# EXPERT-NOVICE INTERACTION IN PROBLEMATIZING A COMPLEX ENVIRONMENTAL SCIENCE ISSUE USING WEB-BASED INFORMATION AND ANALYSIS TOOLS

A Dissertation

by

CAROLYN M. SCHROEDER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2006

Major Subject: Curriculum & Instruction

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May 2006

Major Subject: Curriculum & Instruction

# ABSTRACT

Expert-Novice Interaction in Problematizing a Complex Environmental Science

Issue Using Web-based Information and Analysis Tools. (May 2006)

Carolyn M. Schroeder, B.S., Angelo State University; M.Ed., Texas A&M University

Chair of Advisory Committee: Dr. Cathleen C. Loving

Solving complex problems is integral to science. Despite the importance of this type of problem solving, little research has been done on how collaborative teams of expert scientists and teams of informed novices solve problems in environmental science and how experiences of this type affect the novices' understandings of the nature of science (NOS) and the novices' teaching. This study addresses these questions: (1) how do collaborative teams of scientists with distributed expertise and teams of informed novices with various levels of distributed expertise solve complex environmental science issues using web-based information and information technology (IT) analysis tools? and, (2) how does working in a collaborative scientific team improve informed novices' understandings of the nature of authentic scientific inquiry and impact their classroom inquiry products?

This study was conducted during Cohort II of the Information Technology in Science project within the Sustainable Coastal Margins scientific group. Over two summers, four environmental scientists from various disciplines led ten science teacher and graduate student participants in learning how each discipline approaches and solves environmental problems. Participants were also instructed about NOS by science educators and designed an inquiry project for use in their classroom. After performing a pilot study of the project, they revised it during the second summer and the entire experience culminated with diverse teams problematizing and solving environmental issues.

Data were analyzed using statistical and qualitative techniques. Analysis included evaluation of participants' responses to a NOS pre- and posttest, their inquiry projects, interviews, and final projects. Results indicate that scientists with distributed expertise approach solving environmental problems differently depending on their backgrounds, but that informed novice and expert teams used similar problem-solving processes and had similar difficulties. As a result of the project, I developed a model of distributed group problem solving for environmental science. Participants' understandings of NOS improved and matured after instruction and experience working with scientists. The level of most instructional products was "guided inquiry." The implications are that working with scientists along with direct NOS instruction is beneficial for teachers and science graduate students for their understanding of scientific problem solving, but that much more work needs to be done to achieve authentic inquiry in science classrooms at both secondary and post-secondary levels.

# DEDICATION

In memory of my parents

Marvin and Marjorie Hahn

And to my children

Kenneth, Kristina, and Amanda

# ACKNOWLEDGMENTS

This dissertation is the culmination of a dream, but it would not have been achieved without the support, guidance, and mentoring of a number of people. My committee guided me throughout the process of seeking this degree, and without their encouragement, it would not have been accomplished.

My committee chair and long-time friend, Dr. Cathleen Loving, began it all when she called and asked me to apply for the ITS program and to consider coming back to pursue a doctorate in science education. Cathy's continued support throughout the process and her enthusiasm for science teaching and research have inspired me. The time she spent working with me on this research and her tireless reading and editing have proved invaluable. Dr. Bruce Herbert, another friend of many years, never failed to encourage me and bolster my self esteem when I needed it. He gave me the opportunity to work with his ITS group and treated me as a valued colleague throughout my tenure in graduate school.  Dr. Sarah Bednarz led my first ITS group, and her passion for geography education convinced me that I had made the right choice in going back to school; I would be able to positively affect other teachers. Sarah has always been there with advice when I needed it and with reminders to stay focused on my writing. Dr. Carol Stuessy, with her pragmatic approach – and her diagrams- has supported and challenged me throughout the process. Her sharing of knowledge and expertise has made a great difference for me.  I am deeply indebted and offer my heartfelt thanks to each of them.

The ITS program – and this research – were funded by the National Science Foundation, and for that I am very grateful. None of it would have been possible without the willing participation of the faculty members and participants from the SCM-ITS team. They let me intrude into their busy schedules with questions, kept journals for me, and let me look over their shoulders. Dr. Janie Schielack, director of the ITS Center for Teaching and Learning, provided guidance, access to Center materials and financial support during the process. The two ITS Center Program Coordinators, Trudy Bennett and Denise Drosche, helped out in many ways. Thanks to each of you.

To Dr. Melvin C. Schroeder, Professor Emeritus in the Department of Geology and Geophysics, I owe a great debt of gratitude. He started me on my way as a young teacher by accepting me into an Earth Science teacher training program and then making it possible for me to get my Master’s degree here at Texas A&M. I had the privilege of working for him as teacher consultant and lab instructor for the summer programs for a number of years. Since I came back to school to work on my doctorate, he has called regularly to check on my progress and encourage me to finish. Thank you so much, Mel.

New friends have been a wonderful bonus from this going-back-to-school experience. Gillian Acheson, my first GEO-ITS partner, has been a great friend and made me feel less guilty about drinking so many Diet Cokes. Cathy Ezrailson, who likes to eat out as much as I do, has inspired me with her energy. Dr. Tim Scott and Adrienne Bentz at the Center for Math and Science Education have encouraged me to grow and to finish this dissertation.

Friends of long standing, too, have supported and encouraged me. Jeannie Bassett has celebrated milestones with me as my work has progressed – thanks for the margaritas! Ginny Heilman has a great fund of knowledge about teachers and teaching – and she can always make me laugh. To the "girls of '65" – a special group of friends and classmates from Mason High School – thank you for caring and making me feel that what I'm doing is worth celebrating. And to all my local friends from church and from my school teaching years who have asked on a regular basis if I've finished yet, thank you for keeping me motivated.

Finally, and most importantly, my family has wholeheartedly supported my goals. My son and daughter-in-law, Ken and Deanne Schroeder, and my daughter and son-in-law, Kristi and Shane Meadows, encouraged me to take on this challenge from the very beginning. My grandchildren, Kayce, Kyle, and Emily, give me unconditional love and remind me of what is truly important in life. My sister and best friend Margaret and her husband Fritz Leifeste said "Go for it!" when I asked their advice, prodded me when I needed it, listened when I needed to talk, and assured me that I really could do this. Thank you all. I love you, and I am so very fortunate to have you.

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# CHAPTER I

# INTRODUCTION

Effective science teaching should provide opportunities for students to participate in authentic science. This, in turn, requires an understanding on the part of the teacher of how scientists do science. The role of the scientist in developing this understanding should be to model how science is done using real scientific processes including inquiry, critical thinking, and creativity (Bower, 2004). Synergy between expert scientists and master teachers working at the boundary of theory and practice can enhance that understanding and augment the learning of science at every level (Pelaez & Gonzalez, 2002). Developing synergy requires collaboration between scientists, practicing teachers and teacher educators in authentic, inquiry-based learning environments.

Environmental science provides an ideal vehicle for giving educators the opportunity to experience the ill-defined problem-solving nature of science as practiced by scientists. The complexity of environmental problems demands an interdisciplinary approach so that sociopolitical as well as scientific aspects from various disciplines are addressed. The availability of applicable complex data sets on the Internet makes it possible for educators as well as scientists to conduct problem solving in an authentic manner. An understanding of the processes involved in this type of problem solving is essential before educators can effectively use it in the classroom.

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This dissertation follows the style of Journal of Research in Science Teaching.

Recent research emphasizes the role of collaborative teams in solving complex problems of all types (Benda et al., 2002; Carr, 2002; Goldston & Bland, 2002; Johnson, Ruzek, & Kalb, 2000; Pfirman & AC-ERE, 2003). Problem solving strategies differ from discipline to discipline, and the distributed expertise and expert-novice interactions within collaborative groups result in innovative solutions to the kinds of complex problems prevalent today (Cassel & Kumar, 2002). For classrooms, Bransford, Brown, and Cocking (2000) report on the importance of a focus on community in the learning process. Their research suggests that community-centered classrooms enhance learning and teaching. In community centered classrooms, cooperative problem solving and argumentation among students augments cognitive development. These communities of learners are comfortable with questioning rather than knowing the "right" answer and with building on contributions from all community members to develop a standard of creating new ideas (Bransford et al., 2000; Minstrell, 2000; Pellegrino, 2000).

## Context of the Study

The Information Technology in Science (ITS) Center for Teaching and Learning at Texas A&M University, a five-year project begun in 2000, provides a unique setting for diverse research projects. Educators and scientists from various disciplines spend two summers and two academic years collaborating to a) enhance inquiry teaching using information technology and b) produce researchers in the fields of education and science and leaders for professional development in science education. Scientific teams include interdisciplinary groups of experts (scientists) and interdisciplinary groups of novices (classroom teachers and science and education graduate students, from varied backgrounds) with distributed expertise.

The Sustainable Coastal Margins (SCM) scientific team used a complex, ill-defined environmental issue as the central focus for its experience for twelve participants in Cohort II during 2003-2004. The overall research question for the science team was: What is the environmental quality of the Texas Gulf Coast? After problematizing the issue, participants were taught to use information technology (IT) applications to gather environmental data, create a web site, analyze data, and develop a preliminary inquiry teaching plan for use in their teaching situation. During this time the scientists supported participants through lectures and skill-building activities from the perspectives of each of their disciplines. Participants worked in deliberately-structured teams of three or four from different backgrounds, kept individual daily journals, and produced individual and group artifacts from lesson activities. During the intervening academic year they taught their inquiry lessons in their teaching situation. In the second summer participants continued to learn the IT used in environmental research, revised their teaching plans, and developed an action research plan for use during the following academic year. As a culminating activity and to enhance transfer of learning, distributed teams of participants and a team composed of the faculty members selected, problematized, and proposed a solution for a sustainable environmental issue dealing with the Brazos Valley of Texas.

## Statement of the Problem

The ITS Center (Information Technology in Science Center for Teaching and Learning, 2004), a graduate program designed to replenish the supply of science and mathematics education specialists through interdisciplinary, team-led, learner-centered opportunities involving scientists, mathematicians, education researchers and educators, lists three goals:

1. To produce education specialists through a program of study connecting the practicing educators with scientists, mathematicians, and education researchers.
2. To create, through research, new understandings of the impact of information technology (IT) on the learning and teaching of science and mathematics.
3. To develop and disseminate quality professional development experiences focused on the impact of IT on the learning and teaching of science and mathematics.

ITS seeks to make basic changes in the conventional relationships among scientists, educational researchers and teachers by engaging them in the use of IT to learn how scientific research is done, how science is taught and learned, how the learning can be assessed, and how networks between scientists, educational researchers, teachers and students can be developed for mutual benefit.

Research into how well the ITS Center is meeting its goals is a requisite of its National Science Foundation (NSF) grant. The Sustainable Coastal Margins science team provided an opportunity for some of that research to be carried out.

## Purpose of the Study

This study seeks a) to reach a deeper understanding of how collaborative teams composed of experts and novices with distributed expertise interact to problematize complex problems in the field of environmental science and b) to determine the effect of working in this collaborative team environment on participants' understandings of the nature of authentic scientific inquiry and their ability to translate these understandings into the science classroom at Grade 6 through post-secondary levels.

This research project addresses the following questions:

1a. How do members of a collaborative team of informed novices with various levels of distributed expertise problematize and solve a complex environmental science issue using web-based information and IT analysis tools?

1b. What are the similarities and differences in the way a collaborative team of scientists with distributed expertise and collaborative teams of informed novices with various levels of distributed expertise problematize and solve complex environmental science issues?

2a. How does working in a collaborative scientific team improve informed novices' understanding of the nature of authentic scientific inquiry?

2b. How does working in a collaborative scientific team impact their instructional products translating authentic scientific inquiry into classroom experiences?

## Definition of Terms

In order to ensure that there are no misunderstandings about the terminology used in this research proposal, a glossary of terms is provided to clarify their meanings as used in this context.

*Action research:* Participants carry out scientific research on some aspect of classroom learning to determine the effectiveness of an intervention. (For the ITS situation, the intervention involves some form of inquiry learning.)

*Analysis tools:* In this study, analysis tools for environmental science comprise the IT applications used by the SCM-ITS team for data analysis, including GIS (ARC-View®), MATLAB®, and Excel®. ARC-View® GIS is a geographical information system including computer hardware and software used to manipulate, analyze and link layers of geographic information and to present geospatial data. MATLAB® is a tool for doing numerical computations with matrices and vectors, developing algorithms and analyzing geospatial data such as vector maps and terrain data. Excel® is a spreadsheet application which can be used for data acquisition, manipulation, analysis and display, either alone or in combination with GIS or MATLAB®.

*Authentic scientific inquiry:* Authentic scientific inquiry is the highly complex practice of scientific problem solving as actually conducted by scientists utilizing specialized expertise, elaborate equipment and procedures, and data analysis and modeling techniques (Chinn & Malhotra, 2002).

*Collaboration:* "Collaboration is the process of shared creation: two or more individuals with complementary skills interacting to create a shared understanding that none had previously possessed or could have come to on their own" (Schrage, 1990).

*Collaborative team of informed novices:* In this situation, the collaborative teams of informed novices are composed of science graduate students from different fields, science educators currently employed in public schools and as professional development specialists, and science education graduate students with different science and mathematics backgrounds.

*Collaborative team of scientists:* In this situation, the collaborative team of scientists consists of four practicing scientists, each expert in a different field: geology, hydrology, environmental engineering, and environmental policy.

*Complex environmental science issue:* The environment is constantly affected by interactions among the lithosphere, hydrosphere, biosphere, and atmosphere, compounded by human intervention. Within such complex systems, a large number of processes occur at the same time at different scales. The behavior of the entire system depends on the interactions among these processes (Vicsek, 2002). In addition to dealing with the inherent complexity of the environment, the research issue "What is the environmental quality of the Texas Gulf Coast?" is an ill-defined problem.

*Distributed expertise:* Distributed expertise is varying levels and varieties of skills and conceptual knowledge within a group. Both the scientists and the informed novices on the ITS-SCM team have distributed expertise due to their range of backgrounds, experiences, and skills.

*Information technology (IT):* As utilized by the ITS-SCM team, IT as used in scientific inquiry used primarily computer hardware and its associated software capabilities, including Internet, word processing, spreadsheet, PowerPoint®, and geographic information systems (GIS).

*Informed novices:* For the purpose of this study, informed novices are the science educators and the science and education graduate students who are the participants in the ITS-SCM program and have diverse knowledge and skills in the sciences and as educators. Each participant is informed to some extent about the science involved; no one is a blank slate. Some approach expertise in certain parts of the science but are novice educators while others can be considered expert educators but are less knowledgeable about environmental science.

*Instructional products:* The term “instructional products” refers to the IT-mediated inquiry experiences (ranging from a few lessons to entire curriculum units) produced by participants for use in a classroom or learning environment.

*Interdisciplinarity:* Interdisciplinarity pertains to the application of knowledge and concepts from multiple disciplines in order to solve complex problems such as those in the environmental sciences

*Metacognition:* Metacognition refers to people’s capabilities to understand and control the cognitive processes involved in learning and to monitor and evaluate their ongoing levels of mastery and understanding.

*Problematize:* Problematize, in this situation, means to generate valuable problems for investigation through reflection, brainstorming, and collaboration (Radinsky et al., 1999).

*Web-based information:* Web-based information refers to the plethora of environmental facts and data freely available from governmental and other sources on the World Wide Web.

