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ABSTRACT

This paper reports on the analysis of concept maps of the nature of science constructed by preservice secondary science teachers during a semester-long reflective process. During the 16-week fall semester of 1996, 17 students were enrolled in a 5-credit course. After analyzing all students' concept maps, students were classified as either good mappers or poor mappers. Two students were selected to investigate conceptual development and change from their initial concept maps to their final reflection paper. These case studies reveal some issues that need to be sorted out, including: (1) students did not revise their concept maps over the semester; (2) the issue of the value of science remained unsettled; (3) students focus more on the instability of scientific knowledge rather than on its stability; and (4) few students integrate the scientific assumptions discussed in class into their concept maps or papers. These findings have the potential to inform understanding of how to prepare science teachers. Contains 19 references. (DDR)

PRESERVICE SECONDARY SCIENCE TEACHERS' CONCEPTIONS OF THE NATURE OF SCIENCE:

By Investigating Their Concept Maps and Final Reflection Paper

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ABSTRACTS

An important objective of science education is an adequate understanding of the nature of science. Teachers of science have been charged with the responsibility for achieving this objective. However, the training and experience of many teachers has been dominated by the product of science, scientific explanations and terminology, and they have had little direct experience with scientific methods, values, and assumptions. One of the objectives of methods courses in teaching science is to provide prospective teachers with an understanding of the nature of science so that they are able to help their students appreciate what science is and how it accomplishes its goals. This paper reports on the analysis concept maps of the nature of science constructed by preservice secondary science teachers during a semester-long reflective process. Two students were selected to investigate conceptual development and change from their initial concept maps to their final reflection paper. Results inform our understanding of preparing teachers of science.

INTRODUCTION

An important objective of science education is an adequate understanding of the nature of science (Lederman, 1992; Hazen & Trefil, 1991; Rutherford & Ahlgren, 1990; American Association for the Advancement of Science, 1989). A common view of the nature of science is that it consists of certain methods, values, and assumptions that are inherent in the construction of scientific knowledge (Lederman & Zeidler, 1987). Teachers of science have been charged with the responsibility for achieving this objective. Many teachers, however, lack a sufficient understanding that would enable them to help students construct their own understandings. Their training and experience has been dominated by the product of science, scientific explanations and terminology, and they have had little direct experience with scientific methods, values and assumptions. One objective of methods courses in teaching science is to provide prospective teachers with an understanding of the nature of science so they are prepared to help students appreciate what science is and how it achieves its goals.

THEORETICAL FOUNDATIONS

Constructivism

Learners construct their own meaning concerning a reality that exists independent of human activity. Science students have the task of constructing meaning that correspond to explanations constructed by scientists. The meanings constructed by both students and scientists are socially negotiated. In some cases, that negotiation is a process of give and take, compromise, and consensus building (e.g., science related social issues). The negotiations of scientists, however, are guided by data, interpretations of those data, and a progressive discourse among scientists to advance scientific knowledge. In yet another sense, teachers assist students in negotiating the difficulties, pitfalls, or obstructions that are obstacles to student construction of appropriate meanings (Prawat & Floden, 1994; Bereiter, 1994)

Reflection

Donald Schon (1983) describes expert practice as an artful inquiry into situations of uncertainty. Professionals engage in "reflective conversation" with the uncertain situation, taking stances, experimenting, and learning from the "back-talk" of the situation. Current reform efforts in teacher education are guided by such models of reflective practice. Theoretical underpinnings in cognitive psychology, as well as other forces, are pushing education and especially professional education toward learning through problem solving, authentic projects, apprenticeships and field experiences, and toward learners who act as reflective practitioners. Concept mapping provides science education students with opportunities to participate in "reflective conversation" with teachers, peers, field-based mentors, and students.

Concept Mapping

During concept mapping, each student uses his or her own knowledge structures to map the relationships between concepts using propositional links (Ault, 1985; Novak, 1981; Stewart, 1978). These individual representations of relationships among a set of concepts that exist in the learner's mind are useful to both the student and teacher in assessing the depth of understanding regarding a particular topic.

