Developing Preservice Elementary Teachers' Understanding of Science:

An Integrated Inquiry and Metacognitive Approach

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Abstract

In an attempt to better support the mathematics and science learning experiences of preservice teacher candidates, a new course of study was created as part of a teacher certification program at a mid-Atlantic liberal art university. Entitled Investigations in Science and Mathematics, the two semester course adopted an integrated inquiry and metacognitive pedagogical approach in compliance with the national reform movement. This paper reports some preliminary results of a study that aims to examine the alignment of the course with national standards documents and to explore its effects on the development of the prospective teachers' metacognitive awareness and understanding of science and mathematics. An examination of course syllabi, instructor interviews, and a course content survey are used to determine the course's alignment with national standards documents. Views of the Nature of Science questionnaire are administered to students in a pre/post fashion followed by interviews. Students' course materials (i.e., unit summaries) are evaluated for content to note the development of mathematical and scientific understanding. The results indicate that the course is aligned with the national reform movement, preservice teachers' views of the key NOS aspects are developed with various degrees and understandings of mathematics and science appear to be enhanced. Implications for future research are discussed. (Contains 3 tables and 3 appendices)

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Whereas the literature indicates a strong correlation between student achievement in K-12 science and mathematics and teaching quality and level of knowledge of K-12 teachers of science and mathematics (National Research Council, 2001), there have been concerns nationwide with the cyclical pattern of mathematics and science avoidance that had developed among preservice elementary teachers. The literature suggests that preservice elementary teachers had not only avoided taking mathematics and science courses, consequently they were poorly prepared to teach those subjects when they became teachers (Fulp, 2002; Freeman & Smith, 1997).

To address the nation's need for highly qualified educators that would be able to prepare scientifically literate future citizens, faculty from education, science, and mathematics departments at a small private urban university developed a year long science course, taught as a two course sequence (8 credit hours) for their elementary and special education candidates. The two science courses were titled Investigations in Science and Mathematics (IMS 160 and IMS 161), with a strong math component. By using the national standards of science and mathematics education and other current education reform documents as a guide (AAAS, 1993; NRC, 1996; NCTM, 1989, 2000), the faculty initially piloted the IMS 160 for one semester (4 credit hours) and then expanded it to a full year, two-course sequence (Freeman & Smith, 1997).

The purpose of this paper is to describe the structure and rationale of the IMS courses and report relevant research results from a program evaluation conducted in 2002-2003. The following research questions were investigated:

1) To what extent, are the structure and the nature of the IMS courses aligned with the standards recommended by the current reform documents?
2) To what extent, do the IMS courses facilitate the development of informed views of the Nature of Science (NOS) among the prospective teachers?
3) To what extent, do the IMS courses improve the prospective elementary teachers' metacognitive awareness and conceptual understanding of science and mathematics?

Review of Related Research

Both IMS 160 and IMS 161 courses have been built on the following core principles of learning and teaching in science and mathematics (National Research Council, 1999; AAAS, 1989):

1) Students construct their own understanding of science and mathematics based on their prior knowledge, personal experiences, and social interactions.
2) To develop competence in scientific inquiry, students should: (a) have a deep foundation of content knowledge organized in ways that facilitate retrieval and application; (b) possess scientific inquiry skills, and (c) develop informed views of the nature of science and scientific inquiry.
3) A "metacognitive" approach to instruction can promote metacognitive awareness of science and mathematics learning and help develop lifelong learners.

Learning Science As Inquiry

Scientific inquiry refers to the diverse ways in which scientists study the world and propose explanations based on the evidence derived from their work. It involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results (National Research Council, 1996). In science instruction, Suchman's Inquiry Model suggests a five-step process that begins with the instructor presenting students with a discrepant or problematic event. Students are then asked to make inferences about the event presented. Next the students are expected to produce a hypothesis statement or proposed answer to the event. Students are then directed to gather data, analyze the data and finally make a conclusion about their initial statement based on the evidence (Gunter, Estes & Schwab, 1999). Actual classroom activities may include the use of real life experiences, mentoring, demonstrations, guided and open experimentation, collaborative work, and scaffolding (i.e., questioning, prompting, cueing).