## Methodology

This research was designed as a mixed-methods study using both quantitative and qualitative analysis of collected data. Philosophically, the quantitative and qualitative paradigms traditionally have different views about the nature of knowledge and how knowledge is acquired (Creswell, 1994; NSF Directorate for Education and Human Resources, 1997). The quantitative tradition uses the scientific model and statistical tools to measure social phenomena, tries to reduce observer bias as much as possible, seeks to control the context by using random assignment and multivariate analyses, and tends to ignore anomalies (deviant and extreme cases). The qualitative tradition holds that there is no objective social reality and that all knowledge is constructed by observers who are biased. Biases are admitted up front, understanding of context is emphasized, and anomalies are considered important in analysis of data. Some researchers regard these differences as insurmountable and believe that research must be carried out totally within one tradition or the other.

A compelling rationale can, however, be provided for using mixed methods in social science research. Nau (1995) suggests viewing quantitative and qualitative methods as a continuum rather than as a dichotomy. According to Creswell, Plano Clark, Gutmann, and Hanson (2003), “a mixed methods study involves the collection or analysis of both quantitative and/or qualitative data in a single study in which the data are collected concurrently or sequentially, are given a priority, and involve the integration of the data at one or more stages in the process of research” (p. 212). Using the two methods within the same study builds on the strengths of both methods and increases the richness and quality of final results. The process can provide a more comprehensive understanding of analyzed phenomena, since a focus on only one kind of data limits the amount and types of information that can be gleaned from the study. Both types of data are valuable and add to the knowledge base, and the ability to triangulate data and interpretations strengthens the validity of the study.

This project involved a total of 15 subjects over two years: seven science graduate students, one public school teacher, one public school teacher/science graduate student, one science education graduate student/education service center teacher trainer, and four scientists who are faculty members of Texas A&M University . All participants and scientists applied for and were accepted by the ITS program. Scientific team assignments were determined by participant request (first or second choice), so the demographic structure of the class participants was pre-determined. Participant demographics are reported in the dissertation using information from the ITS applications. The student participants were six white females (one Hispanic) and five white males. The scientists comprised three males and one female, all white, non-

Hispanic. The team leader recruited the other three scientists from different environmental-related fields based on their research interests.

The purpose of this study was to assist the researcher in:

- Identifying how a team of scientists and a team of informed novices (science teachers and graduate students) approach solving a complex environmental problem using web-based information and analysis tools
- Determining the effect of working in a diverse team setting on the SCM-ITS participants' conceptual understanding of the nature of authentic scientific inquiry and their ability to translate these understandings into the science classroom at the secondary and university levels.

On day one of Summer I, participants filled out the participant questionnaire and took the pretest. The participant information questionnaire included questions about environmental science courses and experiences, any work experiences as practicing scientists, and familiarity with the software applications used in the course. The pretest questions concerned the participants' knowledge of authentic scientific inquiry as described by Chinn and Malhotra (2002). I framed the environmental topic questions in collaboration with the scientists and then divided the student participants into intentional groups of three or four with distributed expertise within the groups according to discipline and teaching background. They were given the overarching SCM team question (What is the environmental quality of the Texas Gulf Coast?) and brainstormed how they would go about problematizing the question. After the participants completed their brainstorming sessions and each group reported, the scientists came in and brainstormed the same question in front of the participants.

During subsequent class sessions, interactions between science faculty members, student participants, and between the whole collaborative team were video- and/or voice-recorded. Student participants kept an electronic portfolio with prompts for reflecting on their learning for that day and for answering specific questions about any lesson material presented that day. The electronic portfolio had open-ended prompts to encourage relevant responses. Student participants produced artifacts from the lessons which were evaluated by the scientists using rubrics. They were asked informal interview questions during the class sessions. At the end of Summer I, student participants took the pretest questions over authentic science as a posttest. During Summer II, student participants reported on the inquiry projects conducted for the education component of the project and then worked to revise and improve them during subsequent class sessions. The scientists and participants used a rubric to evaluate the inquiry projects for level of inquiry, science content knowledge, technology use, and assessment.

Quantitative data collected includes pre- and posttest data as well as scores collected from analysis by the scientists (using a rubric for quantification) of artifacts produced in the scientific team class work.

Qualitative data collected includes observation data, video- and audio-recordings, interview data, and electronic portfolio reflections. The researcher also collected data during brainstorming sessions, from participant questionnaires, and from pre- and posttest answer explanations. The researcher retrieved information from ITS participant applications concerning educational background, teaching experience, and technology experience.

## Theoretical Framework

As society becomes more complex, the responsibility of education to prepare students for life weighs ever more heavily. Questions arise about how students learn in the classroom and how educators can ensure that learning is transferred to new situations. Studies (Lave & Wenger, 1991) showing that learning is situational and knowledge is socially constructed have implications for how classrooms and curricula are organized. Clemens (1999) suggests that such research on learning underscores how the convergence of task organization and knowledge organization creates novel opportunities for learning within various settings. A clearer understanding of how learners use existing knowledge when confronted with a new problem and how they can use connections with others to help solve problems is essential in order to effectively prepare students for a successful, productive future.

Bennis and Biederman (1997) begin their work on creative collaboration with the following quote from an unknown author: "'None of us is as smart as all of us'" (p. 1). In scientific research as well as in business organizations, contributions from many talented individuals are necessary to identify and solve the urgent problems facing society. Individual action no longer is sufficient in a world which is increasing in complexity as it shrinks. In our culture, however, individuality is celebrated and students today are often uninterested in collaboration as a means of learning and creative problem solving (Fischer, 1998). As a result, there is a great need for students to engage in science learning in situations that are as authentic as possible within the classroom. We must develop collaboration and communication skills in meaningful ways beginning at an early age . Even as we incorporate technology into learning and problem-solving situations, we must never lose the human contact and collaboration because problem solving and knowledge creation are improved by multiple perspectives.

Since the geosciences incorporate studies of interactions among the Earth's lithosphere, hydrosphere, and atmosphere along with human influences and societal impacts, they employ an extensive array of disciplinary and interdisciplinary expertise in science and technology (National Science Foundation, 2000). They also are value-laden, with concerns for stewardship and sustainability at the forefront of environmental studies. Achieving sustainability is vital for the survival of our planet and depends on "an intricate web of interactions in linked systems, both natural and social"(Kasemir, Jager, Jaeger, & Gardner, 2003). Kasemir, et al. refer to the transition to sustainability as an elusive common journey dependent on the use of information technology, especially computer modeling. The complexities of providing for sustainability for Earth require an educated populace with the understandings and skills to collaborate effectively on decisions and research affecting its future. environmental science, a part of earth system science composed of the intersection of disciplines such as geology, chemistry, physics, mathematics, geography, and economics, provides an integrating theme for authentic science education. Many of the same technologies used in research can be combined with new instructional technologies and used in education to provide active, hands-on, relevant inquiry to motivate K-16 students to appreciate and enjoy science.

A National Science Foundation (NSF) workshop on geoscience education and cyberinfrastructure brought together a total of 50 scientists, educators, and IT specialists to brainstorm and discuss the future of geoscience education (Marlino, Sumner, & Wright, 2004). It resulted in a set of goals recognizing the importance of integrating research and education and supporting that integration with a cyberinfrastructure based on distributed computer, information and communication technology. Participants recognized the need for a pool of disciplinary experts who are creative thinkers and problem solvers and also knowledgeable about innovations in software, sensors, data management and visualization. Success in the production of such a workforce for the future "depends on implementing new approaches to geoscience education that emphasize the kind of experiential learning that leads to technical competence and intellectual self-confidence in research" (p. 3). Goals which emerged from the conference articulate strategies for achieving the integration of scientific research and education:

- collaborate and build new social structures to support future scientific discovery and innovation,
- support ubiquitous learning environments to take advantage of formal and informal learning opportunities,

- maximize a computational approach to geoscience to lead to a better understanding of complex Earth system problems through cutting-edge modeling, visualization and analysis techniques,
- create dynamic models of student understanding to develop truly student-centered learning environments,
- develop smart tools for authentic learning focusing on solving real-world problems that engage students and create understanding, and
- expand educator professional development incorporating the latest scientific data, tools, and analytical techniques and encouraging teachers to become educational and scientific researchers with their students.

Efforts supported by NSF are already under way to address some of these goals, and the SCM-ITS scientific team exemplifies efforts to achieve the last of these goals. The SCM-ITS team offered an opportunity to study collaborative problem solving involving distributed expertise in a group of experts and in groups of informed novices during a professional development experience and to observe the effects of this experience on the participants' views of the nature of scientific inquiry.

Chapter II of this dissertation consists of a review of current literature including research on complex problem solving as practiced in the environmental sciences as well as collaborative problem solving. It contains a discussion of expertise and the differences between experts and novices, and it defines distributed expertise. It also reviews works on situated cognition and authentic scientific inquiry, information technology, and the nature of science and scientific inquiry. Chapters III and IV are written as stand-alone articles for publication. Chapter III, titled “Expert and Novice Distributed Team Collaboration to Solve Complex Environmental Science Problems” considers the differences and similarities in how collaborative groups of experts (scientists) and informed novices (science graduate students and science teachers) generate problems for investigation through reflection and brainstorming and the processes by which the problems are solved. Chapter IV, “Improving Understandings of Authentic Scientific Inquiry: Does Working on a Collaborative Scientific Team Help?” examines the effects of participating in a scientific team on teachers’ and science graduate students’ understandings of the nature of scientific inquiry and their abilities to translate those understandings into the classroom. Finally, Chapter V summarizes the findings and discusses the conclusions and implications of the research.

# CHAPTER II

# LITERATURE REVIEW

Literature and research studies concerning topics relevant to the research questions for this project are reviewed in this chapter. It begins with a look at problem solving, particularly complex problem solving in the field of environmental science, and considers problem construction, solving ill-structured problems, and collaborative problem solving. Expertise research is reviewed to shed light on the differences in how experts and novices solve problems. Work on situated cognition and authentic science inquiry is discussed and related to the nature of science and the use of technology in teaching science. A summary of the findings is presented with the intent of providing a theoretical background for this study.

## Problem Solving

The urgency of learning to live within the limits of our environmental resources makes it imperative that we learn to work together to solve complex environmental problems. Polkinghorn (2000) stresses the importance of the application of multiple disciplines or a systems approach to solving environmental controversies. No single discipline holds the key to resolving – or even understanding – our environmental problems. Input from the components or interrelated elements which make up the complex system must be considered when examining the environment, including the biological, physical, and social realms. Interdisciplinary research has long been recognized as a cornerstone of innovative science and scientific progress, and it is even more necessary today as we attempt to solve the complex problems facing us. (Horwitz, 2003).

Earth system science regards the earth as a dynamic, synergistic system of interactive phenomena, processes and cycles. An understanding of the system is absolutely necessary for an understanding of our Earth relative to human enterprises and needs for sustainability (Johnson et al., 2000). Sarewitz's (2000) model (Figure 1) of the "geologic view" of the search for solutions to environmental controversies makes clear the complexity of the relationships involved in the search for sustainability. Complexity is an essentially interdisciplinary concept which describes the way the world works. The roles of science and scientific knowledge comprise a limited portion of the variables that come into play in the complex interactions between political, cultural, economical, and institutional influences. Scientific knowledge is one of many concurrent inputs, but it does not drive the process. Science begins its most important role after political consensus has been achieved.

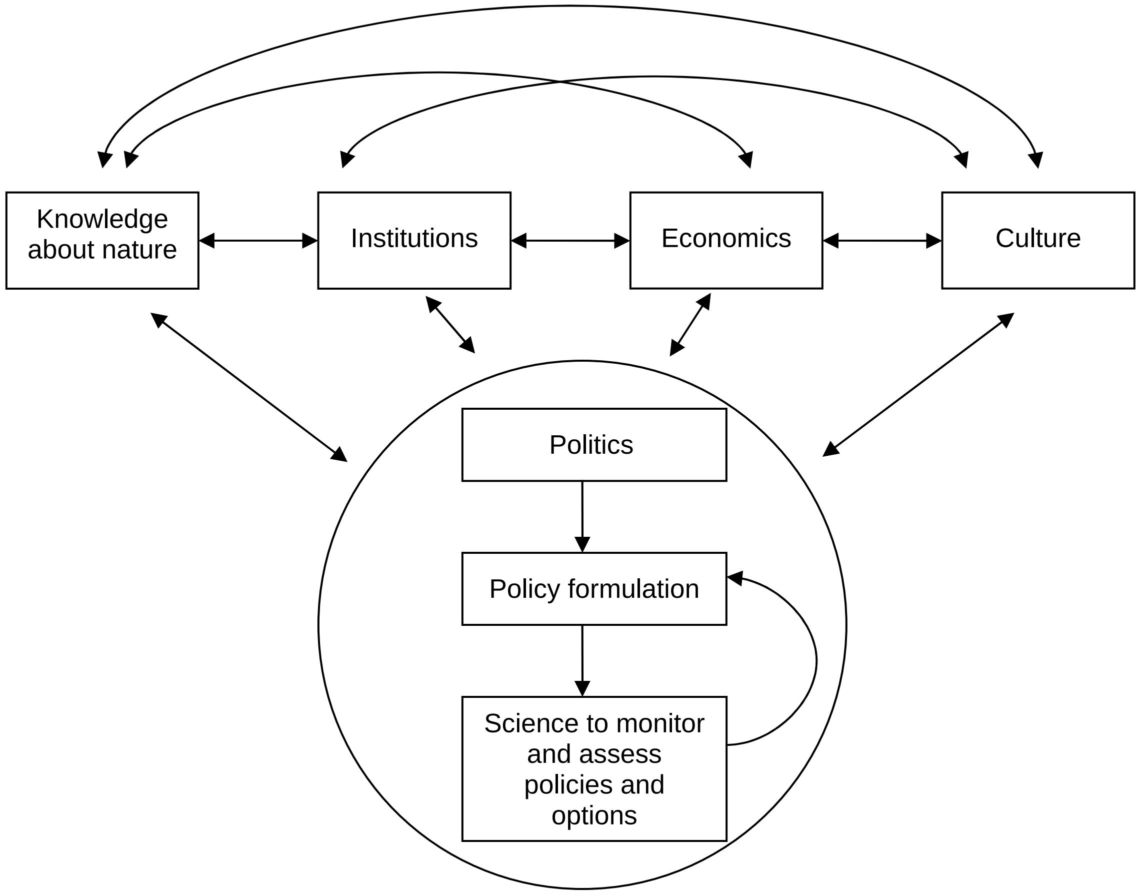


Figure 1. “Geologic view” of the relation among contingent variables in the search for solutions to environmental controversy. (Sarewitz, 2000) Frodeman, Robert; Earth Matters: The Earth Sciences, Philosophy and the Claims of Community 1/e © 2000 Reprinted by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Environmental problems are often ill-structured with one or more of the goals or constraints requiring resolution being poorly defined (Voss & Post, 1988) and its study is inherently interdisciplinary in nature. As a result, environmental science provides an ideal vehicle for giving educators the opportunity to experience the ill-defined complex problem-solving nature of science as practiced by scientists. Andelman, Bowles, Willig, and Waide (2004) describe a collaboration by several entities to create a distributed

Knowledge Network for Biocomplexity, where young scientists are being trained in interdisciplinary, synthetic research. They emphasize that the growing need for synthesis and analysis of large, diversified data sets necessitates that new scientists be skilled in the tools and fundamentals of “relational database management, including data manipulation and integration.” (p. 245)

Problem solving is a complex process consisting of several phases and involving defining or identifying the problem before the solution process can even begin. Albert Einstein is reputed to have said, “The mere formulation of a problem is far more essential than its solution, which may be merely a matter of mathematical or experimental skills. To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advances in science”(Gurteen, n.d.). Following are descriptions of two different research groups’ heuristics for ill-structured problems. Each emphasizes the importance of the problem formulation process and could easily be used to describe what goes on in solving complex environmental problems.