Concept maps can be an effective metacognitive tool in facilitating one's construction of knowledge. Increasingly, concepts maps are being used in a variety of instructional settings as both learning and research tools (Novak, Gowin, & Johansen, 1983; Cliburn, 1990), especially regarding their use to promote meaningful learning. For example, concept mapping has been found to be an effective strategy in helping undergraduate elementary science methods students practice and monitor knowledge construction (Wallace & Mintzes, 1990). Jay (1994) examined a concept mapping strategy as a metacognitive reflection tool in a secondary science methods course.

Nature of Science

Scientific inquiry is understood to be driven by four major epistemological concerns: scientific assumptions, knowledge, processes, and values. The work of scientists is predicated on the assumptions that there is an underlying order to natural phenomena in the universe, this order is caused by rules that are not capricious, and the rules are knowable and understandable (Trowbridge & Bybee, 1990). They use their present knowledge, in the form of concepts, principles, theories, and laws, to guide them in their search for patterns and regularities in natural objects and events (Rutherford & Ahlgren, 1990). New understandings of those patterns, relationships, and basic rules result. Scientists value logic. They have a reverence for data and evidence. The scientific community demands that results be replicable so that they can be verified and their interpretation discussed and negotiated. The meanings constructed in this way are considered to be tentative and open to revision as new data causes the previous body of facts to be reinterpreted. Despite their tentativeness, scientific knowledge is relatively stable.

RESEARCH QUESTIONS

An understanding of the nature of science is required if teachers are to help their students construct their own appropriate views of science. An instructional strategy emphasizing reflection in a number of contexts, including concept mapping, were used with undergraduate secondary science education students. Two research questions were formulated to evaluate the role of concept maps in facilitating students' conceptual development and change regarding the nature of science.

- What are the preservice secondary science teachers' conceptions of the nature of science at the beginning and the end of the secondary science methods course?
- How do preservice secondary science teachers' conceptual systems

regarding the nature of science change throughout the semester?

METHODS AND PROCEDURES

Subjects

During the 16-week Fall semester of 1996, 17 students were enrolled in a 5-credit (6 contact hours) course concerning teaching science in secondary school. The course included both general teaching methodologies as well as those specifically related to teaching science. Students took this course toward the end of their academic preparation for teaching. Student teaching experience occurred during one of the following two semesters. Eleven students were female; six were male. Fourteen were undergraduates pursuing a bachelor's degree in science education. Three were enrolled as post baccalaureate students to take courses required to teach science at the secondary level.

Treatment

To promote conceptual development and change with respect to the nature of science, students engaged in several activities that spanned 14 weeks of the semester: a reading, an initial exploration activity, electronic journaling, concept mapping, a portion of a final reflection paper, and an exit interview. Similar activities were also conducted for four other topics: science literacy; goals of science education; structure of the discipline; and theories, principles, and practices for the teaching of science. The purpose of the preliminary **reading** (Trowbridge & Bybee, 1990, pp. 47-58) was to orient students to the topic. Based upon their understanding of this reading, each student then obtained a journal article that related to the nature of science. The **initial exploration activity**, *The Card Exchange* (Cobern, 1991), allowed student to interact with one another to begin clarify their present views concerning the nature of science and to appreciate the range of views held by their classmates. This activity was followed by the class discussion. Over the next two weeks, students engaged in **electronic journaling**. During this period, they were to make six contributions to a discussion held on a class listserve. Following this exchange of views, each student created a **concept map** that showed his or her understanding of the nature of science. These concept maps were to be reviewed and updated every two weeks over the rest of the semester. Students constructed their concept maps electronically using the software PIViT (Brade, Krajcik, Blumenfeld, Soloway, & Marx, 1995). Students submitted a **final reflection paper** that addressed the nature of science and the four other topics listed above. These papers went through a peer review and a revision before submission to the instructor. This paper focuses on the students' concept maps of the nature of science and the comparison of two students' concept maps with the nature of science portion of their final reflection papers.

Data Collection and Analysis

Three concept maps regarding the nature of science were collected from each student over a six week period of time. Maps were analyzed by evaluating concepts, linking words, links, and levels of hierarchy using the rubric provide by Novak and Gowin (1984). After the initial analysis, two students were chosen for additional analysis. Criteria for selecting students included contrasting technical ability at concept mapping and providing valid concepts and propositions regarding the nature of science.

