledge (Novak, 1993).

We were somewhat surprised to find that we could rather easily transform the information in an interview transcript into a concept map. Figure 3 shows examples of concept maps we drew from interview transcripts for one above-average Instructed student at the end of grades 2 and 12. Note that while new concepts such as “atom” are assimilated into her cognitive structure, she also has acquired some new misconceptions. This is characteristic of students who learn sometimes by rote and sometimes at relatively low levels of meaningful learning. Figure 4 shows concept maps we drew from interview transcripts with one Uninstructed student at the end of grades 2 and 12. This latter student was obviously disposed to learn meaningfully rather than by rote, and he shows clear evidence of progressive differentiation and integrative reconciliation of his cognitive structure in this domain of knowledge. However, the mean quality of maps for Instructed students was substantially better than for Uninstructed students as will be shown below. We found that a 15-20 page interview transcript could be converted into a one page concept map without losing essential concept and propositional meanings expressed by the interviewee. This we soon realized was a very powerful knowledge representation tool, a tool that would change our research program from this point on.

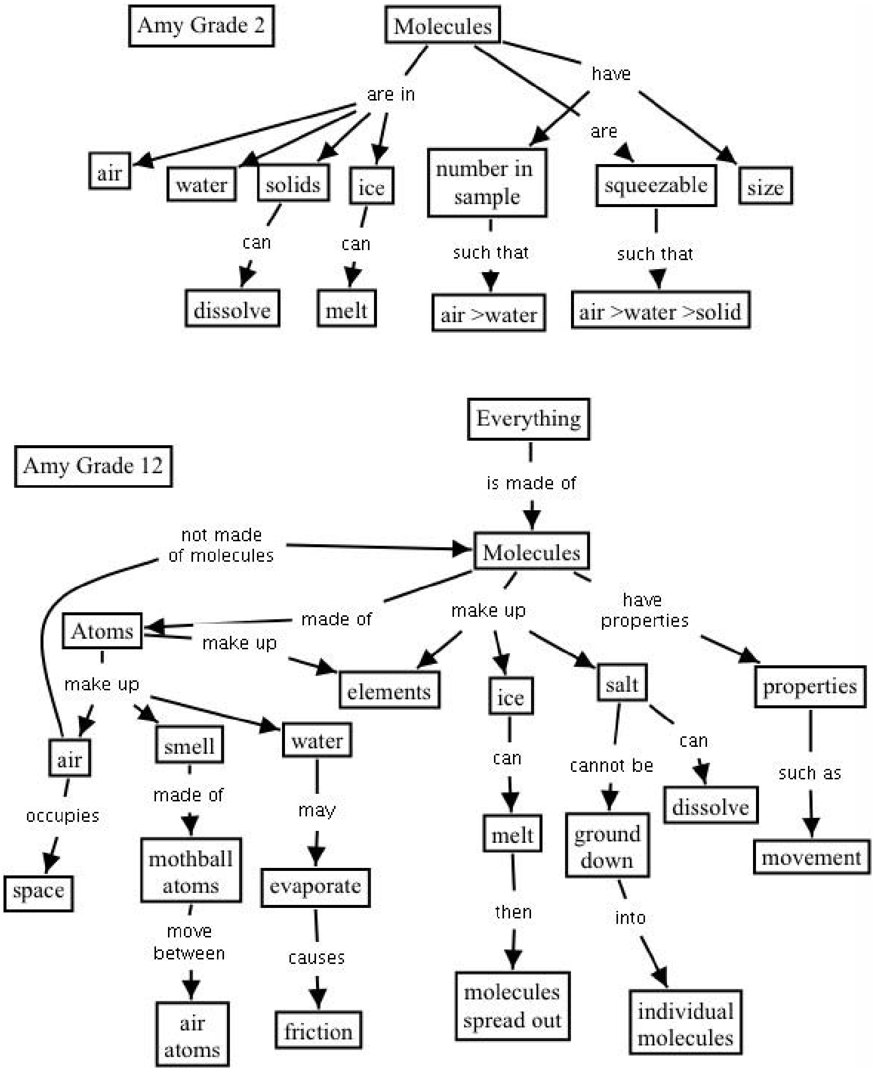

Figure 3: Two concept maps drawn from interviews with an above average Instructed student at the end of grade 2 and at the end of grade 12.