Basadur, Ellspermann, and Evans (1994)suggest that problem solving is a four-stage process: *problem generation, problem formulation, problem solving*, and *solution implementation.* The key behavioral skills necessary for successful problem solving are divergence, deferral of judgment, and convergence. Divergent thinking is imaginative and creative, producing as many ideas as possible while deferring judgment on their quality. It is followed by convergent thinking, which involves critical thinking, analyzing, comparing and selecting ideas, and focusing on reaching the best solution to a problem or issue. The process of *problem generation* consists of sensing or anticipating problems and fact finding. *Problem formulation* is when problem definition, conceptualization, and structuring occur. In their model of the problem solving process, Basadur et al. emphasize that redefinition of the problem as new information is discovered takes place concurrently throughout the problem generating and formulating stages. Only after the problem generation and problem formulation stages are completed can *problem solving* and *solution implementation* take place.

A second model of creative problem solving (Treffinger, Isaksen, & Dorval, 1994) consists of three major components: *understanding the problem, generating ideas*, and *planning for action*. *Understanding the problem* has three stages: mess-finding, data-finding, and problem-finding. Mess-finding is the process of selecting a goal or direction for problem solving and broadly describes the basic need or challenge. Data-finding helps the solvers focus by identifying significant data that will indicate the most productive direction for solution efforts. Problem-finding is the stage when a specific, focused problem statement is selected. An effective problem statement should be concise, free from limiting criteria, and encourage numerous creative, options. The second major component of the model, *generating ideas*, involves only one stage, idea-finding. This stage involves the solvers first in fluent, flexible, original, and elaborative thinking followed by examining and considering options proposed and select the most promising ones. The final component of the model, *planning for action*, consists of two phases: solution-finding and acceptance-finding. Solution-finding comprises evaluating the promising options and prioritizing or ranking them, assessing the potential of each.

Acceptance-finding includes a search for sources of assistance as well as identifying possible resistance for each possible solution and then formulating a plan for action for implementation of a proposed solution.

With a few exceptions, research on problem finding has been conducted either in the field of artificial intelligence or on individuals in artificial situations and in disciplines other than science (Basadur et al., 1994; Chand & Runco, 1993; Silver, MamonaDowns, Leung, & Kenney, 1996). Rostan (1994), however, studied scientists working in a biological laboratory situation. In a study of twenty critically acclaimed professional research biologists and twenty competent research biologists, she looked at problem-solving measures (tests of advanced vocabulary, inference, and paper folding), problem-finding measures (using Wescott's Intuition Scale and two other ill-defined problem-finding activities), and cognitive controls (measuring equivalence range, field articulation, and assimilation between perception and memory). She found that differences exist between the two groups who both would be considered experts. The critically acclaimed researchers spent a proportionally greater amount of time and discovery-oriented behavior to construction of a problem. The professionally competent researchers spent less time in problem formulation, were less likely to take chances in their work and were less productive overall in their professional lives. Rostan suggests that in educational environments we give students too much information, producing expert solvers of well-defined problems, but that we ignore or avoid ill-defined problems in our teaching. Using environmental issues as a basis for lessons gives teachers the opportunity to introduce ill-defined problems to their classes in a meaningful way.

## Expertise

During the last quarter of the twentieth century, a great deal of research was done exploring the differences between experts and novices, particularly in how they go about solving problems (Bransford et al., 2000; Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Farr, 1988; Dufresne, Leonard, & Gerace, 1995). Experts have certain characteristics that differentiate them from novices (Table 1). They are able to perceive features and meaningful patterns of information in their domain that are not noticed by novices in order to chunk information. Due to their deep understanding of large amounts of domain-specific knowledge, experts are able to cluster concepts, problem situations, equations, procedures, and operations, and can use concepts and analogies to find more than one way of representing and solving a problem, enabling them to check their solutions. Novices have sparse knowledge and poor clustering of concepts, often have misconceptions, employ memorization and formulas, and usually see only one way of solving a problem. They are generally unaware of inconsistencies and are unable to check their answers. Because of their richly interconnected and hierarchically arranged knowledge structure and multiple representations, experts are able to quickly retrieve knowledge that is relevant to the context of a problem. Novices with their disconnected knowledge and poorly formed and unrelated knowledge representations are often unable to retrieve or identify appropriate knowledge for an application. Experts also tend to be flexible in both their approach to problems and to their knowledge retrieval. They employ metacognition, the ability to self-monitor and recognize when additional information is needed. Novices evince little understanding of problems and never move beyond their primary interpretations. In a study of experts and novices analyzing complex marketing cases, Easton and Ormerod (2001) found that:

> Experts generated more alternative recommendations, identified more critical issues and used more evaluative criteria than novices. The outcomes of their analyses were generally qualitatively better than those of novices and were more likely to bring in issues not specifically referred to in the case statement. Novices also tended to reach a firm viewpoint or recommendation early (often during the first reading of the case statement), while some experts deferred reaching a recommendation until later in the analysis, were more likely to change their stance during the analysis, and in some cases did not reach a specific recommendation at all. Novice analyses focused more upon outcome while expert analyses were more likely to focus upon process issues. Novice analyses tended to be disappointingly shallow, and constrained by the content and order of the case statement. (p. 2)

Table 1. Differences between experts and novices

| Experts | Novices |
| --- | --- |
| Perceive features and meaningful patterns of information in their domain to chunk information | Cannot use chunking strategy |
| Have abundant content knowledge organized in ways that reflect deep understanding of subject and enable deep level of problem representation | Use memorization, recall, & manipulation of equations to solve problems; no systematic way of making sense |
| Have knowledge that reflects contexts of applicability | Fail to contextualize knowledge |
| Are able to flexibly retrieve important aspects of their knowledge with little intentional effort & quickly solve problem accurately | Effortful retrieval, little understanding of problem |
| Have flexibility in approach to new situations, and metacognition (ability to self-monitor own understanding) | Never move beyond original interpretations of problems or situations |

Note. Based on information from Bransford, Brown, & Cocking, (Eds.), (2000) and Chi, Glaser, & Farr, (1988).

Voss and Post (1988) propose that experts should outperform novices in decomposing an ill-structured problem into subproblems and in selecting goal-appropriate parameter values for open constraints. Political science problems, as described by Voss and Post, are structurally similar to complex environmental science problems. In a research project, the problem “Given low crop productivity in the Soviet Union, how would the solver go about improving crop productivity if he or she served as Director of the Ministry of Agriculture in the Soviet Union?” (p. 273) was given to political science experts on the Soviet Union. During the problem representation process, all the experts established the factor(s) responsible for low productivity, either by problem decomposition or problem conversion. During problem decomposition, the expert solvers set out several factors thought to be the primary causes of low productivity. Experts who used conversion converted the problem into one which could be solved, also settling on a statement of the factor assumed to be primarily responsible for the problem. Experts stated the problem history and searched internally from their own store of knowledge to inform the problem solution. During the solution process, they all justified their solution to the problem, analyzing why it would work, evaluating what implementation of their solution could accomplish, and even discussing what problems implementation might create. Obviously, solving ill-structured problems requires a great deal of domain-specific conceptual knowledge.

Determining when an ill-structured problem such as the one described above – or a complex environmental problem – is solved and whether the solution is a good one is more difficult than for other types of problems. Implementation of a solution after its adoption may take years, meaning that the justification process must build an argument for adopting the solution. Additionally, there are no commonly accepted methods for solving this kind of problem. The problem is considered solved when a workable plan is developed, but the timing of this may vary from situation to situation. Determining solution quality is often delayed, sometimes for many years. It is important to remember in regard to ill-structured problems that there is usually no single right answer and no single right way to determine an answer. Finding solutions to ill-structured problems also often involves issues of values and responsibility (Meacham & Emont, 1989), so justification of solutions becomes extremely important.

Research (Wiley, 1998) has shown, however, that in some instances mastery of a great amount of domain knowledge may actually constrain the production of solutions by experts, fixing them on ineffective solution paths. Wiley refers to this as mental set, or fixation, and cites studies to suggest that it may be caused by experts failing to consider relevant new knowledge because of prior knowledge and a tendency to actually consider less information than novices during problem solving. A study (Wiley & Jolly, 2003) of experts paired with novices on creative problem solving tasks found that expert fixation may be overcome by collaborating with a less knowledgeable partner or even by working with another expert. Nathan and Petrosino (2003) concluded that "expert blind spot" can make effective teaching problematical for domain experts (such as scientists and mathematicians) who go into teaching without an understanding of how people learn.

## Distributed Expertise

Much of the current research on distributed expertise is in the fields of artificial intelligence (AI), business and human resources, and space-related operations. In situations where a single researcher cannot be expert in all areas of an interdisciplinary project, investigators with distributed expertise linked by information technology systems are the most powerful way to carry out the project. Cassel and Kumar (2002) define distributed expertise as "a community in which levels of expertise vary and there is a willingness to share it." In an inquiry-based distributed expertise environment, each participant contributes his/her knowledge to all steps of problem solving, including defining a problem, theorizing, gathering and analyzing data, drawing conclusions and generating new research questions. Interdisciplinary collaboration situations are opportunities for the distributed expertise of the scientists involved to provide meaningful input into the solution of a problem.

In NASA's Mission Control Center, information flow among human experts in both local and remote locations is crucial (Caldwell, 2005). They must be able to exchange critical information and trade off knowledge, timing, and other resources. Caldwell's research-in-progress to describe a network model of an expertise sharing community is based on exploring the range of actual human behavior rather than on rational agent-based (as in AI – artificial intelligence) or economic-based performance systems. He is focusing on developing simulation modules that examine the aspects of expert community behavior, novice-expert transitions, and information flow processes. At this point, four simulation modules are envisioned:

- Asking: novices bring questions to the expert community, e.g., ask-a-scientist bulletin boards;
- Learning: novices become part of an expert community and develop expertise using existing experts and references while learning about the community, e.g., graduate school education;
- Sharing: group consisting of novices and experts interact using IT to exchange information and ideas, e.g., discussion board or chat room; and

- Solving: expert community members are responsible for monitoring situations and troubleshooting problems and are collectively focused on a specific task, e.g., Mission Control environment.

Expectations are that when combined, these modules will be able to robustly simulate actual behaviors in varied distributed expertise situations and to predict and analyze what a group does and what characteristics influence its activities. This would address very high priority research needs in the field of human performance and organization.

## Collaborative Problem Solving

In the field of education, collaborative, open-ended learning activities utilize distributed expertise and multiple perspectives to enable learners to succeed at tasks and develop understandings beyond what any could achieve alone. For example, the Collaborative Visualization (CoVis) Project employs a networked Collaboratory Notebook software to encourage collaborative learning in earth and environmental science classrooms (Edelson, Pea, & Gomez, 1996). Two elements common to most definitions of collaboration are: “working together for a common goal and sharing of knowledge” (Hara, Solomon , Kim, & Sonnenwald, 2003). Neither of these elements, however, proves to be easy to accomplish. Working together is not necessarily easy, and determining a common vision for a project can also be difficult. Sharing knowledge (as well as power, resources, or responsibility) involves taking risks and trusting others and can be especially difficult when reputations or career advancements are at stake.

Bronstein (2002) synthesized current research to identify five components of interdisciplinary collaboration which can be applied in research settings: (a) *interdependence* between participants is necessary for successful problem solving to take place; (b) *newly created professional activities* include collaboration on programs and structures that become more than any one person could achieve alone, thus maximizing individual expertise; (c) *flexibility* refers to the ability to reach compromises and to change roles within the group; (d) *collective ownership of goals* involves shared responsibility for all factors (goal design, development, etc.) involved in achieving goals; and finally (e) *reflection on process* is deliberate attention paid to the entire collaborative process, including relationship building and effectiveness of the process. Successful interdisciplinary collaborative research results in the creation of new ideas and processes due to thinking outside the “box” of any single discipline.

In a case study of academic-practitioner collaboration, Amabile et al.(2001) found that creation of a successful collaboration is often difficult. They suggest that, in order to have a successful collaboration, team members should have diverse backgrounds and skills but a common core of knowledge, be willing to work with others from different professional cultures, have similar perspectives on the value of research, and be intrinsically motivated to participate in the project. Roles and responsibilities of team members should be made clear at the inception of the project, and provisions should be made for team members to get to know each other and communicate on a regular basis. Participants’ institutions should be supportive of their participation in the collaborative process. Finally, the team should examine its functioning reflectively on a regular basis and make any necessary adjustments.

From a study of children involved in the Jasper project, Barron (2000) identified three major dimensions of group interaction: mutuality of exchanges, shared task alignment, and joint focus of attention. Indicators of high coordination for mutuality of exchanges (reciprocity) were productive conflicts, transactional responses, and respect for turn-taking norms. Student groups with high markers of coordination for shared task alignment co-constructed solutions and referenced other's ideas during problem solving. Groups with high joint focus of attention during solution-critical moments tended to have their workbook as the center of coordination and a joint monitoring of solution. The study groups having high markers of coordination for all three dimensions generated, confirmed, documented, and reflected upon correct proposals for solution. Groups with low markers generated proposals, rejected them without rationale, and generally left them undocumented.

Interdisciplinary collaborations provide an effective means of carrying out research involving more than one scientific discipline. Interdisciplinary groups consciously work to integrate knowledge from different disciplinary perspectives (O'Donnell, DuRussel, & Derry, 1997). Cognitive processing by group members is necessary for the members to come to understand the group goals, represent the problem being studied, and identify and implement strategies for accomplishment of the goals. Although various constraints (including time) make true interdisciplinarity difficult to achieve, governmental funding agencies encourage this type of research with grant programs, and some universities and other institutions have initiated cross-disciplinary research programs.

Situated Cognition and Authentic Science Inquiry

Radinsky, Bouillion, Lento, and Gomez (2001) approach curricula design for authenticity in two ways – simulation and participation. For the first, a simulation of a professional practice is created in the classroom, with materials, tools, assignments and interactions to map the enterprise of some real world context. In the second approach, opportunities are created for students to actually participate in the activities of a professional community.

Edelson (1998) characterizes authentic science practice as consisting of attitudes, tools and techniques, and social interaction. Attitudes which define scientific practice include uncertainty (the techniques and results of inquiry are conditional, subject to scrutiny and change) and commitment (scientists are committed to the questions they are striving to answer). The tools and techniques are common to scientists everywhere, establishing a shared context for scientific activity. Social interaction involves the sharing of experimental results, questions, and concerns among the community of scientists, and is accompanied by the cooperation, competition, agreement and argumentation that is common to all human activity. Edelson contends that a successful adaptation of science to the classroom will reflect all these characteristics of scientific practice, and that traditional training does not prepare teachers successfully for their role in providing students with the context for open-ended inquiry.

Chinn and Malhotra (2002) present a detailed model to be used for evaluating inquiry tasks in terms of their similarity to authentic science. They analyze cognitive processes and the epistemology of authentic inquiry and compare each to the types found in simple experiments, simple observations, and simple illustrations. Their list of reasoning tasks characterizing authentic science includes generating research questions, designing studies, developing theories, studying other scientists' research reports, making observations and explaining results. In their epistemology of authentic inquiry, Chinn and Malhotra list the social construction of knowledge and their examples include such statements as "Scientists construct knowledge in collaborative groups" and "Scientists build on previous research by many scientists" (p. 188). Carlone and Bowen (2003) critique these descriptions of authentic science, saying that there is not enough emphasis placed on the importance of extended immersion into research projects, the centrality of the role of science community, the contextuality of acceptable standards to research and the role of informal communications and interactions.