Selection Procedure

After analyzing all (N=17) students' concept maps, the first researcher classified students into good mappers and poor mappers. The criteria for judgment were based on appropriate/inappropriate propositions, overall cognitive knowledge constructions, and technical skills in constructing concept maps. The total number of revised concept maps was not considered as a selection criterion because 11 out of 17 students did not revised their concept maps. Eight students were included in the group of good mappers, and 9 students in the group of poor mappers. In this paper, one student was selected from each group: Martha from the group of good mappers, and Zack from the group of poor mappers.

RESULTS AND DISCUSSION

The artifacts for two case studies consist of three concept maps, a portion of a final paper, and a concept map of the final paper constructed by the investigators. The students discussed here provided insight into the conceptual growth of students attempting to construct new understanding of the nature of science. Students were frequently surprised at their lack of understanding of science as a way of knowing despite several courses in science. These case studies of Martha and Zack reveal some of the issues they needed to sort out. An analysis of 17 students concept maps and the levels of evidence can be found in Kim, Germann and Patton (1998).

Case Study 1 (Martha)

- Martha did not revise her first concept map. Her second and third concept maps were essentially identical to the first. A concept map of her final paper, however, did reveal conceptual change.
- Her concept map attributed three major components to the nature of science: scientific knowledge, ways of knowing, procedures and standards. Science methods was described under scientific knowledge and not considered a major component.
- Martha's final paper included inquiry methods, scientific knowledge, ways of knowing. Scientific methods had now gained the status of major component of the nature of science.
- While the concept of scientific knowledge was relatively undifferentiated in her concept map, it was more thoroughly described in her final paper.
- Martha's conception of scientific knowledge included a role for a diverse community (presumably the scientific community) in modifying and restructuring scientific knowledge.
- Martha included in her final paper that "the knowledge itself is what enables predictions and temporary explanations to be made that further explore the nature of science." It was not at all clear what she meant by this.

- Among different forms of scientific knowledge, she included the concept vocabulary. The inclusion of this concept may have been a function of the prominence of vocabulary and definitions in traditional science courses.
- Martha subsumed applications and technology under scientific knowledge in her final paper. This suggested that she did not perceive technology as a separate way of knowing but as an attribute of science.
- Scientific methods were represented by the term "guided inquiry" in her concept map. This indicated that Martha had not yet properly accommodated and assimilated this concept. She used the term "inquiry methods" in her final paper.
- The term "experiments" was used in its broad meaning of inquiries or investigations rather than into narrow meaning of testing cause and effect relationships under controlled conditions.
- She elaborated on the concept of observation in her final paper. Note that Martha associated the idea of discovery with observation.
- A puzzling concept in her final paper was the statement that "analysis and synthesis are integral responses to many methods, and both require that individuals are able to define the nature of science."
- It was not clear whether Martha was using the term values with a meaning aligned with morality and ethics or with scientific traits scientists value: reverence for data, demand for replication, respect for logic . . .
- Class activities used the idea of ways of knowing in the more global sense of placing science among other views of knowledge, e.g. engineering religion, literacy, everyday ways of knowing. In both her concept map and her final paper, Martha used this concept to refer to a diversity of mindscapes (i.e., belief system) that included an interaction between scientists, community, and society.
- In her concept map, Martha included recent science education reform movements within the nature of science under the concept name of "procedures and standards". This

clearly inappropriate attributes were not included in her final paper. However, since she did not differentiate the concept in her paper, it was unclear what she actually meant.