In the history of science, there are many examples where the necessity to develop new tools to observe events or objects led to the development of new technologies. For our research program, the necessity to find a better way to represent children's conceptual understandings and to be able to observe explicit changes in the concept and propositional structures that construct those meanings led to the development of what has now become a powerful knowledge representation tool useful not only in education but in virtually every sector of human activity. It should be noted that although there were other knowledge or semantic structure representations prior to our development of concept maps, most of these are not hierarchically organized, do not contain explicit single concept labels in the "nodes", and usually do not have "linking words" between the concepts that are necessary to represent propositional meanings. Other forms of knowledge representations have been described by Jonassen, Beissner, & Yacci (1993), as well as others.

For our research project, the use of concept maps drawn from structured interviews became the primary tools we used to ascertain what learners know at any point in their educational experience. While it does take an hour or two for an experienced person to make a concept map from a 20-30 minute interview transcript, the precision and clarity of the learner's cognitive structure represented this way made it relatively easy to follow specific changes in the student's knowledge structures as she/he progressed through the grades. We also used concept maps made by our research staff to identify valid and invalid notions held by students. It should be noted that these concept maps were made by many different graduate students over the span of the study, but still the consistency in the patterns observed for each student was remarkable. This illustrates in part the robustness and validity of this form of knowledge representation, as well as consistency in interviewer elicitations over time.

In our study, the researchers constructed the concept maps from the transcripts of the interviews with the children. Later, and not in the study, we got students to construct maps directly, by giving them key terms which they had to arrange in meaningful patterns and then connect with lines that they labeled with the nature of the relation between the terms. When students are taught how to do this direct form of concept mapping, it is possible to use the concept maps they draw to observe the initial state of a learner's knowledge in a given domain, as well as to monitor changes in their cognitive structure. Edwards & Fraser (1983) have shown that students' concept maps can be as revealing of learners' cognitive structures as clinical interviews. We have found student concept maps to be good indicators of their knowledge when learners have sufficient skill in concept mapping and motivation to construct their own concept maps. We did not attempt to have students in our samples construct concept maps, since the training in the use of concept maps was not feasible. While our longitudinal study was in progress, we made little effort to encourage the use of concept maps, since this may have confounded our study results. There were a few of the teachers in Ithaca schools interested in the use of concept maps, but most preferred to continue with their usual teaching practices. As Kinchin (2001) has observed, it is difficult to "fight the system".