Brown et al. (1989) discuss how schooling is different from apprenticeship learning and how apprenticeships produce learning that evolves into expert-like behavior. The features of apprentice, practitioner, and student activities shown in Table 2 represent the ways in which apprentice behaviors are similar to practitioner behaviors because the activities are situated within the constraints of the cultures in which they occur. Student behavior, on the other hand, occurs out of context and problems are solved through the use of algorithms which may not be useful in the context of an authentic situation. Brown et al. argue that authentic activity is crucial for learners because it is the only means by which they are able to reach the position from which practitioners solve problems in meaningful and purposeful ways. Methods of cognitive apprenticeship try to enculturate learners by developing concepts through continuing authentic activity in ways much like those employed in craft apprenticeships.

Table 2. Student, apprentice, and practitioner activity

| | Students (Novices) | Apprentices (Authentic situations) | Practitioners (Experts) |
|---|---|---|---|
| **Reasoning with:** | laws | causal stories | causal models |
| **Acting on:** | symbols | situations | conceptual situations |
| **Resolving:** | well-defined problems | emergent problems & dilemmas | complex, ill-structured problems |
| **Producing:** | fixed meaning & immutable concepts | negotiable meaning & socially constructed understanding | negotiable meaning & socially constructed understanding |

Note: Adapted from Brown, Collins, & Duguid (1989). Copyright 1989 by the American Educational Research Association; reproduced with permission from the publisher.

Recent research in science education indicates that long-term learning of science is most effective when it occurs as inquiry learning modeled on the norms of authentic science as a social process. Brown et al. (1989) assert that groups of practitioners are particularly important for enculturation because it is only within groups that conversation and social interaction can occur. Group learning provides for cooperative problem solving, experiencing multiple roles, confronting ineffective techniques and misconceptions, and developing collaborative work skills. Hmelo-Silver, Nagarajan, and Day (2002) contend that “by incorporating collaborative activities into inquiry, students must explain their understandings, argue with evidence, and critically evaluate the scientific explanations of others” (p. 220). Stewart and Lagowski (2003) suggest that cognitive apprenticeship theory describes almost exactly what is done in the successful processes of preparing chemistry graduate students for careers as researchers. Cognitive apprenticeship theory suggests that students at all levels learn science most effectively when they verify or revise theories by performing experiments they have designed, recording and analyzing data, and communicating their results to their peers (Schauble, Glaser, Duschl, Schulze, & John, 1995).

Richmond and Kurth (1999) studied twenty-eight high school students who participated in a seven-week summer research apprenticeship program. Through working with a mentor, students developed more complex and realistic ideas about what it means to do science and a deeper appreciation for the service science performs for society in asking critical questions and advancing cogent explanations. The authors suggested four opportunities for classroom teachers to provide more authentic experiences for their students:

- Structure investigations in order to problematize data collection and analysis and help students realize that ambiguity is not necessarily the result of mistakes on their part but may be inherent in the problem itself.
- Distribute expertise among group members so that it parallels distributed expertise within scientific communities.
- Scaffold understanding so that terminology supports knowledge construction rather than hindering it.
- Plan longer, integrated investigations that build on earlier learning.

They concluded that educators can purposefully develop opportunities for students to acquire authentic skills along with the culture of science even though true apprenticeship experiences cannot be completely transferred to the classroom.

Barab and Hay (2001) describe the Science Apprenticeship Camp (SAC), where small groups of eighth graders worked with scientists to carry out scientific research. They used six characteristics of participatory science learning environments (Table 3.) gleaned from the literature on apprenticeship learning in order to evaluate the Science Apprenticeship Camp. They found that, despite limitations inherent in the situation (e.g., short time frame, scientist determined research agenda), many students saw themselves as doing legitimate science and making meaningful contributions to the work of the scientist. The researchers see a need for more grounded research into authentic science situations as most literature on this type of interaction is theoretical, discussing what authentic science instruction *should be* like rather than what it *is* like.

Table 3. Characteristics of participatory science learning

1. Learners *d*o domain-related *practices* to address domain-related problems.
2. Scientific and technological knowledge and practice are *situationally constructed* and *socially negotiated*.
3. Learning occurs “at the elbows” of *more knowledgeable others*, including teachers, scientists, and peers.
4. Practices and outcomes are *authentic to* and *owned by* the learner and the community of practice, and are in response to real-world needs.
5. Participants develop an *identity* as a member of a community of practice.
6. Formal opportunity and support for both *reflection-in action* and *reflection-on-action* are present.

Note: Modified from Barab & Hay (2001), italics in original. (Reprinted with permission from John Wiley & Sons, Inc.)

Table 4. Comparison of science apprentice experiences with authentic inquiry

| **Reasoning Task** | | | |
|---|---|---|---|
| **Cognitive Process** | **Authentic Inquiry** (Chinn & Malhotra, 2002) | **Summer Research Apprenticeship** **7 Weeks, 10th & 11th Graders** (Richmond & Kurth, 1999) | **Science Apprenticeship Camp** **2 Weeks, 8th Graders** (Barab & Hay, 2001) |
| **Generating research questions** | Scientists generate their own research questions | ? | No |
| **Designing studies** | Scientists design their own studies, including selecting variables, planning procedures, controlling variables, planning measures, and making observations | Designed own protocols<br>Operated apparatus<br>Made observations | Did not design studies<br>Operated apparatus<br>Made observations |
| **Explaining results** | Scientists explain their own results, including transforming observations, finding flaws, using indirect reasoning, making generalizations, and employing multiple types of reasoning | Found flaws<br>Used evidence | Analyzed & interpreted data<br>Made inferences<br>Hypothesis testing |
| **Developing theories** | Scientists construct theories, coordinate results from multiple studies, and study other scientists' research reports. | Read research reports | Reports/articles available in labs |
| **Dimension of Epistemology** | | | |
| **Purpose of research** | Scientists aim to build and revise theoretical models with unobservable mechanisms | | |
| **Theory-data coordination** | Scientists coordinate theoretical models with multiple sets of complex, partially conflicting data. | Recognized complexity | Had to deal with anomalous data |
| **Theory-ladenness of methods** | Methods are partially theory laden. | ? | ? |
| **Response to anomalous data** | Scientists rationally and regularly discount anomalous data. | | Anomalous data not always discounted |
| **Nature of reasoning** | Scientists employ heuristic, nonalgorithmic reasoning, multiple argument forms, and uncertain reasoning. | Recognized uncertainty as part of process | |
| **Social construction of knowledge** | Scientists construct knowledge in collaborative groups, build on previous research by others, and use peer review and exemplary research models. | Collaborated in research groups<br>Read papers<br>Recognized science as cumulative body of work | Collaborated in research groups |

A comparison of the summer research apprenticeship (Richmond & Kurth, 1999) and science apprenticeship camp (Barab & Hay, 2001) experiences to the cognitive processes and dimensions of epistemology of authentic science as described by Chinn and Malhotra (2002) results in some interesting observations (Table 4). Students experiencing both apprenticeship situations were able to participate in many of the cognitive processes listed by Chinn and Malhotra. (My observations are of necessity limited to the descriptions provided in the two research articles and therefore may not reflect all the actual student experiences.) In both situations, students worked with scientists in their own laboratories, so the field of research was constrained. The older students wrote their own protocols and carried out their experiments as working lab members but it was unclear whether they generated their own research questions. The younger students began by observing the scientists, learned the necessary techniques for the scientists' work, and soon were able to carry out the experimental procedures and collect data on their own. The older students were immersed in scientific literature associated with their projects and became adept at the discourse of the discipline, enabling them to develop their ideas as well as their skills.

Fewer experiences in the dimension of epistemology were apparent from the reading of the articles. Some of the eighth graders at the science apprenticeship camp were exposed to anomalous data and had to decide, with the help of the scientist, how to handle it. They learned the importance of statistics and realized that the observed anomaly should not be discounted out of hand. Students in both apprenticeship situations worked in collaborative groups of peers, graduate students, and scientists. Both experiences seem to have provided students with age- and experience-appropriate opportunities to become enculturated in authentic science, much as the SCM-ITS program provided those experiences for educators and science graduate students.

## Information Technology

Advances in information technology and in understanding how people learn have enabled educators to make learning more interesting and relevant to learners. McLoughlin and Luca (2002) list a number of ways (p. 578) by which information technologies scaffold learning. Information technologies serve as tools for knowledge construction by representing ideas, beliefs and understandings, and serve as vehicles for exploring knowledge by enabling students to access information and compare and evaluate differing perspectives and world views. Information technologies also provide contexts to support active learning by representing and simulating real world situations and provide a controlled, shared problem space for the comparing of ideas, revision of work, and hypothesizing and justifying hypotheses. They are a social medium for communication and collaboration, enabling the creation of knowledge by supporting conversation, inquiry, and argument among communities of learners. Finally, they serve as an intellectual partner, supporting reflection and allowing learners to articulate and construct personal representations of reality. Educators, therefore, can create learning environments which include authentic problem solving and knowledge integration tasks, fostering knowledge application and skill transfer to real world problems and moving novices along the continuum toward expertise.

Science education standards from the National Research Council (National Research Council, 1996) reflect the expectation that students understand the role of technology in collecting, manipulating and interpreting data and be able to use appropriate technologies to conduct inquiry. Students learn about scientific inquiry and the nature of scientific models, simulations and visualizations as well as improve their conceptual understandings through the use of technologies (Linn, 2003; White & Frederiksen, 2000). Kozma (2000) discusses the role of technology in having students actively engaged in collaboratively building knowledge and constructing meaning. Activities in technological environments “can engage students in focused inquiry that involves authentic scientific tasks, such as making predictions, observations, and explanations that support their sense-making conversations” (p. 35).

The GLOBE program (Means & Coleman, 2000) uses the Internet for data recording, archiving and visualization as well as for communication between schools and with scientists. GLOBE evaluators assert that the use of technology is crucial in making the experience feel authentic and important to the students using it. In addition, students have the opportunity to reflect on data anomalies, think critically and construct explanations. The social nature of science is represented, and students who participate in GLOBE tend to understand that scientists spend a substantial amount of time explaining the results of their work, discussing their results with other scientists and justifying their points of view.

## Nature of Science

National standards for science education (National Research Council, 1996) stress that science education should provide for three kinds of scientific knowledge: (a) the concepts and precepts of science, (b) the reasoning and process skills of scientists and (c) an understanding of the nature of science (NOS) as a way of knowing. In other words, NOS relates to the values and epistemological assumptions which undergird the processes of science and the development of scientific knowledge (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2001). Agreeing on what constitutes the nature of science is, however, a difficult task and, in fact, it is generally agreed that there is no single NOS (Alters, 1997; Loving, 1997; Southerland, Gess-Newsome, & Johnston, 2003) although some science educators do say there are certain tenets all would agree on. McComas, Clough, and Almazroa (1998) include as agreed-on tenets the tentativeness of science, the theory-ladenness of observations, the social, cultural, and historical nature of science, and the observational and experimental nature of science, among others.

A review of the literature reveals differing viewpoints on what constitutes science and scientific investigation and what should be included in science education in order to produce scientific literacy. Matthews (1994) describes the liberal tradition in science education as including an education both *in* science and *about* science. It should provide students with an understanding of scientific methods, an appreciation for methodological issues such as theory evaluation and a "sense of the interrelated role of experiment, mathematics and religious and philosophical commitment in the development of science" (p. 2). It should include knowledge of pivotal episodes in the history of the discipline as well as of its processes and products.

Duschl (2000) argues that, in order to make the nature of science explicit in science education, radical changes must be made, beginning with teacher education. This new approach must be one that "examines the relationship between data, observation, fact and theory and develops a sense of the criteria used to evaluate these relationships. The data texts of science result from the various and sundry ways we observe, collect, select, represent, model and explain our investigations of, and inquiries into, the material world" (p. 190).

By focusing on "myths of science," McComas (1998) chose to concentrate on fifteen commonly held misconceptions about NOS. These misconceptions are those often held by the public, teachers and students and are sometimes the result of inclusion in textbooks (e.g., the idea that there is a single scientific method). Other misconceptions are most likely the result of omissions by textbook authors (e.g., scientific knowledge is socially constructed). Still other misconceptions concern the role and nature of hypotheses/theories/laws and models, the idea that scientific knowledge and the means of producing it (experimentation) are absolute, the lack of creativity in science, the omnipotence and objectivity of science, and that science and technology are identical. McComas concludes that schools must give students the opportunity to experience authentic science and its processes in order to produce scientific literacy.

In proposing a set of four "commonplaces" of science, Helms and Carlone (1999) attempt to develop a heuristic which provides a robust description of aspects of the nature of science and their relationships. Their commonplaces include the following:

#1: Science is an activity in which *evidence* is gathered through *observation* and *experiment* to *explain* and *predict natural phenomena* (p. 236).

#2: Science is an activity through which people *negotiate* the production of *artifacts* and *facts* in order that they may *explain, predict,* and *control natural phenomena* in their *interests* and the *interests of others* (p. 237).

#3: Science is an activity in which people studying *natural phenomena* use and produce *technologies* to pursue *questions* and solve *problems* that influence and are influenced by external *social structures* (p. 238).

#4: Science is an activity in which people employ *lenses* and *methods* to investigate *questions* and produce *knowledge* concerning *natural phen*omena, all in a particular *context*, in the service of some *goal* or *set of goals* (p. 240).

Commonplace #1 is from an empiricist viewpoint and is a central tenet of reform-based instruction although it presents a limited picture of how science is done. Commonplace #2 takes a microsociological (or internal) view, including how science is carried out in the laboratory and is influenced by individual values and interests of the participants. The third commonplace expands the boundaries of science to the macrosociological, connecting science with external factors including the social, political, cultural, religious, and economic perspectives. Finally, commonplace #4 portrays science as multifaceted, depicting the empirical as well as the sociological elements of the practice of science. The authors argue that using their commonplaces framework would enhance teaching and teacher education by making explicit the links between nature of science and the teaching of science. Rather than lobby for a more authentic science education, they attempt to give direction to science education by presenting a heuristic which emphasize science as a contextualized activity, providing a lens for critical examination of contexts of science learning. Missing from this portrayal, however, is any mention of the role of models and theories in guiding all aspects of scientific investigations.

Wong (2002) suggests that, rather than emphasize the commonalities shared by scientists as a group, people should appreciate the uncommon features. Variation among individual scientists reveals the creativity, adaptations, and judgments inherent in scientific work. He agrees that the broad descriptions of scientific activity are useful, but should not provide the sole portrayal of NOS. A portrayal of the vitality and inspiration of science is necessary for a successful science education in which students, in their turn, appreciate the vitality of science and are inspired to do science.

In a study examining the effects of  a science research internship course incorporating authentic science inquiry, explicit NOS instruction, and guided reflections, Schwartz, Lederman, and Crawford (2004) targeted the following NOS aspects: tentativeness, empirical basis, subjectivity, creativity, sociocultural embeddedness, observation and inference, laws and theories, and interdependence of these aspects. They identified three important factors for NOS developments: (1) opportunities for reflection, (2) authentic context for inquiry and (3) the reflective perspective of the intern. They agree with previous research which has found that simply doing science is not sufficient for developing an understanding of NOS; explicit NOS instruction is necessary (Abd-El-Khalick, Bell, & Lederman, 1998).

Southerland, et al. (2003) describe the difficulties encountered in an attempt to reform collegiate level science teaching by implementing an integrated science course designed to emphasize NOS. The NOS beliefs of the three scientists who designed and taught the course were manifest in their teaching practices, but the manifestations were not simplistic. They found that personal NOS beliefs sometimes varied from those of the course so that what was taught did not always match what was originally conceived in the curriculum. Even when personal NOS beliefs were sophisticated and matched the course objectives, those beliefs were not always directly rendered into practice. Factors which were determined to have contributed to these problems included limited pedagogical content knowledge, problems with integration of the disciplines and lack of time for scaffolding to achieve true consensus among the scientists involved.