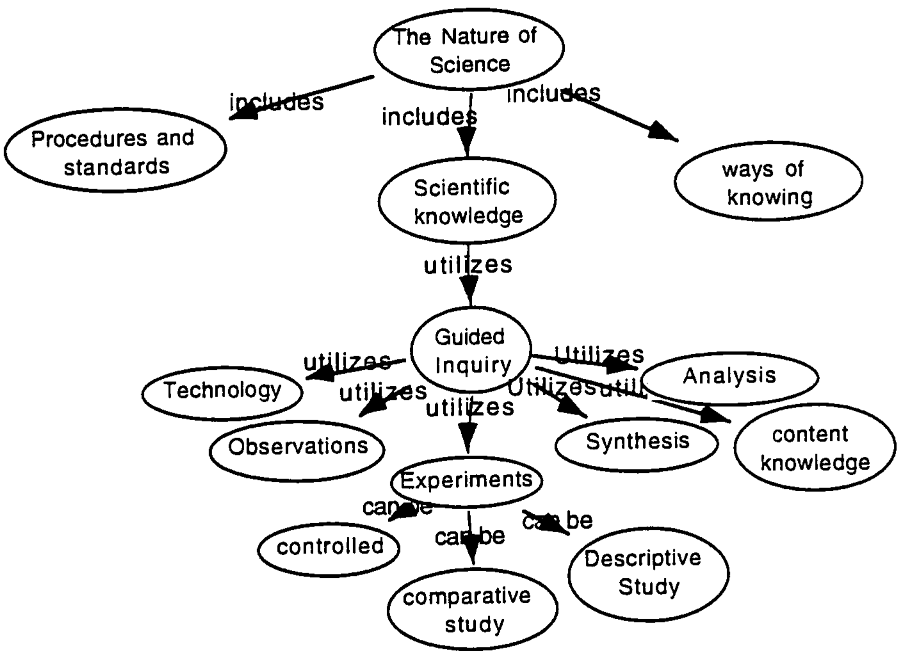
<u>Case Study 2 (Zack)</u>

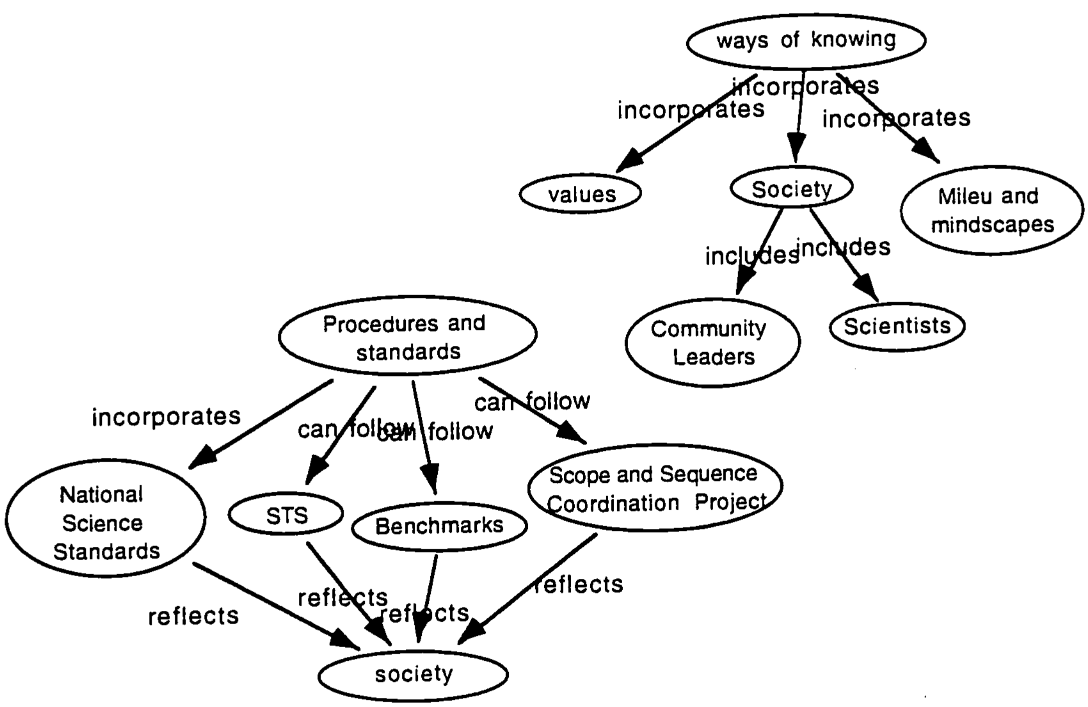
- Although three revised version of the concept maps were requested, Zack did not change the representation of his views in concept maps 2 and 3.
- Zack's concept maps included a branch on diverse interpretations of science depending on one's religious beliefs, morals and ethics, cultural background and scientific background. This reflects a general concern of students for these issues at the start of the semester evident in their electronic journaling. In the final paper, Zack dropped this issue.
- The attributes assigned to the nature of science in Zack's concept map were that "science is always changing, is a method of explanation, has many interpretation and is an explanation process." The product or knowledge component of science was represented by science as a method of explanation. The process, dimension was also represented.
- Attitudes, values and assumption of science were misrepresented by religious beliefs, morals and ethics, and cultural background.
- In the final paper Zack changed his view of science as an explanation, process, including scientific methods, to well-differentiated concepts of process and methods. Process now included the ideas of classifying, organizing, concluding and revising. His description of methods focused on its step-by-step nature and the need to be unbiased. The step-by-step view was moderated by allowing that scientists may make "jumps in information and conclusion, but the general flow of discovery is steady." The meaning of the last phrase was ambiguous in this context.
- With the concept of adaptability, Zack wrestled with the tentative yet stable nature of scientific knowledge. On the one hand, he believed that the fundamentals can remain unchanged, but asserts that new information may change prior facts. In the next sentence, he qualified this by writing that the old ideas do not necessary change but are reinterpreted, providing different ways of understanding them.