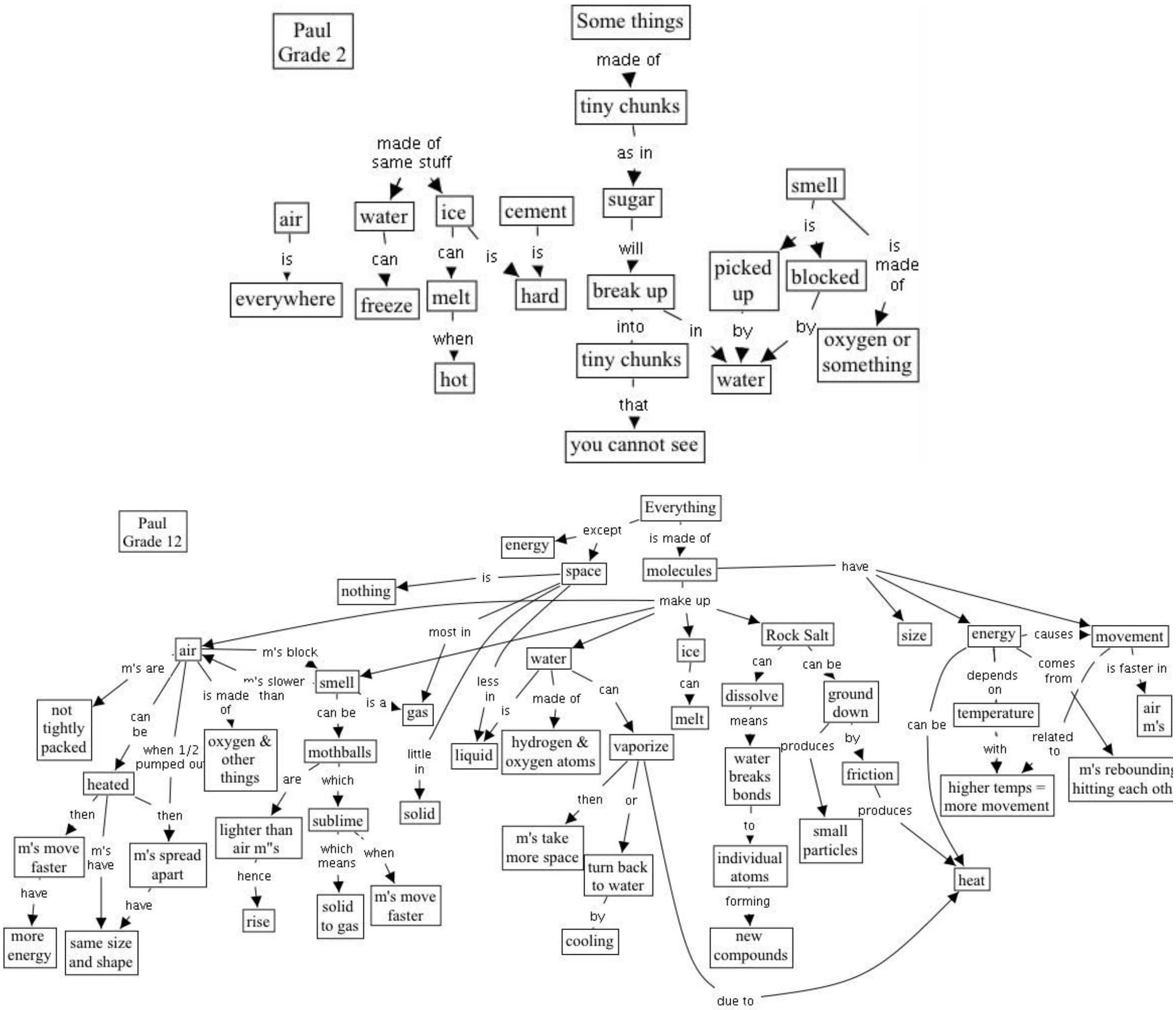

Figure 4.Two concept maps constructed from interviews with an exceptionally good Uninstructed student at the end of grades 2 and 12.

It is important to note that these explicit changes were observed in different interviews done by different graduate students over the span of 12 years. We were careful to have graduate students draw concept maps without knowing whether the interviews were with Instructed or Uninstructed children. The consistency with which the same valid or faulty knowledge structures were shown in concept maps drawn by different researchers illustrates the robustness and reliability of the technique of representing children's understandings in the form of concept maps. Subsequently other investigators have also found concept maps to be reliable, valid indicators of conceptual understanding and changes in relevant concept and propositional structures over time (Ruiz-Primo & Shavelson, 1996; Shavelson & Ruiz-Primo, 2000; Kankkunen, 2001).