To achieve the goal of scientific literacy for all, recent science education reforms advocate instruction that centers on scientific inquiry and promotes students' understanding of nature of science (Crawford, 2000). The literature suggests that an inquiry model of instruction is an effective strategy in helping students make sense of the inquiry process and developing conceptual understanding of science (Windschitl, 2000; Brown, 2000; Haefner & Zembal-Saul, 2001). Some research also indicates that explicit approaches (e.g., using examples or elements from history and philosophy of science and/or explicit instruction to improve science teachers' understanding of the various aspects of Nature of Science) were generally more effective in fostering "adequate" concepts of nature of science and knowledge of scientific inquiry (Adb-El-Khalick & Lederman, 1998, 2000, & Gess-Newsome, 2002). In addition, it has been noted that the use of reflective journaling, feedback, and inquiry-based instruction positively influences preservice teachers' conceptions of science (Bell, 2000).

Metacognitive Awareness of Science and Mathematics Learning

Metacognitive awareness refers to one's knowledge about one's thought processes. Flavell (1976), the theorist associated with the term, suggests that metacognition consists of both metacognitive knowledge and metacognitive experiences. Metacognitive experiences are further divided into knowledge of personal variables (how a person learns), task variables (nature and demands of the task), and strategy variables (when and where to use strategies) (Livingston, 1997).

However, those who do research in this area suggest that metacognitive awareness is much more than what is described above and it has a profound effect on students' ways of knowing about science and mathematics. Metacognition involves the knowledge of one's cognition as well as the regulation of that cognition (Brown, 1987). Schraw and Brooks (1999) refer to the construct as something that controls one's "will" and one's "skill". Additionally, one's "will" and "skill" form a reciprocal interchange. A person's "will" then is a function of her/his self-efficacy. On the other hand a person's "skill" is a function of the instructional strategies that one has learned.

However, Grotzer (1996) suggests that knowing the thinking skills for mathematics and science is not enough to enact them. To become self-regulated (i.e., metacognitive) one must be sensitive to the opportunity to use them, able to use them, and inclined to use them (Grotzer, 1996). Research also suggests that in order to develop metacognition in learners both cognitive processes and strategies must be explicitly taught along with actual practice of the strategies and evaluation of the outcomes of their efforts (Grotzer, 1996; Livingston, 1997; Schraw & Brooks, 1999; Conner, 2000). In a study on physics learning conducted by White and Frederiksen

(1998), it was found that the development of students' metacognitive knowledge and skills is beneficial, particularly for academically disadvantaged students.

Methodology

Sample

The study involved three instructors and 39 pre-service elementary and special education students (generally sophomores) who enrolled in three respective sections of the IMS courses at a small private, urban institution. The majority (> 93%) were Caucasian and female. They were primarily sophomores (90%).

Design

The one-group pretest-posttest design was adopted (Borg & Gall, 1989). To evaluate the nature of instruction and the level of alignment of the course content with the National Science Education Standards and the State Teacher Education Program Standards, course syllabi from all instructors were collected and analyzed. An Inquiry Element Survey instrument, adapted from the Fundamental Abilities of Inquiry (grades K-12) in the National Science Education Standards (See Appendix A), was used to collect information on the inquiry elements at the end of each semester. Both students and instructors were asked to respond to the Inquiry Elements Survey. Follow-up interviews were conducted with instructors to clarify the content of the syllabi as written.