In summary, the following generalizations have been made.

- Students did not revise their concept maps over the semester. There may be several reasons for this. Many students felt that they had no changes to make even though new learning activities had provided opportunities to clarify and deepen their understanding. In the time constraints of dealing with course work and other responsibilities, students admitted in exit interviews that they took the easy way out. Also they questioned the need to redo an assignment that was already "done."
- The issue of value was not settled despite explicit discussion about the meaning of the word in the content of "values of science" (i.e., what do scientists value.)
- The concept of the "tentative yet stable" nature of science was expresses by students as scientific knowledge was "always changing." They seem to be more focused on the tentative nature of scientific knowledge and have limited understanding of its stability. Scientific methods showed progress from a poor understanding to a somewhat better view, students still have difficulty considering the highly fluid and dynamic nature of scientific inquiry.
- Although the assumptions of science were addressed through a reading and class discussion, few students incorporated these concepts into their maps or paper.

CONCEPT MAP OF MARTHA





FINAL PAPER OF MARTHA

To be an affective educator, one must first understand all the intricacies of the nature of science. Science is a complex discipline that is influenced by many outside forces. This in turn gives individuals a belief system that scientific processes have gone through a process of checks and balances and therefore people have confidence in those theories. The nature of discipline incorporates various methods, knowledge, and ways of knowing that give credibility and confidence to the current scientific schools of thought. Without these basic guidelines, very little about science would be reliable.