## Summary

This review of the literature discussed the components of research relevant to systems problem solving in the environmental sciences by expert and novice groups with distributed expertise. It looked at current research in the fields of situated cognition, characteristics of authentic scientific inquiry, and nature of science. The SCM-ITS program provided professional development for teachers and science graduate students and employed situated cognition through experiencing authentic inquiry. Participants learned to problematize complex environmental issues in distributed expertise groups and experienced the nature of science as practiced by environmental scientists from several backgrounds. In the future, their experiences in SCM-ITS will guide them as they prepare authentic scientific inquiry experiences for their students.

# CHAPTER III

# EXPERT AND NOVICE DISTRIBUTED TEAM COLLABORATION TO SOLVE COMPLEX ENVIRONMENTAL SCIENCE PROBLEMS

## Introduction

Reports such as the *National Science Education Standards* (1996) and *Project 2061: Science for All Americans* (American Association for the Advancement of Science, 1989) recommend curricular changes to ensure that the U.S. reaches the goal of high literacy in science and mathematics. In order to be considered literate, today's students are expected to be able to think critically and to solve complex problems in various disciplines. Changes in curricula and instruction recommended in order to achieve those goals include emphasis on developing thinking skills such as relating factual knowledge to important concepts, describing and solving problems, acquiring information and reasoning with it, and communicating with others about results of experimentation. The reports advocate the use of multidisciplinary and interdisciplinary approaches to teaching science in situations that encourage active participation including hands-on activities, learning in collaborative groups, and completing long-term projects (National Assessment Governing Board, 2004).

The framework of the 2005 National Assessment of Educational Progress (NAEP) includes the categories of conceptual understanding of science, scientific investigation, and practical reasoning . Conceptual understanding is the "mastery of basic scientific concepts [which] can best be shown by a student's ability to use information to conduct a scientific investigation or engage in practical reasoning" (p. 21). It includes facts and events; scientific principles, laws, and theories; procedures for conducting inquiries and applying scientific knowledge; and an understanding of the nature of science, as well as its history and philosophy.

Recent publications address how inquiry-based learning helps students learn science content material , but for inquiry-based teaching and learning to be successful, teachers must understand what inquiry means (American Association for the Advancement of Science, 2001; National Research Council, 2000). They must be able to interpret inquiry for others and defend its use and so must understand its processes as well as its research-documented advantages. For most teachers and students, conducting successful teaching and learning through inquiry requires change from traditional attitudes and behaviors. Change to inquiry teaching requires teachers to develop new skills, instructional methods and assessment activities. Research suggests that changes in teacher beliefs and attitudes result when teachers experience a new practice such as inquiry and see their students benefit from it.

Earth systems science provides an ideal milieu for giving educators the opportunity to experience the ill-defined problem-solving nature of science as practiced by scientists. The complexity of environmental problems demands an interdisciplinary approach so that sociopolitical as well as scientific aspects from various disciplines are addressed. The availability of applicable complex data sets on the Internet makes it possible for educators and students to conduct problem solving in an authentic manner.

An understanding of the processes involved in this type of problem solving is essential, however, before educators can effectively use it in the classroom.

In an effort to reach this kind of understanding, this research project addressed the question: How do members of a collaborative team with various levels of distributed expertise interact to problematize a complex environmental science issue using web-based information and information/ analysis tools? It considers the differences and similarities in how collaborative groups of experts (scientists) and informed novices (science graduate students and science teachers) generate valuable problems for investigation through reflection and brainstorming and the processes through which the problems are solved.

## Supporting Literature

Earth systems science is an integrative study of the complex environmental processes involving the synergistic relationships which occur between the geosphere, hydrosphere, atmosphere, and biosphere at various spatial and temporal scales. Since no process occurs in isolation, no single traditional discipline (geology, climatology, ecology, toxicology, etc.) is able to satisfactorily understand and explain the complexity involved (Journal of Earth System Science Education, 2001). As a result, Earth systems science is a social process requiring scientists to communicate and collaborate with each other and the public and to deal with a combination of biological and physical systems which interact and must be simplified into models. They must deal with matters outside their own fields of expertise on a regular basis and, therefore, must collaborate with experts from other disciplines who do not necessarily share a common vocabulary or thought process (Garwin, 1995; Norgaard, 1992). This collaboration differs from that in other sciences because the needs and stakeholders are different from those in the individual sciences and because theory in environmental science is not immediately testable but must be tested over time, often under conditions which are poorly controlled. The importance and complexity of Earth systems science challenges educators as well as researchers to provide a deeper and interdisciplinary understanding of the factors which contribute to the environmental system as a whole.

Policy issues must be considered along with the scientific issues involved in environmental science. These factors point to the need for effective collaboration among scientists from different disciplines, policymakers, and stakeholders, all of whom may view problems from diverse perspectives (Hara et al., 2003; Linn, 2003; Norgaard, 1992). Collaboration between natural and social scientists is made more difficult by the differing epistemologies of the disciplines. The implication of these differing epistemologies is evident, since the natural sciences progress by eliminating debate and working toward consensus while the social sciences progress by encouraging debate and conceding the legitimacy of opposing views and discrete epistemologies (Redclift, 1998). As a result, both natural and social scientists are often frustrated with the attempts at discussion, since the two cultures are fundamentally disparate.

Advances in technology and methodologies have created the need for collaborative teams of natural, social, and applied scientists who are willing and able to go beyond disciplinary frameworks. The distributed expertise among the members of collaborative teams brings approaches from different disciplines to the table during the problem-solving process. A  successful collaborative problem-solving environment has been described as one in which diverse participants are actively contributing to all steps of problem solving, engaging in dialogue or discussion, sharing ideas and assistance, negotiating resolutions to conflict, analyzing strategies, and supporting each other to achieve a common goal that could not be accomplished by a single individual (Amabile et al., 2001; Cassel & Kumar, 2002; Wilczenski, Bontrager, Ventrone, & Correia, 2001). Collaboration differs from cooperation in that while cooperation may involve division of labor among participants, collaboration involves active engagement by all participants to solve a mutual problem (Kneser & Ploetzner, 2001). Effective collaborative groups where all members are positively involved in the process achieve a synergistic effect, accomplishing more together than any one individual could alone. Interactions between participants create new possibilities for inspiration, and numerous researchers (Barron, 2000; Brophy, 1998; Okada & Simon, 1997) have found that groups often were more successful than their best member in solving complex problems when group members' thinking, strategies, and knowledge were distributed so that each member could contribute. Groups also did better than individuals on tasks involving analysis, synthesis, and ingenuity.

Characteristics of teams and team members which may predict successful collaboration include project-relevant skills and knowledge, collaboration skill, and attitudes and motivation. The most critical aspects of project-relevant skills and knowledge appear to be diversity and correlativity in the skills, knowledge and points of view of participants, including a mutual core of knowledge about the problem domain.

Collaboration skill apparently results from experience in collaborative situations. The most important attitudes and motivation are trust and mutual respect among team members (Amabile et al., 2001).

The practice of modern science requires solving complex, large-scale, ill-structured problems involving ever-changing technologies, exponential growth of knowledge, and specialized expertise. Ill-structured problems are usually contextual and have vaguely-defined goals, open constraints, and known elements that are minimal at the beginning of the solution. They do not have general rules for solution or solutions that are universally accepted by all experts in a field, tend to be found in the social sciences or in some natural sciences such as environmental science and may require components from several content domains for solution (Jonassen, 1997). The nature of ill-structured problems demands that problem solvers begin by imposing constraints on the situation and developing a problem representation or model which may be very complex (Mumford, Baughman, Threlfall, Supinski, & Costanza, 1996; Voss, 1988). Justification, which argues the difficulties of the problem and how they may be overcome, is extremely important because the complexity of ill-structured problems makes testing difficult (Jonassen, 1997; Voss, 1988).

Table 5. Characteristics of experts and novices

| Characteristic Category | Experts | Novices |
|---|---|---|
| • Information chunking strategies | • Notice features and meaningful patterns of information to chunk or cluster information | • Have poor chunking strategies; may lead to misconceptions |
| • Knowledge organization, depth and amount | • Abundant, highly organized content knowledge reflecting a deep understanding of domain | • Use memorization, recall, & manipulation of equations to solve problems; no systematic way of making sense; knowledge disconnected |
| • Flexibility of problem-solving strategies | • Have more than one way to solve problem, can check answers | • Usually have only one way to solve problem, cannot check answers |
| • Knowledge contextuality | • Have knowledge that reflects contexts of applicability; knowledge is "conditionalized" on a set of circumstances | • Have "inert" knowledge, fail to "conditionalize;" do not recognize context where knowledge is useful |
| • Knowledge retrieval | • Are able to flexibly retrieve important aspects of their knowledge with little intentional effort | • Effortful retrieval, little understanding of problem |
| • Knowledge of discipline content | • Know discipline thoroughly but are not necessarily able to teach others | • Sparse content knowledge |
| • Metacognitive ability | • Have varying levels of flexibility in approach to new situations; have metacognition (ability to monitor own level of understanding) | • Never move beyond initial interpretations of problems or situations |
| • Problem representation | • Construct multiple representations of problem | • Poor, unrelated representations of problem |

Note. Based on information from Bransford, Brown, & Cocking, (2000); and Chi, Glaser, & Farr, (1988).

Earth systems scientists are usually experts in a single domain of the environmental sciences. Cognitive scientists define an expert as a person who is very knowledgeable or skilled in a domain. Expertise depends on the kind of extremely organized, domain-specific knowledge that can develop only after protracted experience and practice in the domain. Comparing experts and novices makes it possible to differentiate the ways they understand, store, recall, and manipulate knowledge during problem solving (Table 5). Expert knowledge, organized around basic concepts in a domain, guides the thinking of experts. For example, physicists use the applicable major laws and principles of physics to solve problems, along with sketches, where novices use formulas and recall. Experts are flexible in the ability to retrieve knowledge and able to transfer knowledge in order to solve complex problems. They have the ability to draw from and use a number of strategies that go beyond the context in which they are learned or normally performed in order to generate alternative and creative solutions to a problem in less time and more accurately than novices to the field (Bransford et al., 2000; Bruer, 2003; Costa & Kallick, 1995; Crismond, 2001; Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999; Hmelo-Silver et al., 2002; Larkin, McDermott, Simon, & Simon, 1980).

One aspect of expertise is representational skill, or the ability to organize contextual knowledge (Lesgold, 1984), which is knowledge "of a set of features, an environment, or setting within which a learner makes connections, comparisons and analogies (Wignall, 2003). Goldman et al. report that research has found differences in representations or mental models used by experts and novices in problem-solving situations. Experts' models are richer, reflecting deep understandings of relationships, whereas novices' models are more superficial, reflecting a lack of conceptual and contextual understanding. The development of a cogent problem representation or model, a crucial element in problem solving expertise, depends on the encoding of the problem information and representation of this information using pertinent domain knowledge (Sutherland, 2002). Solving ill-structured problems requires that domain knowledge be organized around experiences (contextualized) and that the solvers employ metacognition (self-monitoring and evaluation) throughout the process and construct justifications for their solutions.

Little research has been carried out to specifically study complex systems problem solving in order to identify differences between experts (complex systems scientists such as environmental scientists) and novices (e.g., science graduate students and/or science teachers). Jacobson (2001) studied a group of experts and a group of novices in an attempt to determine the type of mental models constructed by individuals when solving complex systems problems such as the formation of traffic jams and the design of an efficiently-operating large city. His work provides an impetus for more research in this area to contribute to a deeper understanding of the processes involved in solving complex environmental problems.

The current study examines expert environmental scientists and informed novices solving complex environmental problems in collaborative teams with distributed expertise. It explores the finding and solving of systems problems involving interactions of physical processes such as hydrology and geology rather than interactions of individual elements. The research questions addressed are:

1. How do members of a collaborative team of informed novices with various levels of distributed expertise problematize and solve a complex

environmental science issue using web-based information and IT analysis tools?

2. What are the similarities and differences in the way a collaborative team of scientists with distributed expertise and collaborative teams of informed novices with various levels of distributed expertise problematize and solve complex environmental science issues?

Context of the Study

The movement toward enduring reform in science and mathematics education spurred by the AAAS (Rutherford & Ahlgren, 1990) and the *National Science Education Standards* (National Research Council, 1996) inspired numerous efforts to improve science literacy. The mandate of the National Science Foundation (NSF) to promote the progress of science and engineering led to the creation of diverse programs for the enhancement of science education.

The Information Technology in Science (ITS) Center for Teaching and Learning at Texas A&M University is an NSF-funded interdisciplinary graduate program that "seeks to replenish the nation's supply of science and mathematics education specialists through team-led, learner-centered opportunities involving scientists, mathematicians, education researchers and education practitioners" (Information Technology in Science Center for Teaching and Learning, 2004). Cohort II, over a period of two years, involved participants in two three-week summer programs and additional activities during the academic years. During the summer programs, participants spent mornings in one of seven scientific teams and afternoons with education research faculty. For the education portion, the first summer participants created the framework for a math or science inquiry project to implement in their own teaching situations and piloted it during the following academic year. They improved the inquiry project and developed an action research project to carry out during implementation as a part of Summer II, and finally implemented the revised project, carried out the action research, and reported on the results during the second academic year. (For a more detailed description of the activities for the two summers, see Appendix B.)

Research for this project was carried out within the Sustainable Coastal Margins (SCM) scientific team of the ITS program. The goal of this team was "to explore the use of information technology to enhance understanding of interdisciplinary environmental problems of the Texas Gulf Coast" (B.E. Herbert, personal communication, May, 2003). Science faculty included Dr. Curtis, a biogeochemist and team leader, Dr. Hatcher, an environmental engineer, Dr. Morgan, a hydrologist and civil engineer, and Dr. Matthews, an environmental planner. (Details about faculty members are shown in Table 6.) Throughout the program, the scientists involved consciously strived to authentically portray the complex nature of environmental science as it is practiced by scientists in a social context.

Table 6. Faculty information

| Faculty Member | Department | Research Interests |
|---|---|---|
| Dr. Curtis | Geology & Geophysics | Environmental geochemistry: pollutants in soils, groundwaters and surface waters; organic biogeochemistry; geoecology |
| Dr. Hatcher | Agricultural Engineering | Wetlands, nonpoint source pollution control, water quality, hydrologic modeling |
| Dr. Morgan | Civil Engineering | Hydrometeorology, land atmosphere interactions, atmospheric boundary layer, remote sensing and hydrology |
| Dr. Matthews | Landscape Architecture & Urban Planning | Collaborative ecosystem planning, coastal management & sustainability, environmental dispute resolution, spatial analysis, natural hazards mitigation |

*Three-week SCM Schedule – Summer I*

To begin Summer I, faculty members of the Sustainable Coastal Margins team presented participants with a complex environmental science issue ("What is the water quality of the Texas Gulf Coast?") and asked them to problematize it. Faculty then modeled how they would problematize the issue and, over a period of three weeks in half-day sessions, scaffolded the skills needed to solve similar problems using web-based information and information/analysis tools. Each faculty member had three half-days for their presentations. Dr. Curtis began his portion by having participants create their own web pages and then introduced important core concepts and terminology in environmental science, the systems approach to environmental problem solving, spatial versus temporal scales, and population impacts. The following day, he discussed the hierarchy model of landscapes and formation of the Texas coastal plains and panhandle.

The class visited a biogeochemistry lab and Catarina (one of the science graduate student participants) and her professor discussed their research projects. Participants were then introduced to Arc-View® GIS (geographic information system) and began learning to map using the technology.