4 Major Findings of the Study

Using the concept maps drawn from interviews as the primary source of information, we extracted valid and invalid propositions or notions evidenced in the concept maps. It was clearly evident that Instructed children had fewer and fewer misconceptions as they progressed through school, when compared with Uninstructed students. Conversely, the Instructed students had an increasing number of valid ideas or notions as they progressed through the grades. The results are shown in Figure 5. We see that by the end of grade 2 the Instructed students significantly outperformed the Uninstructed students in their understanding of energy and molecular kinetics ideas. When students begin the formal study of science in grade 7, both Instructed and Uninstructed students improve in their understanding of energy and molecular kinetics concepts, but a highly significant ($p<.001$) superiority of Instructed students compared with Uninstructed students was observed, both for valid and invalid ideas. Moreover, the Instructed students showed steady improvement as they progressed through high school science courses, whereas improvements for Uninstructed students were small. This significant difference in performance over the years for the Instructed and Uninstructed groups led to a significant interaction variance for years in school. Other statistical results have been reported elsewhere (Novak and Musonda, 1991). Clearly the students who were helped to form basic science concepts in grades one and two had developed their cognitive structure (their *subsumers*, in Ausubelian terms) for energy and molecular kinetics ideas in a way that continued to facilitate their meaningful learning, further developing their understandings and reducing their misconceptions. Such remarkable results shout for replication, but to my knowledge, no one else has attempted a 12-year longitudinal study of children's science concept development.

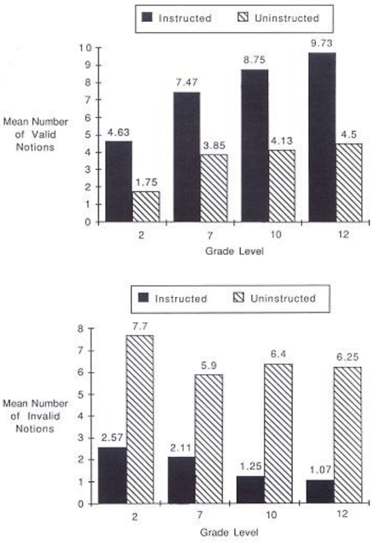

Figure 5: The number of valid and invalid) notions held by Instructed) and Uninstructed) students in grades 2, 7, 10, and 12.

It would appear in retrospect that we were successful with the great efforts we made to devise the right kind of experiences and sequences of experiences in the audio-tutorial lessons, and to provide the necessary concrete-empirical props most of the students needed to acquire the concepts presented meaningfully and substantively. In fact, the data suggest that many of the junior high school science courses failed to do this and hence many of the Uninstructed secondary school students did not progress substantially in their understanding of basic ideas about energy and the structure of matter. Limitations of Piaget's ideas capability of children to develop abstract ideas have been pointed out by others (Cf. Flavell, 1985).

The results reported here and in the published paper (Novak and Musonda, 1991) were initially met with some skepticism, since they fly in the face of the commonly accepted dogma. There remains in the science education literature an overwhelming commitment to the idea that only discovery or inquiry approaches to learning science can result in meaningful learning. Of course, most classroom teachers continue to use lecture and “cook book” laboratories in their teaching, and assessments requiring primarily recall of specifics, with the result that they confirm the limited value of this kind of instruction. What we achieved in our audio-tutorial instruction, and what we propose to do in future projects utilizing computer technologies and the Internet very significantly departs from the common form of classroom science instruction. While my position remains largely a minority position in science education circles, I have every confidence that the validity of the idea that young children can learn to a significant degree basic, abstract science concepts necessary for developing understanding of the wide array of concepts in all of the science disciplines will be validated in the next decade or so, perhaps in Latin countries if not in the USA. One only has to look at where we were in this country for half a century as *behavioral* psychology diminished at best, and prevented at worst, progress in developing a *cognitive* understanding of human learning. We have made great strides in better understanding what is required for science teaching to effect student understanding of science (Mintzes, Wandersee, and Novak, 1998; Bransford, Brown and Cocking, 1999). We have also made progress in identifying better ways to assess student’s understanding of science (Mintzes, Wandersee and Novak, 2000). What is needed now is a new longitudinal study utilizing the latest technological resources to provide the kind of instruction and guidance to teachers and students that could only be done rather crudely with audio-tutorial instruction, albeit the latter was shown to be effective in our work and the work of others (Fisher and MacWhinney, 1976). This new kind of program is described below.