To evaluate the effectiveness of the IMS courses in promoting prospective teachers' informed views of nature of science, the Views of the Nature of Science questionnaire, Form D (VNOS-D, Lederman et al., 2002) was administered to each student before and at the conclusion of the courses, along with follow-up interviews for clarifying written responses. The questionnaire contains seven open-response items (Appendix B). During the data analysis phase, a pre-constructed rubric (adapted from the annotated scoring guide for VNOS D and Views of Nature Of Science (C) -Items and item descriptions) was used to analyze the questionnaires and generate pre- and post-instruction profiles of each participant. The intercoder reliability for creating the first three participants' profiles by two independent coders was 0.86, which was calculated using the formula: r = no. of agreements /(total no. of agreements plus disagreements). Then, discrepancies were discussed and one coder completed the coding of the remaining data. Finally, the pre- and post-profiles were compared to determine changes in participants' views of NOS.

The IMS courses include several major modules (each module lasted from three to six weeks). During the course study, students were required to write a unit summary upon the conclusion of each module or unit. They were also asked to reflect in their unit summaries about the strategies, procedures, techniques that they use to understand each unit within the courses by using the journal prompts provided (see Appendix C). In addition, each unit summary was evaluated by both instructor and students themselves based on the criteria established in class, i.e., paper should be organized to show the relationship between concepts/principles/theories, rather than in the sequence of class activities; examples inside and outside of class should be used to explain the presented concepts/principles/theories; proper style and language should be used to write a coherent, logically consistent, and well-organized paper.

Results

Alignment of the Structure and the Nature of the IMS Courses with National Standards Documents

By interviewing course instructors and examining the course syllabi and inquiry elements survey data (Appendix A), it was found that both the structure and nature of the IMS courses were generally aligned with the Standards recommended by the current reform documents. During the first week of the courses, the instructors engaged participants in two introductory activities that explicitly addressed several aspects of Nature of Science: "Tricky tracks" and "The cubes." Both activities targeted differences between observations and inferences, alternative ways of looking at existing evidence, and the empirical, creative, imaginative, and tentative nature of scientific knowledge. "The cubes" activity also addressed the idea of science as a blend of logic and imagination, and the use of technology in making new scientific observations (Lederman & Abd-El-Khalick, 1998). This initial activity-based explicit instruction was intended to make the prospective teachers be aware of the "adequate" views of NOS by relating science to their personal experience or prior knowledge, in a non-threatening environment. Throughout the remainder of the courses, the prospective teachers' understandings of NOS were facilitated through the inquiry instructions and content of coursework implicitly.

With no intention to cover all of the topics involved in the elementary science and mathematics curriculum, the IMS faculty had focused on fewer fundamental scientific concepts in more depth. The emphasis of the courses was on measurement, estimation /prediction /probability, ratio and scale, models, systems, force and motion, behavior of living things, and nature of matter. The courses employed the use of hands-on/minds-on, active, problem-solving investigations that were guided by a team of mathematics/science professors. The courses were also designed to help students understand the interdisciplinary connections of science and nature of science by relating science to the students' everyday life. The development of scientific curiosity and skills in critical thinking and communication was emphasized throughout the two-course sequence.

By examining the Inquiry Elements Survey marked by IMS students and instructors, it was confirmed that all major inquiry elements, recommended by the National Science Education Standards (K-12), were addressed in both courses. In addition, multiple assessment forms were used to document students' learning before, during, and after each unit of instruction. For instance, before each unit was started, students' prior knowledge was identified either through instructor-guided class discussion, or by explanations in students' journals what they think they know about a topic or a phenomenon presented by the instructors. During the period of each module/unit, students were challenged to solve problems of the week (POW) relevant to the class work. Appropriate class time was provided for group discussion of these problems. Each student was expected to explain her / his solution to the rest of the class after submission of the assignment. Approximately every two weeks, all students were required to submit a short paper, Science in the World Around Us (SIWAU). It was a critical review of assigned science-related articles, TV shows, movies, etc., or a reflection on some way in which science and math tie into everyday experiences.

At the conclusion of each course unit, besides the traditional quizzes or tests, each student was required to write an essay summarizing class experience and what she/he has learned in that unit. The main purpose of the unit summary is to display the knowledge the student arrived at as a result of the experiences and the processes by which that knowledge was achieved. Each unit summary was organized into two distinct segments. The first [and longer] segment was the discussion of the content of the unit. The second segment was for the students to reflect on the effectiveness of the strategies, procedures, and techniques that they used to understand each course unit.