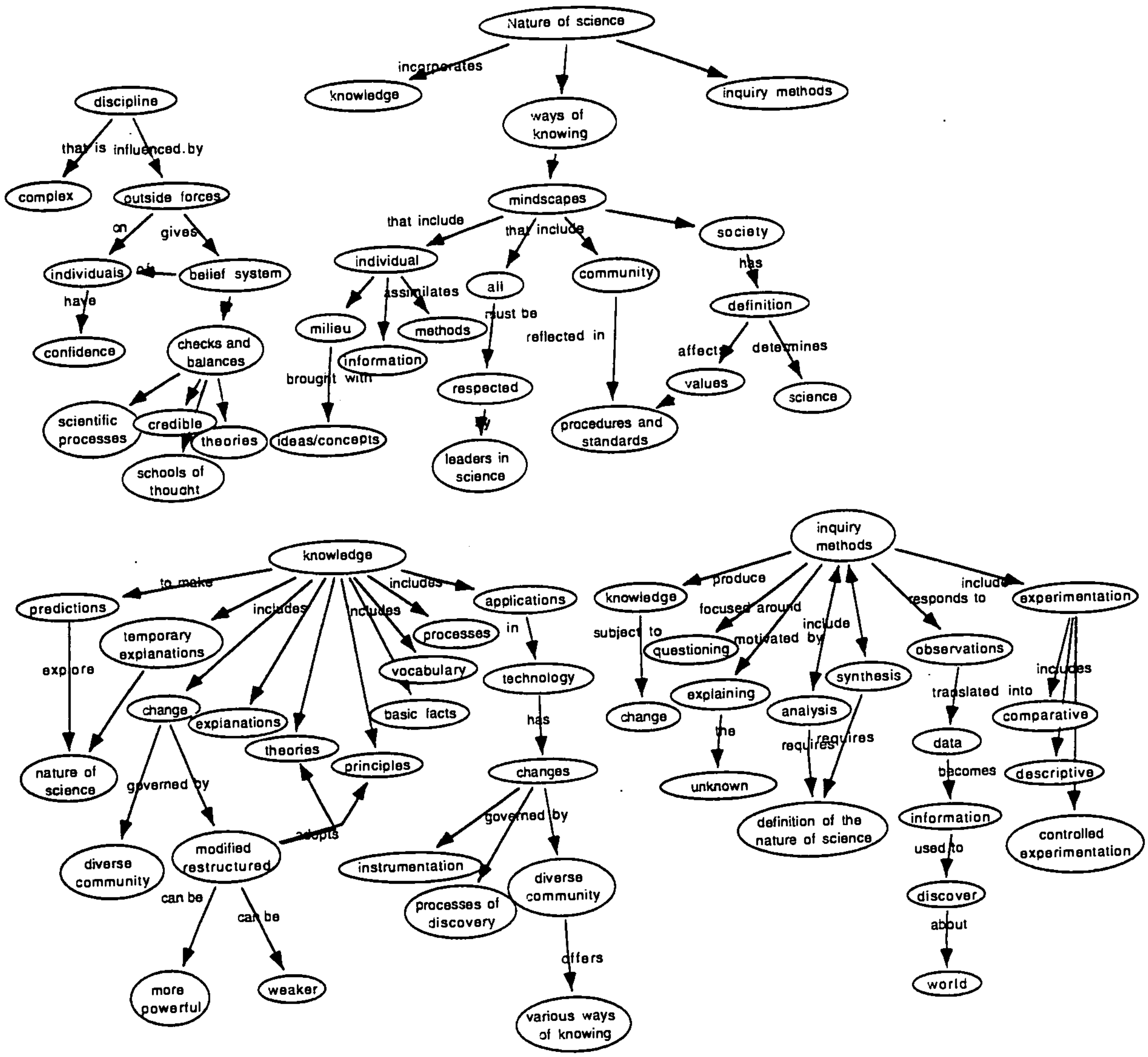
Science has developed its own method of inquiry or questioning. The discipline is forced around questioning and relies on the motivation of explaining the unknown. Inquiry is just a portion of a scientific method. Analysis and synthesis are integral to many methods, and both require that individuals are able to define the nature of science. Other methods utilized in understanding the nature of science are the roles of experimentation and observation. Experiments are performed regularly. A variety of studies may be examined to obtain data: comparative studies, descriptive studies, and controlled experiments. The observations made during these studies can then be translated into data, and the subsequent information can then be used to discover more about the world. The processes and methods of science produce knowledge. "Inevitably, any scientific knowledge is subject to change because new observations and experiments will result in knowledge that challenges extant explanations" (Understanding Science and Technology, Chapter 3).

Through scientific methods question knowledge, the knowledge itself is what enables predictions and temporary explanations to be made that further explore the nature of science (Understanding Science and Technology, Chapter 3). Scientific knowledge is in a continuous modification and restructuring process, the most powerful of knowledge/explanations tends to survive while the weaker of the theories are discarded. As a result, the scientific community adopts theories and principles that can withstand the test of time. Scientific knowledge can also include basic facts, vocabulary, and processes, as well as the application of that information. Technology has emerged as an ideal of the obtained knowledge are not only governed by instrumentation and processes of discovery, but also by a diverse community offering various ways of knowing science.