During his teaching days, Dr. Morgan taught students about soil and water systems and how they are modeled. Distributed expertise groups worked on estimating evaporation using data sets and modeling watersheds using GIS technology. Dr. Hatcher’s time was spent on nonpoint source pollution, best management practices and the engineering design process. Participants worked in distributed groups using the Internet to research related topics and shared their findings with the class. They also used Excel® to estimate mass loading for a year and used PowerPoint® to develop an animation modeling contaminant transport. They used best management practices and engineering design concepts to develop a conceptual design for controlling nonpoint source pollution from a fictional watershed undergoing urbanization.

Dr. Matthews’ portion dealt with land and resource use patterns and socioeconomic and demographic patterns in coastal Texas along with environmental dispute resolution and conflict management in planning. Participant teams used GIS to make maps showing the spatial patterns of land use and population characteristics around Corpus Christi Bay and estimated the impact on water quality and evaluated the relationship between land use and population growth in the area. They proposed ways to alter land use patterns and population patterns to both protect water quality and ensure sustainable development. They also mapped potential stakeholder conflict for different management objectives for Matagorda Bay and did a role play activity dealing with conflict management.

The final days of the first session were spent with participants presenting their inquiry implementation projects (developed during the afternoon education portion of the session) to the class. Faculty and peers critiqued the plans, making suggestions for possible improvement.

*Three-week SCM Schedule – Summer II*

During the second summer session, SCM-ITS participants began by reporting the results of piloting their inquiry projects in their classrooms. Again, faculty and participants critiqued the projects and made suggestions for overcoming any problems experienced during implementation. Summer II was less structured than Summer I, and on subsequent days there were a variety of activities. Presentations on GIS applications and assessment in science teaching were given to provide guidance for those who needed assistance on those areas. Dr. Hatcher presented a tutorial/scaffolding project where students developed a digital self-guided learning module supporting scaffolding for their inquiry projects. The four scientists, as a group, discussed the nature of science and scientific inquiry from each of their perspectives and participants looked at their inquiry projects to determine how they could incorporate nature of science and experimental design into them. Guest speakers (two science education professors) came into the class to discuss motivation and participants then worked on using motivation theory to improve their implementation frameworks. Dr. Matthews taught the class about spatial analysis using social science data sets and class members used CrimeStat® and Arc-

View® programs to perform spatial autocorrelation exercises. Dr. Morgan taught a class on remote sensing and the class brainstormed ideas for how to use this type of imagery in an inquiry project. Dr. Curtis took part of the group for a day on the Texas Gulf Coast to see how researchers there work, and on that day the remainder of the class worked on spatial analysis with Dr. Morgan. As a culminating activity for the entire group, teams of scientists and participants selected environmental issues and developed solutions for them.

## Methodology

This research project is a case study based on a mix of quantitative and qualitative data (Yin, 2003). The case study method was chosen in order to deliberately explore the contextual conditions of the SCM-ITS experience for both the scientists and the participants, and it relies on multiple sources of data. It attempts to explain and explore the complex interactions that occurred.

### *Data collection*

In order to understand the complex situation occurring in the SCM-ITS team, data collection began with questionnaires to determine the participants' backgrounds and experiences and continued throughout the entire professional development experience. Multiple sources of data were collected, including the following:

*Participant questionnaires.* Participants were asked about their educational and scientific backgrounds, research experiences, and familiarity with various information technologies. These questionnaires were completed before they came to campus.

*Faculty interviews (Recorded and transcribed)*. SCM-ITS faculty members were questioned about their educational backgrounds, research experiences, IT use and beliefs about problem-solving methods used in their research. These were semi-structured interviews with open-ended questions and were conducted in the faculty members' offices.

*Participant interviews (Recorded and transcribed).* Participants were asked for additional information about their backgrounds and research experiences, IT use, and how they would have approached a problem at the beginning of the course. These were also semi-structured interviews with open-ended questions and were conducted in various meeting places.

*Participant journals*. Participants were given time on a daily basis during Summer I to reflect and journal about their experiences. Questions were provided each day as a starting point for reflections, and participants were asked to write a paragraph or two along the line of the questions and encouraged to add any other comments they felt were important or interesting. The questions repeated, with the same set of questions each Monday, another set each Tuesday, and so on throughout the week. (Table 7)

Table 7. Participant journal reflection questions

| | |
|---|---|
| **Monday** | Is your group changing any of its approaches to solving the overall problem as you get deeper into it? Is everyone contributing to the effort to solve the problem? Are you personally changing any of your ideas about how scientists work to solve problems? Do you feel that you are achieving a greater expertise in any parts of the scientific team work? Are you able to build on what you learned earlier in this session as time passes? |
| **Tuesday** | Did you learn new science content and/or IT skills today? If so, describe. Do you think you will be able to use the knowledge or skills in your classroom in the future? Do the new knowledge and/or skills help you to understand how you might solve the overall question of "What is the environmental quality of the Texas Gulf Coast?" What kind of model or models do you envision that might answer or partially answer the question? |
| **Wednesday** | How did you feel about what went on in class today? Do you feel that the instruction was at an appropriate level for you? If not, were you able to get help from someone or to teach someone else what you already knew? Describe. What expertise do you contribute to the group? |
| **Thursday** | Is your group functioning well? Do you feel comfortable there, that all group members value the contributions of others? As a group, are you successful at solving the problems posed by the scientists? Are you working together outside the science team time? |
| **Friday** | Are the members of your group flexible, willing to compromise or to play different roles (leader, technology operator, etc.) within the group during different activities? As a group, are you able to achieve more than you would if you were working by yourself? What changes are you noticing in the way your group works together to accomplish tasks? |

*Participant observer field notes.* I closely observed the teams as they worked to solve problems and took notes, occasionally asking questions about what was happening. From time to time, I would sit in with a group in order to follow closely what the group was doing, and occasionally participated in activities as a member of a group.

*Classroom artifacts.* Electronic copies were kept of all products from activities during the classes. Artifacts included team problem-solving journals, written reports detailing problem solutions, and PowerPoint® presentations of projects.

*Project evaluations.* Final projects were evaluated by three outside experts (scientists from various fields who regularly do environmental research) for congruence with an environmental problem-solving model. The experts gave numerical scores and often commented on various aspects of the project.

*Final team project surveys.* Faculty and participants were asked about their project problem-solving experiences, collaboration experiences, and IT use. This questionnaire was administered electronically through the ITS web site after the completion of Summer II, and consisted of both Likert-scale questions and open-ended questions.

*Participants*

The participants who completed the SCM-ITS Cohort II experience were from varying backgrounds. (Information about the participants is shown in Table 8.) Participants on the SCM-ITS team included science graduate students, science educators, and a mathematics educator. The seven science graduate students (four women and three men) had backgrounds in such varied fields as chemistry, geosciences, biological and agricultural engineering, urban planning, marine science and oceanography, biology, and rangeland ecology. Each of them had some interest in and experience with environmental issues. At the beginning of the project, their estimations of their own IT skills in the types of software used for modeling and data analysis in the class (Excel®, PowerPoint®, and ARC-View® GIS) ranged from novice to expert. Two considered themselves expert in all three applications. ARC-View® GIS was unfamiliar to the other five. All had done scientific research in their fields, and several had also worked as teaching assistants for their departments.

Table 8. Participant information

| Participant | Educational Background | Experience | Current Department |
|---|---|---|---|
| Deanne | BS (Biology, Elementary Education) MEd* (Science education) | Elementary & middle science teacher, Science specialist | Education |
| Catarina | BS (Chemistry) MS (Geology) | Research assistant, Teaching assistant | Geology/ Geophysics |
| Shane | BS (Renewable natural resource management) MS* (Urban planning) | Research assistant | Landscape Architecture & Urban Planning |
| Craig | BS (Biological Systems Engineering) MS* (Biological & Agricultural Engineering) | Research assistant | Biological & Agricultural Engineering |
| Kristi | BS (Biology, Education) MS* (Geography) | Middle school science teacher, Teaching assistant | Geography |
| Jodie | BS (Marine science) MS* (Geoscience) | Research assistant, Teaching assistant | Geology/ Geophysics |
| Emily | BS (Marine science) MS (Oceanography) PhD* (Geoscience) | Research assistant, Teaching assistant | Geology/ Geophysics |
| Kyle | BS (Education - life/earth, physical sciences | Middle school science teacher | N/A |
| Ken | BS (Biology) MS* (Biology) | Research assistant, Teaching assistant | Biology |
| Larry** | BS (Mathematics) MS (Mathematics) PhD* (Mathematics Education) | High school math teacher, Teaching assistant | Mathematics Education |
| Kayce** | BS, MS* (Rangeland Ecology & Management) | Teaching assistant, Research assistant | Rangeland Ecology & Management |

Notes. All names are pseudonyms
* Degree in progress during ITS experience
** Only participated first summer

Of the three science educators, the two women had backgrounds in the biological sciences while the male had teaching fields in life/earth and physical sciences. All three had been middle school science teachers, with one working at the time of the project for a Texas Regional Education Service Center as a science teacher educator and consultant. They each had some interest in and experience with teaching environmental issues. None had ever done scientific research, and all rated themselves as moderately experienced with using PowerPoint®, only slightly to moderately familiar with Excel®, and only one of the three had even heard of ARC-View® GIS.

The mathematician had little background in any sciences, with only introductory biology and chemistry classes at the college level. He was experienced at teaching mathematics at the high school and college levels and had some experience using Excel®. He was slightly familiar with PowerPoint® and had never heard of ARC-View® GIS.

## Data Analysis and Discussion

### *Summer I Journal Entries*

Participants were charged with keeping a journal beginning on Tuesday of the first summer session. They were asked to reflect on one set of prompts each day, with the prompts repeating from week to week. Comments relevant to this research dealt with participants' views on collaboration. Although two participants (Shane and Craig, both science graduate students) consistently felt that they would rather work alone, they all felt their groups worked well together most of the time. Catarina felt uncomfortable with her first group, but by the second week the makeup of the groups had changed and she reported that her new group was functioning well. Emily observed that although working in a group was sometimes frustrating because she would rather solve a problem on her own, at other times group input was beneficial.

Several participants noted that the distributed expertise among the group members was helpful, with each individual having some expertise to contribute to the group. Craig commented that the heterogeneity of his group enabled him to help others who were less well-versed in ArcView® and some of the mathematical skills necessary for the more complex calculations. Others reported that their groups sometimes would split up assigned work and then get back together to finish up. On the whole, journal entries portrayed the collaborative experience as positive.

*Summer I Participant Interviews*

On the last day of the three weeks of Summer I, the scientists and this researcher conducted semi-structured interviews of each participant and recorded their responses. Questions relevant to this research included the following:

- The project team is built upon a model of distributed expertise (hypothesis: professional development environments have greater impact in distributed expertise environments.) Has working with others of varied background improved your learning? Do you see any advantages to working in your team as compared to completing assignments by yourself?
- What have you learned about problem solving techniques? Are some of the techniques you are using now new to you or were you experienced with them?

In response to the first question, all said they felt that working with others of varied backgrounds was beneficial. Several commented that they were forced to think of things in different ways and consider other points of view. Catarina, who didn't like working in distributed groups at first, commented, "I really enjoyed talking to them, listening to their points of view, and I think it was very rich to get that side from each of them, [they] really completed my understanding and my thoughts." All also felt that there were definite advantages to working in groups. Jodie noted that it saved time, "[The person with the expertise was] able to put the team in the direction we needed to go rather than spending all our time looking for the information we needed. . . . somebody knew where to go and so we could just go from there." Larry, the mathematician, said, "I knew nothing about science and so I had to learn a lot from them. Just listening to their conversations and them explaining a lot of things to me really helped my knowledge. I couldn't have done it without them."

When asked about problem solving techniques, Emily and Catarina, two of the science graduate students, felt that they had not learned anything new since they were experienced in scientific research. After thinking about it for a moment, however, Catarina decided that she had learned that not everyone attacks a problem in the same way. Kayce also felt that she had learned different approaches to problem solving and was able to talk about some things she hadn't really thought about previously, saying,

> I really hadn't thought about . . . that science can be debated, and yeah, I knew that, like when I went to professional meetings it was obvious. I'm sitting down with my committee members and my thesis and everyone is debating what the things mean and how it should be worded. And so the approach to the technique, I may have known them but now I am aware of them.

Jodie, who had also worked as a researcher, remarked that she had learned:

> That it's definitely interdisciplinary to solve a problem. One person – one area – can't solve it because something else is just going to come up. Like looking at Dr. Curtis and Dr. Matthews, one being social [science] and one just geology. You have to look at both of them because one of them is not going to be 100% right, so the interdisciplinary teams have helped in problem solving.

Shane, the graduate student from social sciences, felt that problem solving techniques "in the context of inquiry and scientific knowledge" were new to him. Several felt that they were more aware of having to actively teach scientific problem solving to students. Larry, the math educator, brought out that problem-solving skills were incorporated in the way they learned the materials in the SCM class, and that that was very helpful to him. For most of the class members, the SCM experience was beneficial in helping them to understand scientific inquiry.

*Scientist Interviews*

During the spring of 2004 (between the two summer sessions) each of the scientists who comprised the SCM-ITS faculty was interviewed about the first year's experiences. The interviews were semi-structured, and three basic questions on problem solving were asked of all interviewees plus other questions as they came up during the interviews. The basic questions were:

- Refresh me on your initial thoughts on the first day of the session when you scientists talked about how to problematize the issue of the environmental health of the Texas Gulf Coast.

- Do you have any new perspectives on the problem after having worked with your colleagues in last summer's ITS environment?
- What is the relationship between what you chose to spend your class time on and how you problematize the issue?

*Dr. Curtis – Biogeochemist***.** Dr. Curtis described his approach to problem solving as starting from a reductionist standpoint and moving up to a systems standpoint. [Reductionism is the theory that complex systems can be understood in terms of their components. (Holland, 1998)] He starts with trying to identify the specific variables that might be important and then the individual processes that might be important. He then places the "processes in a spatial and temporal context in the geological system" and considers how the system as a whole might behave, with all those processes/subsystems interacting. He described the process as qualitative, and said, "You can do it in your head, and you have an idea what might happen, a mental model." He commented, "There are not many things in life I don't approach the way I described. Even when it's not environmental problems I use that same thing, a reductionist systems model. I've never found it to fail." Dr. Curtis also mentioned that ITS was helping to support a jump within his research group from basic reductionist research where components of a system are dealt with in isolation to systems dynamics questions where all components of problems are linked.

As Dr. Curtis reflected on the scientists' modeling of problem-solving on the first day of class, he remembered being surprised by the range of approaches used by Dr. Morgan, Dr. Hatcher, and himself, but not being surprised by Dr. Matthews' social science approach. He recognized that he barely acknowledged the social side and went directly to considering the processes and variables that he is most knowledgeable about. He felt that the approach espoused by Dr. Morgan (hydrologist) was very theoretical "in a way that cried academic" and that Dr. Morgan wasn't really interested in solving a real or applied problem. He asserted that he (Dr. Curtis) was far more willing to place his knowledge out there to see if he could come up with a solution than Dr. Morgan was. He recalled Dr. Hatcher (environmental engineer) as advocating a very practical approach.

In summing up the four scientists' various approaches to solving an environmental problem, Dr. Curtis said:

> I don't think the differences between us were [that we are] essentially experts who are all in the same field nit-picking about differences or magnifying differences. There were some clear and quite important differences in how each of us was approaching the problem [that] would likely actually constrain the answers that we got because of the assumptions that we held inherent or the methodology we were going to use. We were going to come up with four different answers.

Dr. Curtis noted that because there was an element of trust between the four scientists, they were willing to put what they knew and did not know out in front of the group. That implied a respectful relationship between them; they did not feel threatened. In groups where the other people are unknown quantities and a scientist is trying to protect his/her reputation, it is much more difficult to go against what the first person to speak says or what the group consensus seems to be. He felt that the class benefited from the scientists' willingness to speak out and to show that they respected each other's opinions even when they disagreed.