Development of the Prospective Teachers' Informed Views of Nature of Science

In the present study, several aspects of Nature of Science that we believe to be emphasized in the IMS courses were examined. These aspects are that scientific knowledge is empirically based (based on and/or derived from observations of the natural world), tentative (subject to change due to new evidence and/or new ways of looking at existing evidence), and partly the product of human inference, imagination, and creativity. The participants' views of NOS before and after instruction were analyzed and the percentage of participants with informed views of emphasized aspects of NOS was presented in Table 1.

Table 1

Percentage of participants with informed views of emphasized aspects of NOS

NOS Aspect	**Prospective Elementary Teachers' Views**	
	Pre-instruction (%)	Post-instruction (%)
Empirical nature of scientific knowledge	13	78
Tentativeness	17	30
Observations, inferences, and theoretical entities in science	22	76
Creativity and imagination in science and scientific experimentation	13	48

It was evident that the majority of participants held naïve views of one or more target aspects of NOS, which is consistent with the literature (Abd-El-Khalick, 1998; Akerson, Abd-El-Khalick, & Lederman, 2000). None of the participants had adequate views of all four investigated NOS aspects before the instruction. At the conclusion of the IMS courses, it was found that substantially more participants held adequate views of the emphasized aspects of NOS. However, the observed changes were not consistent across all investigated aspects. Fewer participants (<25%) had demonstrated an internalized understanding of the investigated aspects of NOS by recognizing the interrelationship between those aspects. It seemed that the current course structure and content were more effective in promoting the development of adequate views of the empirical nature of scientific knowledge than in developing understanding of the tentative and creative aspects of NOS among the participants. The courses were also quite successful in promoting participants' understanding of the differences between observations and inferences. The following sections discuss some representative examples of the participants' NOS views before and after instruction.

Empirical and tentative nature of scientific knowledge. Before instruction, when asked to define what science is, most participants described science as the study of the world around us without mentioning or emphasizing the role of observations and testability of scientific ideas. When further questioned about the tentative nature of scientific knowledge, many participants believed that scientific laws are proven facts and not subject to change whereas scientific theories can change due to advances in technology. Only 17% of participants held adequate views of the tentative aspect of NOS, i.e., scientific knowledge changes due to new evidence and/or new ways of looking at existing evidence.

> Science is everything around us and the study of all of those elements.
> (PT 06, pre-questionnaire)

> Science is an understanding of, or interest in the world around us, of our existence, our bodies, nature and the environment… Science is always changing due to more resources and technology.
> (PT 03, pre-questionnaire)

After instruction, substantially more participants adopted adequate views of the empirical aspect of NOS. Most of them (78%) emphasized the role of observation and experimentation in science when asked to compare science with other disciplines. About 30% participants demonstrated adequate views of the tentative nature of science. However, still many participants simply attributed the change of scientific knowledge and theories solely to discoveries of new information and technology, without realizing the role of reinterpreting extant data.

> Science is different because so many things can be measured. Through observations and data collection, you can draw conclusions about the world. Like other subjects such as art and religion, creativity can be used in science. (PT 04, post-questionnaire)

> Science requires testing and experimenting ideas and theories. … Scientific knowledge changes because new technology and resources can prove ideas wrong. Scientists are constantly testing and retesting knowledge. (PT 14, post-questionnaire)

> I think that knowledge will definitely change in the future as we gather more information about the world. This is the same as the change from Aristotle's view that there always had to be a force when an object is in motion to the concept of Inertia. (PT 10, post-questionnaire)

<u>Observation vs. inferences.</u> In response to the question of how certain scientists are about the way dinosaurs looked and weather patterns, many participants initially believed that scientists are very certain or quite certain about the appearance of dinosaurs based on fossils and other evidence. For some of them, scientific knowledge would be truth as long as scientists had found enough information. An understanding of the inferential nature of scientific models was not evident in the pre-questionnaires.