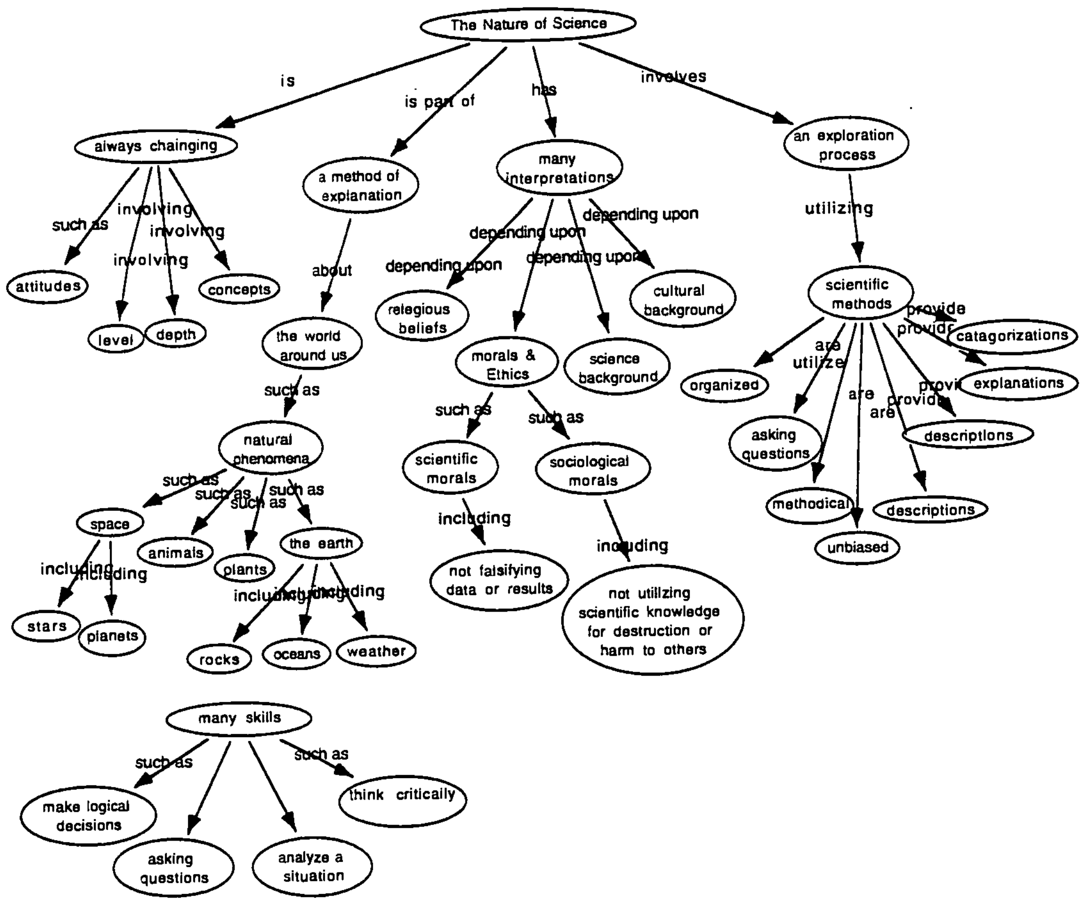
Science is a discipline influenced by a variety of sources, each contributing their own ways of knowing the discipline. With each science idea/concept, an individual brings his or her own milieu. As a result, information and methods are assimilated to fit into a person's "model mindscape." It is imperative that science must respect all mindscapes and work within those bounds. The subject is also influenced by societal pressures. These reflect a community of mindscapes, therefore they should be respected by leaders in science. Society's definition also greatly affects the sciences, as well as determining the values of the discipline. With the help of the community, the procedures and standards of science reflect the values representative of the society.

Unique bodies of knowledge, methods, and ways of knowing are used in science and technology. The three concepts emulsify to form what is known as the nature of science. Science originates from question about the natural world, procedures and methods are used to obtain knowledge, and ultimately society determines the value of that knowledge. Unfortunately though, it has provided individuals a fascinating process to explain the universe.

CONCEPT MAP OF MARTHA'S FINAL PAPER



CONCEPT MAP OF ZACK



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FINAL PAPER OF ZACK

In order for an instructor to effectively teach science they need to have an understanding of the nature of science. Science is a discipline that can be used to explain the unknown (Schmidt, REJ1A). The versatility of science enables it to be used to explain virtually everything in the entire world. Science explains both known and previously unknown phenomena.

There is not one set way for an individual to "do science," rather, science as a whole is a collection of different methods and processes, The ultimate goal of these processes is to answer the question "Why?" By answering this question science can also be thought of as a mean of classifying data and organizing ones thoughts into logical ideas which can be used to explain and describe events, processes, and organisms. In addition to this, the conclusion to the question "Why?" of one scientist may stimulate the thoughts of another resulting in new conclusions and revisions to existing ideas.