As he considered whether his perspective changed from working with the other scientists, Dr. Curtis commented that he has a great deal of experience with engineering views and styles, so it was not too likely there would be anything new in three weeks. He observed that he did become aware that the solution to environmental problems is far more controlled by social issues as Dr. Matthews asserted than by science knowledge or engineering skill. He said, "In fact, I always tack that stuff on at the end and it was interesting to consider what it would be like to actually place social concerns and laws first and then tack the science in there somehow."

Dr. Curtis spent his class time teaching the building blocks (such as Arc-View GIS) the students would need for solving the problem rather than following the way he would problematize the situation. He was concerned that their background in geochemistry, hydrology, geomorphology, and ecology was insufficient for understanding the complex models. He had the students explore the spatiotemporal complexity of coastal systems using visualizations, then match what they observed to their mental models and test the quality of their models. If he had not had to concentrate on skill building, he would have let them go off in the direction they thought was most fruitful in order to try to solve the problem of the environmental health of the Texas Gulf Coast. He would have given participants the big problem and the data the four scientists had collected before the class started, inviting them to go and find more. He commented that almost every person has to have an adaptive approach to problem solving, where "you try to solve a problem, figure out what you don't know, go and learn it, then go back and try to solve the problem." Then when the students ran into trouble and were getting frustrated, he would have given them an analogous system as a guide and explained the approach to that problem.

*Dr. Morgan – Hydrologist, Civil Engineer*. Dr. Morgan described his approach to solving problems as empirically data-driven. If confronted with the problem of the environmental health of the Texas Gulf Coast, he would first want to "take some measurements of standard water quality parameters" so he would have some data. Until he had collected data, he would feel uncomfortable saying what the problems are or how big they are and would feel unable to back up any statements, given the broadness of the question. As a function of his academic background and training, he would look for water quantity and quality if asked to problematize that issue.

Dr. Morgan also observed how different Dr. Matthews' approach to the problem was from the other three scientists. He said that he thinks about that approach, but that actually doing it is "not his cup of tea," probably because of his personal uncomfortable feelings about talking to strangers. Although that "qualitative, social science" approach is very different from his own training in engineering, he said he values it and had even written a proposal with Dr. Matthews since working with him during the summer. In regard to how he spent his class time relative to how he would problematize the issue, Dr. Morgan felt in retrospect that he gave "traditional civil [engineering] lectures, almost too traditional," but that was how he would frame the problem for his background.

*Dr. Hatcher – Environmental Engineer*. Dr. Hatcher characterized her approach to problematizing the complex issue of the environmental health of the Gulf Coast as a "strong engineering perspective." She described the steps used in engineering design, beginning with defining the system that is being worked with. In reflecting on the modeling of problem solving by the scientists, she remembered feeling very frustrated because the other three were not interested in delineating the specifics of exactly what needed to be measured and how far they wanted to go in including things. Dr. Hatcher said a second step would then be to "ferret out what the major issues are" and to determine the major constraints and priorities. How much money is available for the task? How do you want to spend that money? Her perspective on the problem-solving modeling was that they were trying to depict how they would design a study.

When the interviewer commented that she looked at it differently from the biogeochemist, for example, who probably doesn't think as much about the money, Dr. Hatcher replied that any researcher is going to have to think about money. She thought, however, that he might already have a specific process in mind to look at and that he is more process oriented where she was looking at the big picture, "What's going on in a bigger system scale. He may be interested in a couple of particular components, so he may not worry so much about trying to define a box on the system because he's looking at a couple of different chunks and he already knows where his boxes are." She noted that the ties between her, Dr. Curtis, and Dr. Morgan were more visible, while Dr. Matthews brought in such a different viewpoint, involving the political and policy aspects of things. As an engineer, she felt that the social viewpoint is something engineers are just starting to think about when they are drawing system boundaries and that Dr. Matthews brings a “cool and different” perspective to the process.

Dr. Hatcher acknowledged that although differing viewpoints can be really frustrating sometimes, they “lend so much richness to what you do.” In her area of environmental work, they are beginning to see a lot of interest in working with clientele and stakeholders involved in the process. She described an interesting and successful project she worked on in the San Antonio area which involved working with people from communications, political science, and psychology (a researcher in the field of group decision making). The group went in to educate the stakeholders as part of the process of getting them to make management decisions about the watersheds they were in. Dr. Hatcher went on to say that the linking of the physical and chemical attributes of the water resource to what it means for the communities that rely on it is a very important process. Her interest began with the San Antonio project and has been fostered by working with the ITS group, particularly with Dr. Curtis’ emphasis on the biological aspects and how the water relates to the nonhuman communities such as algae, birds, fish, or aquatic insects that rely on it.

*Dr. Matthews – Environmental Planner*. Dr. Matthews referred to his problematizing technique as an ecosystem planning approach where he looks at the defined boundaries of an ecological system (not what is defined by humans) and the interaction between growth and development and critical natural resources. He described the approach as interdisciplinary, looking at both socioeconomic data and ecological data. His perspective is that he doesn't do science for science's sake, but uses it to understand problems in order to make positive changes. Dr. Matthews said:

> If you have an ecological problem on a coast that's a result of an increased impervious surface, the idea is not to just study the increase of the impervious surface or the impact on the water quality, it's to do that to understand how to better manage the water quality or to better manage the human impact on the water quality. So whether you're a lab scientist or a systems ecologist, you can't divorce yourself from the policy, politics, and management objectives. . . . to really get at these problems, you need to think about how to solve the problems. Natural scientists historically say, 'Oh, we just give the evidence and we give the scientific outcome, and the planners and the politicians, they make the decisions.' That's inadequate because they use our hardcore data to make rational decisions. Open your eyes, look around, read the newspapers. No scientific finding when it's applied is going to be divorced from human values and human politics and even perceptions. And all the good science in the world is not going to lead to good decisions unless the scientists are involved in the decision-making process.

Dr. Matthews believed that his role in teaching the class was to make sure that the students understood that the science they learned meant nothing without understanding "perceptions, conflict resolution, management strategies, and the human condition of politics." His message was, "We don't manage the resource; we manage humans impacting the resource." He emphasized that, for example, the clean air policies, wetland policies, and clean water policies that come out of the government are not based on science; they are based on politics and conflict and other agendas that need to be incorporated into understanding and solving a problem.

Dr. Matthews felt that due to the interdisciplinary nature of his work, he probably had more impact on the other scientists than they on him. He is very used to going to other departments such as engineering to get information he needs, but other disciplines are less likely to come to his department. He perceived the greatest benefit to him from working with the other scientists as learning about their approaches to sharing knowledge with others, as well as forming and solidifying relationships with the other scientists, which he felt would increase future interdisciplinary collaborations. He summed his feelings up:

> The height [of interdisciplinarity] is when you are working in teams, because I have to work with a scientist, natural scientist, or an artist, on a common problem, and that's where you learn, where you boost your collective capacity to do something even better. . . . I just like to look at what other people are doing and try to make sense of it in my own world. That is interdisciplinary thinking. That's what it's all about.

*Academic Year Participant Interviews*

During the academic year between the two summer sessions, three participants (chosen because of their availability) were interviewed about their perceptions of problem solving. They were asked to recall how they approached the issue of the environmental health of the Texas Gulf Coast and whether their approach had changed as a result of the class activities.

Kristi, a teacher with a biology background who worked with the two other educators the first day, recalled that a primary part of her group's discussion was how a healthy ecosystem would be defined in the first place. They felt that in order to assess the health of an ecosystem, they needed to conceptualize what the ideal would be so they would be able to compare current conditions to the ideal. At the time of the interview, she still felt that that was the ideal way to begin the process. She mentioned that ecosystems cannot be isolated from the impacts of human beings, so you have to look at what constitutes a healthy ecosystem with human beings as a part of that ecosystem, and what the goal is for that ecosystem.

Craig, whose background as a science graduate student was in biological and agricultural engineering, felt that questions generated in a teaming or multidisciplinary environment would be different than those he would generate alone. Concerning problematizing the environmental health of the Texas Gulf Coast, he commented that it would depend on how "you wanted to define the spectrum of the environmental health," and that you would have to "draw the line somewhere" or be overwhelmed by the attempt to determine what kinds of questions to ask.

Catarina, a geochemistry graduate student, found the initial question too broad and a little scary. She was more used to being asked to look at a specific contaminant in water and thought that you would have to start with defining what constitutes water quality. Catarina observed that before the class, she had never cared about political issues relating to water quality although she knew that it was an area of concern to some people. As a result, the role playing activities in Dr. Matthews' portion of the class made her aware of the importance of the social aspects of water quality. She began to realize that to get her scientific findings taken seriously, she would need to present them in a way that would be understandable to the stakeholders and policy decision makers. The class gave her a different perspective on the importance of interdisciplinary considerations in how she would be required to do her work in the future.

*Final Projects*

The culminating project for Summer II was a distributed-expertise group digital problem-solving assignment developed by Dr. Hatcher with input from the other faculty. The four faculty members comprised one group; three participant groups each had one educator and two science graduate students with different areas of expertise. The objective of the assignment was to identify an environmental problem and develop a solution for it. Classroom time given to complete the project was of necessity limited to two mornings (8:30 – 12:00) plus 30 minutes on the third morning to organize presentations. Project constraints limited the geographical scope of the problem to Brazos County, Texas and the research question to sustainable development, required the use of information technology and well-referenced resources, and required the production of a journal delineating how the group identified and solved their question. Suggested items to be included in the journal were:

- How did you develop your question? What alternatives did you consider? How did you select your project question?
- How did you go about answering your question? What data did you consider? What data did you end up using? If you discarded data, why?

- Who contributed particular ideas and skills to the project? How did individual areas of expertise influence how team members worked on the project?

For evaluation of the final digital projects, I developed a scoring rubric to reflect the conceptual framework of Sarewitz's (2000) physics model of problem solving (Figure 2). The model incorporates both the scientific and political processes which are ideally components of policy development in the search for sustainable solutions to environmental problems as adapted from Sarewitz.

Of the nine objectives evaluated by the rubric, the first four could be considered methodology objectives, the next three look at the problem from a systems approach, and the final two objectives deal with predictions and implications of the solution. In rubric construction, qualitative descriptors of ideal representations for each objective were designated by the researcher as being worth four points (for a possible total of 36 points), the lack of all parts of the representation was described as being worth zero points, and partial satisfaction of the objective was assigned a value of two points. For example, for the objective *creation of problem/hypothesis*, a project receiving a four-point score would have the problem and goals clearly stated and the problem would be appropriate for the assignment. A problem which was vague or inappropriate and had no goals set would receive zero points. For the objective *identification of possible aesthetic, physiochemical, and biological impacts*, a score of four points would indicate evidence of identification of major impacts and strong evidence of critical thinking about the impacts. If there was no evidence for consideration of possible impacts, zero points

| Objectives | 0 Points | 1Pt | 2 Points | 3 Pts | 4 Points | Points |
|---|---|---|---|---|---|---|
| **Creation of Problem/Hypothesis** | Problem vague/ inappropriate No goals set | | Problem somewhat clear/appropriate Goals present but unclear | | Problem clearly stated Goals clearly stated Problem appropriate | |
| **Creation of Project Plan/ Conceptual Model** | No consideration of possible alternative solutions | | Sketchy consideration of possible alternative solutions | | Considered possible alternative solutions | |
| **Acquisition of Data Using Appropriate Information Technology** | Ineffective use of IT in problem solution Used/considered only 1 data source | | Limited use of available IT Limited consideration/use of data sources | | Effective use of appropriate IT Used data from multiple sources | |
| **Analysis of Data** | No/incorrect analysis of relevant data | | Some correct data analysis but insufficient to answer question | | Data thoroughly & correctly analyzed using appropriate methods | |
| **Consideration of Relevant Laws/Regulations** | No consideration of relevant laws/regulations | | Some consideration of relevant laws/regulations | | Evident allowances for relevant laws/regulations | |
| **Identification of Possible Aesthetic, Physiochemical, & Biological Impacts** | No consideration of possible impacts | | Some impacts identified Some evidence of critical thinking | | Identification of major impacts Strong evidence of critical thinking about possible impacts | |
| **Identification of Possible Socioeconomic Impacts/Costs** | No consideration of possible impacts | | Some impacts identified Some evidence of critical thinking | | Identification of major impacts Strong evidence of critical thinking about possible impacts | |
| **Production of Model/Predictions** | No model/prediction produced | | Model/prediction present but explanation insufficient/unclear | | Clear portrayal of model/prediction Thorough understanding of problem demonstrated | |
| **Consideration of Sustainability of Proposed Solution** | No consideration given to sustainability of proposed solution (no justification for solution) | | Sustainability considered but insufficient evidence for sustainability provided (little justification) | | Arguments well-supported Evidence provided for sustainability (well-justified) | |
| | | | | | **Total Score** | |

Figure 2. Assessment rubric for final products

would be awarded. I solicited input from several experts in environmental science before finalizing the rubric.

In evaluation of a team, components of all three parts submitted for the assignment (paper, PowerPoint® presentation, and journal) were considered. Evaluators who considered the quality of the final projects are experts with experience in the field of environmental problem solving (one environmental engineer and two physical geographers) from outside the SCM-ITS project team. To assure objectivity, they had no knowledge of the identity of team members or which team was composed of the expert scientists. Evaluators were instructed not to give credit for any objective unless they saw evidence for it in some component of the deliverables. They were also made aware of the project constraints, the availability of IT (computers with Internet access, ARC-View® GIS, and Excel® as well as other Microsoft Office® products for each person) and the time limitations on production of the final project components. There was, however, no actual training on use of the rubric. Interrater reliability among the three raters was .61. The scores of rater number 3, one of the geographers, were often very different from the scores awarded by the other two raters. Interrater reliability calculated only for raters 1 and 2 was .88. Scores for each team by objective and by scorer are reported in Table 9 along with mean scores and standard error of the mean. Mean scores and standard error of the mean are shown graphically for each team by objective in Figures 3-6.