> I think scientists are very certain (about the way dinosaurs looked) because they can base it on bone structure. (PT 23, pre -questionnaire)

> Archeologists have discovered fossils that prove dinosaurs once existed. The bones of these creatures prove that they once lived on earth. Scientists can be fairly certain of how

> dinosaurs looked because in some cases fairly complete skeletons have been found which allow scientists to accurately define their shape and physical characteristics. (PT 21, pre-questionnaire)

After instruction, most participants seemed to have an adequate understanding of observations, inferences, and theoretical entities in science although about 24% remained naïve views of NOS.

> One important aspect of science is validation through observation. Scientists observe fossils of dinosaurs which prove they really existed. … Scientists have tentative hypotheses about the way they (dinosaurs) may have looked supported by logic and close examination. (PT 21, post-questionnaire)

Creativity and imagination in science. Before instruction, most participants (87%) did not demonstrate adequate views of the role of creativity and human imagination in generating scientific knowledge. When asked in what part(s) of investigations scientists may use their imagination and creativity, some believed no imagination allowed while many others pointed "planning" and "experimenting" stages only. In the post-questionnaires, about 48% participants recognized that scientists use their imagination and creativity throughout the entire process of their investigations,

> I do not think that scientists use their imaginations and creativity when they do investigations/experiments. They have to do what books tell them to do. (PT 25, pre-questionnaire)
>
> I think they (scientists) use their imagination in the actual planning and experimenting. (PT 28, pre-questionnaire)

> I think all parts (of investigations) include creativity. … For interpretation the scientists may use imagination and creativity to analyze the studies. They use their own creative thinking to develop theories, make observations, and planning experiments. They also are creative in how they report their results. (PT 04, post-questionnaire)

Development of prospective elementary teachers' metacognitive awareness about and understanding of science and mathematics

A general consensus among the IMS faculty was that unit summaries as an assessment tool was one of the most powerful indicators reflecting students' understanding of what was learned during the course. At the end of each course unit, all students were required to submit a unit summary demonstrating an understanding of content knowledge and metacognitive awareness of science and mathematics learning. Table 3 reported the average percentage of the IMS student participants with different levels of understanding of the course content, ranked by instructors. By using the scoring criteria described in the above methods section as a guideline, instructors read each paper and assigned a score of "5" for thorough understanding, "3" for somewhat and "1" for no understanding at all. The results were presented in table 2.

Table 2

Average percentage of participants with different levels of understanding of science and mathematics content

Well understand (Rating Score=4 or 5)	**Somewhat understand** (Rating Score=3)	**Do not understand** (Rating Score=1 or 2)
64%	24%	12%

Considering the generally low level of conceptual understanding of the course content evident in the pre-assessments (usually not graded, format varying from one class section to another, including class discussion and /or paper-pencil questionnaires), the IMS courses appears to have substantially enhanced adequate understanding of some fundamental science and mathematics concepts among the participants, although the fact that 12% participants failed to achieve the course objectives indicates the necessity of further improvement of the learning and teaching in the IMS courses. The following sections elucidate participants' self-reflections on the learning and teaching of science and mathematics topics in the IMS courses.

> Before I entered this class, I never wanted to think too hard for the answer, I wanted to just do the problem and get it over with. Problems with no answers frustrated me. I realize that much of my learning was hindered because of this. If a problem was presented in two different ways, I would become confused. Instead of working to understand the different means for finding solutions, I would give up. I feel this has hurt me in the areas of math and science.
>
> However, after working with probability, I have expanded my views and strengthened my thought process. From there, I learned to ask questions, which usually led me in different directions. However, instead of getting frustrated, I started working out different "theories" that led to results. Not all my results had answers or gave me exactly what I wanted to know, but I was able to see what I could come away with from these problems. Now, when doing the problems, the first thing I do is to start thinking about what it is that I am working with and what angles I can use to find what I am looking for. (PT 31, unit summary – estimation / probability)