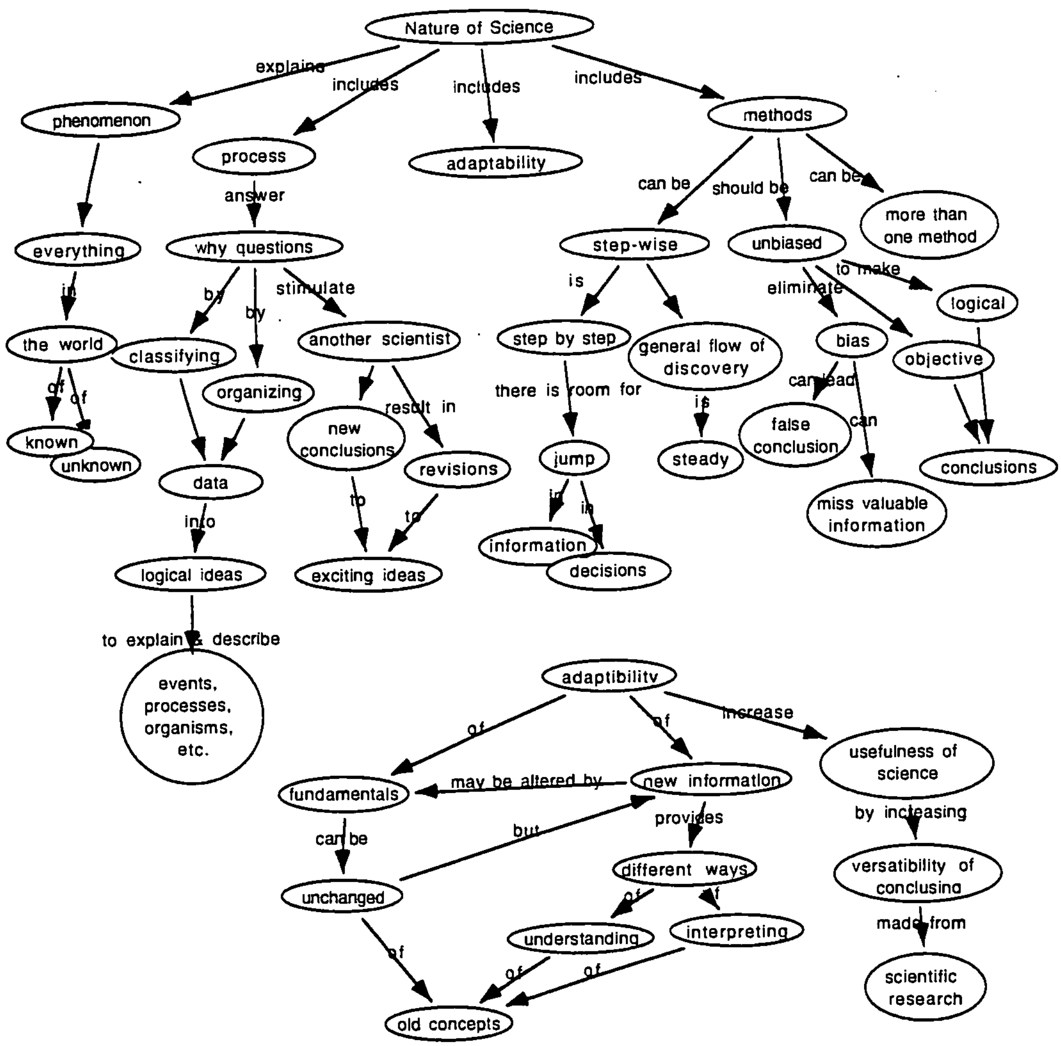
The ability of science to be revised and changed contributes to a changing nature of science as a whole. The fundamental ideas in science can remain unchanged for many years, but there is potential for new information to alter what was previously held to be a fact (Thornhill--REJ1A). The new information does not necessarily change old ideas, rather it generally results in different ways of understanding or interpreting old concepts. This adaptability does not weaken science, rather it increases the usefulness of science by increasing the versatility of conclusions made from scientific research.

Scientific research differs depending upon what is being investigated. There is not one set scientific method, but there is a consistent group of characteristics native to scientific research. The first is that scientific processes involve an organized step-wise process (Tappe--REJ1A). This step-wise process proceeds in a methodical step by step approach from point "A" to point "B" (Tappe--REJ1A). There is room for jumps in information and decisions, but the general flow of diversity is steady.

The other characteristic universal to all scientific methods is the purposeful lack of basis in any form (Tappe--REJ1A). This is a necessary trait because if a scientist allows a bias in any form to enter decisions that have reached, the risk of drawing false conclusions or missing valuable information is high. Scientists eliminate this risk by eliminating bias and attempting to be objective and logical in the conclusions that they reach.

The conclusions that scientists reach are useless there are people who utilize them either directly or indirectly. This use of scientific knowledge can occur on many levels and is referred to as science literacy.

CONCEPT MAP OF ZACK'S FINAL PAPER



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