Another significant outcome of the study was to illustrate the power of carefully designed, technologically mediated instruction. While admittedly we dealt with only a limited domain of science, we chose to focus upon the domain of molecular kinetics and energy transformations since this is a notoriously difficult area of instruction in science, especially at the elementary school level. Furthermore, an understanding of these ideas is essential to understanding almost all science phenomena.

5 Development of a New Model of Education

There was in our data strong support for the principal ideas in Ausubel’s Assimilation Theory of cognitive development and general support for the value of cognitive over behavioral psychological theories. Here again the psychological landscape has changed quite dramatically since the 1960’s, with virtually all educational psychologists moving to embrace *cognitive* theories of learning by 1990. In short, the cognitive learning and development ideas that were the foundation of our 12-year longitudinal study are now generally accepted, albeit much of this acceptance was based on hundreds of mostly short term “experiments” done by psychologists and educators, and many of these studies were driven by essentially positivistic epistemological assumptions. Nevertheless, there remains considerable debate in science education circles on the cognitive limitations of young children, and therefore what science should be taught in early grades. In my view, the American Association for the Advancement of Science’s *Benchmarks* (1993) and *Atlas* (2001) and the National Research Council’s *Standards* (1996) grossly underestimate the conceptual learning capability of younger children and unnecessarily and unwisely recommend postponement of instruction in basic energy and molecular kinetics ideas until the middle school years. This precludes the early development of these fundamental concepts needed to understand almost any of the concepts in science, and relegates the early years largely to descriptive studies of biological and physical phenomena. Our 12-year study, and the research of others noted earlier, would argue against postponing instruction in molecular kinetics concepts, as well as other basic science concepts.

Vygotsky (1928 in Russian; 1978 translated) introduced the idea of the “zone of proximal development” (ZPD), implying understandings a child has that can be built upon for further cognitive development. He anticipated Ausubel’s idea that meaningful learning must begin with what the learner already knows. One of the values of concept maps is that when children construct their own concept maps for a question or problem in any domain, they reveal with considerable specificity what is their developmental potential for the topic of study. Thus we are provided with a clear view of “what the learner already knows” and we can design instruction to build upon this. We generally recommend that children build concept maps in small groups, since the exchange that occurs between children can often serve to correct faulty ideas and promote meaningful learning. In part this results from the fact that the cooperating students are at approximately the same level of understanding, much more so than teacher and student. Cooperative learning confers an advantage to students over the usual independent, competitive teaching approaches (Qin, Johnson, & Johnson, 1995; Cañas, Ford, Novak, Hayes, Reichherzer, & Suri, 2001).

Another use of concept maps is to provide maps made by experts to serve to “scaffold” learning of students (O’Donnell, Dansereau & Hall. 2002). The idea of “scaffolding” learning goes back to early studies by Vygotsky where he described his studies showing that language and the social exchange using language can significantly enhance children’s cognitive development. Through proper use of language, adults can “scaffold” the learning of concepts by children. Although we were not aware of the scaffolding and ZPD ideas when we designed the audio-tutorial lessons, we were doing things congruent with these ideas. When we were designing our audio-tutorial lessons, we interviewed children to see what their thinking was about a particular concept or problem and then designed experiences that would build on what they knew and would extend their ideas by providing hands-on experiences and appropriate scientific vocabulary to explain the events they were observing. Perhaps one of the reasons the relatively brief instructional experiences children had in audio-tutorial lessons in grades one and two had such a sustained impact on their later learning in sciences was that we were on the right track in working within children’s ZPD and using activities and appropriate language to “scaffold” their learning.