> Never before I looked at area, perimeter, circumference, or volume formulas and wondered why they are what they are. With this entire unit that we just learned, however, I now understand the reasoning/principles that are involved in order to construct and pick apart the different formulas. … This paper helped me better understand the concepts because in order to explain something you must really understand it first. (PT 35, unit summary – measurement)

As researchers in the current study, we had anticipated that students with lower performance might also had lower metacognitive awareness levels of science and mathematics learning. This claim was supported by comparing the participants' self-rating scores with instructor's rating scores (see table 3). It was found that lower achieving students (i.e., instructor's rating score <=3) consistently overestimated their understanding of content knowledge (t-test, p=0.003, two tails), whereas higher achieving students (i.e., instructor's rating score >3) tent to slightly underestimate their understanding levels (t-test, p=0.05, two tails).

Table 3

Mean difference scores between instructors' rating and student's self-rating (unit topic: measurement)

n	$M_{(IR>3)}$	$SD_{(IR>3)}$	$M_{(IR<=3)}$	$SD_{(IR<=3)}$
	Instructor's Rating (IR) –Self-Rating(SR)		Instructor's Rating (IR)– Self-Rating(SR)	
39	0.26	0.63	-0.5	0.52

Discussion and Implications

The results of this study indicate that the IMS courses aligned with current reform documents was effective in promoting preservice teachers' adequate views of NOS and enhancing their understanding of science and mathematics. Consistent with research on preservice elementary teachers' views of NOS (e.g., Gess-Newsome, J. 2002; Akerson, Abd-El-Khalick, & Lederman, 2000; Bloom, 1989), most participants in the current study held naïve views of the investigated aspects of NOS before instruction. Participants' views of NOS also lacked coherency and internal consistency. After instruction, participants made substantial gains in their understanding of empirical nature of scientific knowledge and differences between observations and inferences in science. This result was expected given the hands-on /minds-on, inquiry nature of the courses. However, the courses seemed to be less effective in facilitating preservice teachers' understanding of two other investigated aspects of NOS, i.e., scientific knowledge changes due to new ways of looking at extant evidence; scientific knowledge is created based on observations and inferences - creativity permeates entire scientific processes. In fact, the participant students had first-hand experiences (implicitly, without explicit instructor-led discussions) dealing with the above two aspects of NOS throughout the courses. This result suggests that a combined implicit and explicit approach in the content instruction might be more beneficial to promote informed views of NOS for all prospective teachers.

From a constructivist perspective of situated learning, IMS courses are believed to be a most suitable context in developing prospective teachers' informed views of NOS and their conceptual understanding of science and mathematics. As reflected in the metacognitive portion of the unit summaries, it was evident that the IMS instructional approach had changed students' general mindset from learning through memorization to learning through investigation, explanation and logical thinking. In addition, the integrated inquiry and metacognitive approach made preservice teachers' metacognitive awareness of science and mathematics learning more transparent to their instructors. Through this "metacognitive" communication channel, instructors should be able to identify the strength and weakness of class instruction at a regular base and make informed decisions accordingly. It is anticipated that preservice teachers' conceptual understanding of science and mathematics could be enhanced more substantially if more attention was given to develop metacognitive awareness and skills among those lower achievers in the courses.

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References

AAAS (American Association for the Advancement of Science). (1989). Science for all Americans: A Project 2061 report on literacy goals in science, mathematics, and technology. Washington, DC: AAAS.

Adb-El-Khalick, F. and Lederman, N. G. (2000). Improving science teachers' conceptions of Nature of Science: A critical review of the Literature. International Journal of Science Education, 22, 665-701.

Adb-El-Khalick, F. and Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. Journal of Research in Science Teaching, 37, 1057-1095.

Akerson, V. L., Adb-El-Khalick, F. & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. Journal of Research in Science Teaching, 37, 295-317.

Bell, R. L., Lederman, N. G. and Adb-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. Journal of Research in Science Teaching, 37, 563-581.