Over the years that our longitudinal study was in progress, we became increasingly aware of the extent to which school learning programs lead most students into predominantly rote modes of learning. Some children, for reasons of their genetic make-up or early childhood experiences, resist the effect of school instructional and assessment practices that push students towards rote learning patterns. We have found that interviews and questionnaires can be used to assess individual’s proclivities to learn by rote or meaningfully, with most people falling somewhere along a continuum from very rote learners to highly meaningful learners (Edmondson and Novak, 1993; Bretz, 1994). We wish now we had been more aware of the problem of commitment to rote learning and had made assessments of our students in grades one and subsequently of their preferred learning approach. It is likely that such data would have tracked well those students who progressed in their conceptual understandings over the 12 years, and those students who made little progress in their conceptual understanding. While it may be wishful thinking to consider that the audio-tutorial program would have shifted some children’s patterns toward meaningful learning, it would have been wise to at least monitor this parameter. I would urge other researchers doing longitudinal studies to monitor their subject’s disposition to learn with greater or lesser commitment to meaningful learning.

We have also found in our more recent research that it is useful to assess individuals’ commitments to constructivist versus positivistic epistemological views (Edmondson and Novak, 1993; Chang, 1995). In general, we observe that learners who are more constructivist in their epistemological orientation are also more likely to employ meaningful learning strategies than learners who are more positivistic in their orientation. In recent years there has been a large increase in papers published in the *Journal of Research in Science Teaching* dealing with epistemological issues, including a recent paper by Sandoval & Morrison (2003) that deals with the relationship between learning approach and epistemological views held be students. I would urge researchers doing future longitudinal studies to include measures of learner’s epistemological ideas, as well as their learning approach.

Audio-tutorial technology is now obsolete, and we have vastly more opportunity to facilitate learning in the sciences as well is in other fields using computer guided instructional strategies and excellent software available for concept mapping, such as the CmapTools (Cañas et al., 2004) software available to schools at no cost from the Institute for Human and Machine Cognition (www.ihmc.us). I see great promise for instructional strategies that combine the use of “expert” concept maps to scaffold student (and teacher) learning using the Internet in conjunction with CmapTools software, inquiry activities and collaborative learning, as I have described elsewhere (Novak, 1998; 2003). These new tools and approaches should provide some very exciting research opportunities for future longitudinal studies that will show the potentials that young minds possess that are not being developed adequately in schools today.

A full discussion on the use of “expert” concept maps to scaffold student and teacher learning using CmapTools with the Internet and related laboratory and field experiences is beyond the scope of this paper. It will be discussed further in the closing lecture for this Conference, titled “Building on New Constructivist Ideas and CmapTools to Create a New Model for Education” (Novak and Cañas, 2004).

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Underlying the research program and the development of the concept mapping tool was an explicit cognitive psychology of learning and an explicit constructivist epistemology, described briefly in this paper. Keywords. Cognitive Structure Knowledge Model Meaningful Learning Digital Resource Basic Science Concept. These keywords were added by machine and not by the authors. This process is experimental and the keywords may be updated as the learning algorithm improves.Â Washington, DC: National Assn. for Education for the Education of Young Children.Google Scholar. Bransford, J., Brown, A. L., & Cocking, R. R. (Eds.). (1999). How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press.Google Scholar. Cardemone, P. F. (1975). Concept mapping tool and a new model for EDUCATION1. Joseph D. Novak. Cornell University. Institute for Human and Machine Cognition. jnovak@ihmc.us, www.ihmc.us. 1 Introduction. When I began my graduate studies in 1952 at the University of Minnesota, the only psychology of learning.Â 3. Can the development of childrenâ€™s understanding of science concepts be observed as specific. changes in their concepts and propositions resulting from the early instruction and from later. science instruction? 4. Will the findings in a longitudinal study support the fundamental ideas in Ausubelâ€™s (1963). assimilation theory of learning? Answers to these questions could only be obtained by first designing systematic instruction in basic science.