Bloom, J. W. (1989). Preservice elementary teachers' conceptions of science: Science, theories and evolution. International Journal of Science Education, 11, 401-415.

Brown, A. (1987). Metacognition, Executive Control, Self Regulation, and other Mysterious Mechanisms, In F. E. Weinert and R. H. Kluwe (Eds.), Metacognition, Motivation, and Understanding Hillsdale, New Jersey: Lawrence Erlbaum Associates, pp.65-116

Brown, F. 2000. The Effect of an Inquiry-Oriented Environmental Science Course on Preservice Elementary Teachers' Attitudes about Science. Journal of Elementary Science Education, 12(2), 1-6.

Borkowski, J. G., Estrada, M. T., Milstead, M., & Hale, C. A. (1989). General Problem Solving Skills: Relations between Metacognition and Strategic Processing. Learning Disabilities Quarterly, 12, 57-70.

Conner, L. N. (2000). Inquiry, discourse and metacognition: Promoting students' learning in a bioethical context. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (New Orleans, LA, April 28-May 1, 2000). ERIC Document 440877.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. Journal of Research in Science Teaching, 37, 916-937.

Fecho, B. 2000. Developing Critical Mass: Teacher Education and Critical Inquiry Pedagogy. Journal of Teacher Education, 51(3). 194-199.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In L.B. Resnick (ed.), The nature of intelligence. Hillsdale, NJ: Erlbaum

Freeman, C. C. & Smith, D. L. Active and engaged? Lessons from an Interdisciplinary and collaborative college mathematics and science course for preservice teachers. 1997. Paper presented at the Annual Meeting of the American Educational Research Association (New Orleans, La, April 24-28, 2000. ERIC Document 411210

Grotzer, T. A. (1996) Teaching Thinking Skills: does it Add to for Math and Science Learning?. Math/Science Matters: Resource Booklets on research in Math and Science Learning. Booklet 2: Issues of Instructional Technique in Math and Science Learning. Cambridge, MA: Harvard Project on Schooling and Children, Exxon Education Foundation

Gess-Newsome, J. (2002). The use and impact of explicit instruction about the nature of science and science inquiry in an elementary science methods course. Science and Education, 11, 55-67.

Gunter, M. A., Estes, T. H., & Schwab, J. (1999). Instruction, A models approach (3rd ed.). Allyn and Bacon.

Haefner, L. B. & Zembal-Saul, C. (2001). Engaging in Science as Inquiry: Prospective Elementary Teachers' Learning in the Context of an Innovative Life Science Course. Paper presented at the Annual Meeting of the American Educational Research Association (Seattle,WA, April 10-14, 2001)

Fulp, S. L. (2002). 2000 National survey of science and mathematics education: Status of elementary school science teaching. Horizon Research, Inc. NC: Chapel Hill. Retrieved August 19, 2003, from http://www.horizon-research.com.

Lederman, N.G., & Abd-El-Khalick, F. (1998). Avoiding de-natured science: Activities that promote understandings of the nature of science. In W.F. McComas (Ed.), The nature of science in science education: Rationales and strategies (p. 243-254). Dordrecht, NE: Kluwer Academic Publishers.

Livingston, J. A. (1997). Metacognition: An overview. An unpublished manuscript. Retrieved on March 4, 2009 from: http://www.gse.buffalo.edu/fas/shuell/cep564/Metacog.htm.

National Council of Teachers of Mathematics (NCTM). 1989. Curriculum and evaluation standards for school mathematics. Reston, VA: Author.

NCTM. 2000. Principles and standards for school mathematics. Reston, VA: Author.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

National Research Council. (1999). How people learn: Brain, mind, experience, and school. Washington, DC: National Academy Press.

National Research Council. (2001). Educating Teachers of Science, Mathematics, and Technology. Washington, DC: National Academy Press.

Schraw, G. & Brooks, D. W. (1999). Helping Students Self-Regulate in Math and Sciences Courses: Improving the Will and the Skill. Retrieved on March 4, 2009: http://dwb.unl.edu/Chau/SR/Self_Reg.html.

Windschitl, M. 2000. Pre-Service Teachers and the Independent Inquiry. Paper presented at the Annual Meeting of the American Educational Research Association (New Orleans, La, April 24-28, 2000), ERIC Document 441703.

Appendix A

Inquiry Elements Survey (Student)
(Adapted from National Science Education Standard-*Fundamental Abilities of Inquiry*)

During the course, were you given opportunities to do the following.

	Always	Sometimes	Never
Learner asks scientifically oriented questions			
Learner identifies questions that can be answered through scientific investigation			
Learner identifies concepts that guide scientific investigations			
Learners develops models using scientific evidence			
Learner develops predications using scientific evidence			
Learner revises models and explanations			
Learner plans scientifically oriented experiments			
Learner conducts scientifically oriented experiments			
Learner uses equipment to gather data			
Learner uses data to create an explanation			
Learner recognizes and analyzes alternative explanations			
Learner communicates investigations			
Learner communicates scientific explanations			
Learner defends a scientific argument			
Learner uses mathematics to solve problems			
Learners use technology to solve problems			

Appendix B

Views of Nature of Science Survey – Form D

1. What, in your view, is science?

2. How is science different from the other subjects (for instance, Art, Religion, etc.) you are studying?

3. Scientists produce scientific knowledge. Some of this knowledge is found in your science books. Do you think this knowledge may change in the future? Explain your answer and give an example.

4. (a) How do scientists know that dinosaurs really existed?
   (b) How certain are scientists about the way dinosaurs looked?
   (c) Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen. Why do you think they disagree even though they all have the same information?

5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns.
   (a) Do you think weather persons are certain (sure) about these weather patterns?
   (b) Why or why not?

6. What do you think a scientific model is?

7. Scientists try to find answers to their questions by doing investigations /experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments? **YES** **NO**

   a. If **NO**, explain why?
   b. If **YES**, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

Appendix C

Writing Unit Summaries

As we complete relatively self-contained modules of the course students will be expected to write Unit Summaries summarizing their experiences in a given module and describing how the ‘raw data’ of these experiences has been turned into coherent knowledge. The basic thrust of a US should be to summarize the experience of the module by leading the reader through its ‘logic’, through the kinds of questions that have been raised and answered and how these answers have been achieved, through the conclusions that have been arrived at, and into any remaining open issues/questions that may merit further investigation. In a ‘metacognitive’ component of the US students may want to comment on how prior knowledge did or did not prepare them for the unit, on implications that the unit has for the student’s own teaching or reading plans, on the mode of presentation of the material, and on whether or not the experience was a valuable one and why. ***The main purpose of the US is to display the knowledge that the student arrived at as a result of the experiences and the processes by which that knowledge was achieved.*** Serious thought should be given to including graphs and diagrams in the US if appropriate.

It is anticipated that there will be about 2-3 US’s assigned in each semester and that each will be marked. They collectively form a large part of the course grade and this reflects the importance that the instructor believes that they have for a student’s really learning the material and displaying what has been learned to the instructor. Keeping a good daily log of classroom activities and conclusions that the student comes to from these activities should facilitate the writing of the US considerably. If the student locates the theme of the unit and uses it as an organizing principle then the US should have the right focus. The instructor is always open to discussing the US with a student before it is submitted and a writing assistant who can help in the organization and writing of the US will be available. US’s will typically be three to five typed pages in length and should be written in an impersonal, ‘scientific’ style—except for portions like the metacognitive one that may indicate personal reactions to the material.

More formally, the unit summary should be organized into two distinct segments. The first [and longer] segment should be the discussion of the content of the unit as outlined above. The second segment should be your addressing of the following sort of ‘metacognitive’ questions:

- What did you know about the material before you began this course segment?
- What strategy, procedure, or techniques did you use to assist you in understanding the material?
- What strategy, procedure, or techniques were <u>ineffective</u> in your attempts to understand the material?
- What new knowledge did you acquire?

In what situation(s) could you use this new information in the future?