Table 9. Group scores, means, and error by objective and evaluator

| | Group 1 | | | | | | Group 2 | | | | | | Group 3 | | | | | | Group 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Evaluator # | | | | | | Evaluator # | | | | | | Evaluator # | | | | | | Evaluator # | | | | | |
| **Obj.*** | **1** | **2** | **3** | **M** | **SD** | **E** | **1** | **2** | **3** | **M** | **SD** | **E** | **1** | **2** | **3** | **M** | **SD** | **E** | **1** | **2** | **3** | **M** | **SD** | **E** |
| 1 | 2 | 2 | 3 | 2.33 | 0.58 | 0.33 | 3 | 1 | 0 | 1.33 | 1.53 | 0.88 | 4 | 4 | 2 | 3.33 | 1.16 | 0.67 | 3 | 0 | 2 | 1.67 | 1.53 | 0.88 |
| 2 | 2 | 2 | 2 | 2 | 0 | 0 | 2 | 2 | 3 | 2.33 | 0.58 | 0.33 | 3 | 3 | 0 | 2 | 1.73 | 1 | 2 | 1 | 2 | 1.67 | 0.58 | 0.33 |
| 3 | 2 | 3 | 2 | 2.33 | 0.58 | 0.33 | 3 | 3 | 1 | 2.33 | 1.16 | 0.67 | 4 | 4 | 3 | 3.67 | 0.58 | 0.33 | 3 | 1 | 2 | 2 | 1 | 0.58 |
| 4 | 1 | 2 | 2 | 1.67 | 0.58 | 0.33 | 2 | 0 | 2 | 1.33 | 1.16 | 0.67 | 4 | 4 | 2 | 3.33 | 1.16 | 0.67 | 2 | 1 | 1 | 1.33 | 0.58 | 0.33 |
| 5 | 0 | 2 | 1 | 1 | 1 | 0.58 | 3 | 2 | 3 | 2.67 | 0.58 | 0.33 | 3 | 3 | 1 | 2.33 | 1.16 | 0.67 | 1 | 2 | 2 | 1.67 | 0.58 | 0.33 |
| 6 | 0 | 2 | 1 | 1 | 1 | 0.58 | 2 | 3 | 2 | 2.33 | 0.58 | 0.33 | 4 | 4 | 3 | 3.67 | 0.58 | 0.33 | 3 | 2 | 2 | 2.33 | 0.58 | 0.33 |
| 7 | 0 | 2 | 1 | 1 | 1 | 0.58 | 0 | 3 | 2 | 1.67 | 1.53 | 0.88 | 2 | 3 | 0 | 1.67 | 1.53 | 0.88 | 3 | 2 | 1 | 2 | 1 | 0.58 |
| 8 | 1 | 2 | 2 | 1.67 | 0.58 | 0.33 | 0 | 1 | 0 | 0.33 | 0.58 | 0.33 | 4 | 4 | 0 | 2.67 | 2.31 | 1.33 | 1 | 0 | 0 | 0.33 | 0.58 | 0.33 |
| 9 | 0 | 2 | 1 | 1 | 1 | 0.58 | 1 | 2 | 2 | 1.67 | 0.58 | 0.33 | 3 | 4 | 0 | 2.33 | 2.08 | 1.20 | 2 | 1 | 0 | 1 | 1 | 0.58 |
| **Total** | 8 | 19 | 15 | 14 | 5.57 | 3.22 | 16 | 17 | 15 | 16 | 1 | 0.58 | 31 | 33 | 11 | 25 | 12.17 | 7.02 | 20 | 10 | 12 | 14 | 5.30 | 3.06 |

* Objectives:
1. Creation of Problem/Hypothesis
2. Creation of Project Plan/ Conceptual Model
3. Acquisition of Data Using Appropriate Information Technology
4. Analysis of Data
5. Consideration of Relevant Laws/Regulations
6. Identification of Possible Aesthetic, Physiochemical, & Biological Impacts
7. Identification of Possible Socioeconomic Impacts/Costs
8. Production of Model/Predictions
9. Consideration of Sustainability of Proposed Solution

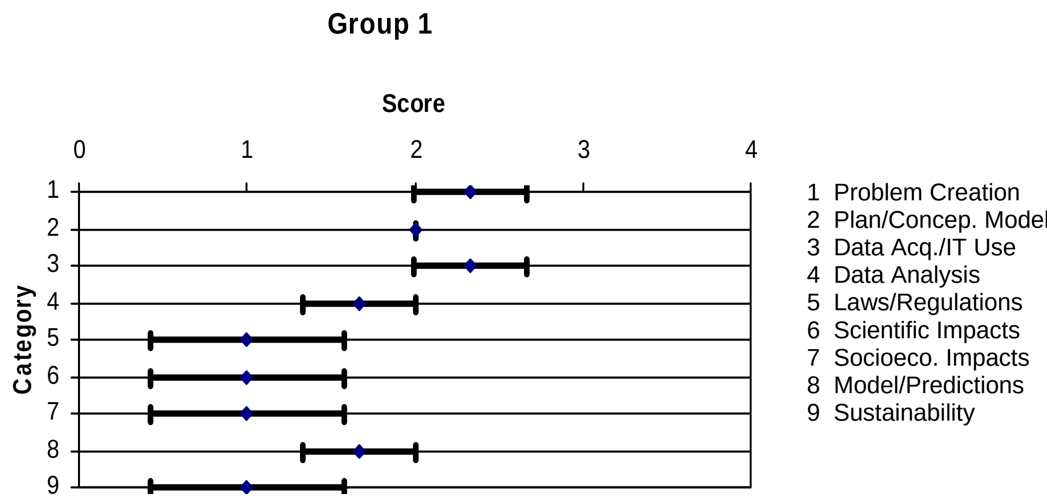


Figure 3. Mean and standard error of scores for Group 1

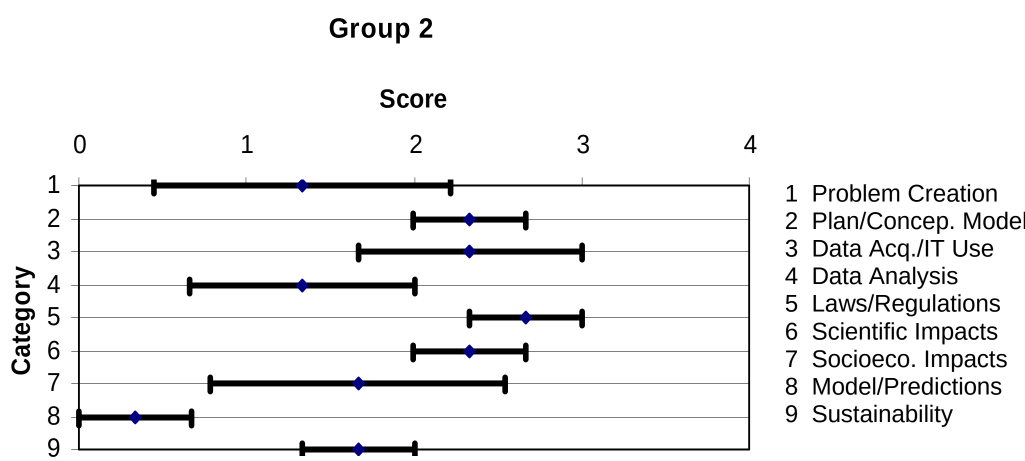


Figure 4. Mean and standard error of scores for Group 2

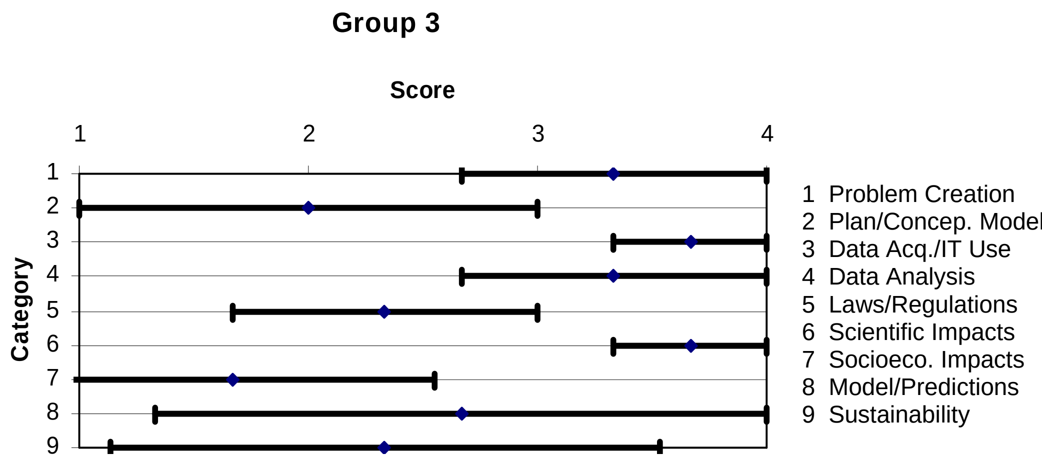


Figure 5. Mean and standard error of scores for Group 3

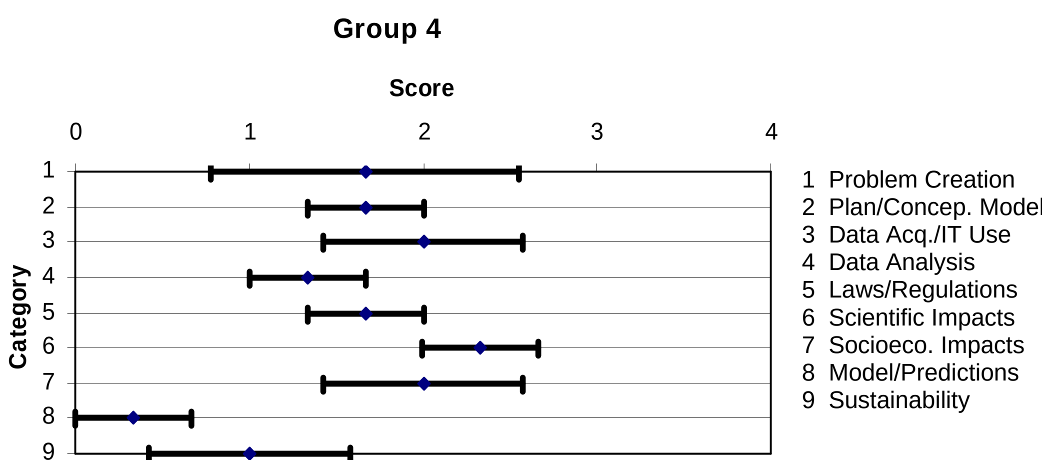


Figure 6. Mean and standard error of scores for Group 4

*Discussion of Projects*

*Group 1.* This group consisted of Deanne (teacher educator), Catarina, and Shane (science graduate students). The question they chose to answer was “As the population of Brazos County increases, does the volume of the Brazos River increase accordingly?” Deanne commented in the post-Summer II on-line questionnaire that she had pushed for that topic and the rest of the group went along with her, and Catarina concurred with that assessment. The mean total project score given by the three evaluators was 11.33 out of a possible 36, with a standard deviation of 3.51 and error of 2.03. The lowest total score was awarded by the engineer and the higher scores by the two geographers.

On the assessment rubric, the objective *creation of problem/hypothesis* received a mean score of 2.33. Two of the three evaluators commented that this was a poor choice of question/study area as the river basin is too large and flow is regulated by dams. The team consulted a few websites, looking at census, hydrologic, and GIS data, before deciding on their topic, but realized after there was no time left to change that it wasn’t the best choice. One of the evaluators commented, “Of all the groups, this group did the best job in posing and answering a testable hypothesis – the only problem is the question they posed made very little sense. . . . If the group had picked a smaller tributary that would have been more heavily urbanized (say Wolf Pen Creek) you may be able to see something, but I realize the data might not be available.” The group hypothesized that as population increases, runoff increases due to an increase in impervious surfaces. As a result of the growth and development of Brazos County, the volume of water carried by the Brazos River would increase.

All three evaluators agreed that the project showed evidence of only sketchy consideration of possible alternative solutions in the *project plan/conceptual model* phase, giving a score of 2. Although the group itself recognized that IT was very important in working on this problem, the mean score on *acquisition of data using appropriate information technology* was 2.33, with a standard deviation of 0.58. The mean score on *data analysis* was 1.67 with a standard deviation of 0.58; one of the evaluators criticized the fact that precipitation data was gathered and included in the analysis when precipitation was not relevant to the problem.

For the systems approach objectives, *consideration of relevant laws/regulation*s, *identification of possible aesthetic, physiochemical, and biological impacts* and *identification of possible socioeconomic impacts/costs,* the mean scores on the rubric were all 0.33 with standard deviations of 0.58, indicating that the evaluators agreed that little, if any attention was paid to relevant laws or regulations or to consideration of possible impacts. One evaluator indicated that these factors are perhaps not really relevant to the problem under consideration.

*Production of model/predictions* and s*ustainability of proposed solution* earned mean scores of 1 and standard deviations of 1. Low scores on these sections suggest that very little in the way of models or predictions was produced, and that team members provided no justification or plan for sustainability of the proposed solution. Several factors probably contributed to low scores on the last five objectives. The lack of time to do a thorough job of problematizing and proposing a solution for a complex environmental issue was probably a major factor. When the group realized that their question was not really appropriate, they had no time to begin the process again. The group as a whole spent only about an hour (according to the researcher's observation notes) on developing their problem although Catarina commented later that they spent a "long time because we wanted to be sure that we had the resources available to answer the question." Quite possibly more up-front time spent researching the problem would have been worthwhile. Deanne said "We should have spent a little more time trying to think things through at the beginning and perhaps we would have come up with the plan that we made at the end when we realized we had gone down the wrong path."

This group definitely relied on the expertise Shane had in the fields of GIS, data manipulation and graphing, and statistics. Deanne worked on getting data and on writing the final report. Catarina did some of the research, kept the journal for the team and did most of the work creating their PowerPoint® presentation. When presented with definitions of cooperation as the division of labor among participants and collaboration as the mutual engagement of participants to solve a problem together, both Deanne and Catarina replied that their team was more cooperative than collaborative. Deanne felt that this was partly due to the time factor, and "it's also difficult for three people to collaborate around a single computer, so dividing up the tasks seemed like the most efficient way to proceed." Catarina, who said she felt stressed by the activity, commented that the group did "not engage in the others' task. This particularly made me uncomfortable," and that the team needed better communication. Deanne observed that although Catarina did not feel comfortable with the task or her skills in helping, she did make valuable contributions to the effort.

*Group 2*. The team composed of Emily and Ken (science graduate students) and Kyle (teacher) asked “How can College Station expand while maintaining sustainable development?” Their PowerPoint® presentation was titled “Managing Growth of a Mid-Sized City While Minimizing Nutrient Runoff Entering the Local Watershed.” A second research question asked in the presentation was “How can College Station re-zone the eastern area to single family housing without increasing flow of nutrient concentrations to Carters Creek?” When asked why they chose this problem, Ken said “[W]e all just started searching for possible topics. My perception is that the topic evolved with input from all team members.” Kyle observed “We chose this problem because we believed that College Station would continue to grow. With this outward growth of the city they would be faced with numerous problems with runoff. I was interested in this problem once we finally agreed on a problem to solve.” The three evaluators were in close agreement about the total score awarded to this project, with a mean project score of 16.00 out of 36 possible points, a standard deviation of 1.00 and error of 0.58.

The objective *creation of problem/hypothesis* received a mean score of 1.33 with a standard deviation of 1.53 and error of 0.88 on the assessment rubric. One of the evaluators granted no points, observing that the team “does tie together the social and physical worlds and addresses an important environmental issue. However, the group poses no real testable question.” For the *project plan/conceptual model* and *acquisition of data using appropriate information technology*, the mean scores were 2.33 with standard deviations of 0.58. One of the geographers evaluating the project commented that there was some consideration given to possible alternative solutions when planning the project, but they were inappropriate to the research question. For *data analysis*, the mean score was 1.33 with a standard deviation of 1.15. These methodology standard deviations indicate slightly more disagreement among the evaluators than for Group 1, but no evaluator gave a score of above 3 on any of the objectives in this section.

Scores on the systems approach objectives were somewhat higher for this group than for the methodology objectives, and also higher than Group 1 scores on the systems objectives. For *consideration of relevant laws/regulations,* the mean score was 2.67 with a standard deviation of 0.58. The mean was 2.33 with a standard deviation of 0.58 for *identify possible aesthetic, physiochemical, and biological impacts,* and for *identify possible socioeconomic impacts/costs*, there was a mean of 1.67 and standard deviation of 1.53. These indicate somewhat less consideration given to the area of scientific and socioeconomic impacts.

For the objectives dealing with predictions and implications, scores were slightly lower. Two of the three evaluators saw no indication of *production of model/predictions* and one gave one point, resulting in a mean score of 0.33 and standard deviation of 0.58. The group received slightly more credit for *sustainability of proposed solution*, resulting in a mean score of 1.67 and standard deviation of 0.58.

One of the evaluators observed, “A major problem with this project is that [the] cause of high bacteria levels is already assumed to be erosion/runoff from (urban) areas . . .but [this is] not documented. Cause and effect variables are fuzzy.” Another remarked “[T]hey assert that College Station cannot continue to grow ‘horizontally,’ but I would argue that College Station will continue to grow predominately through low density spreading as there are few real barriers to prevent this type of growth." In response to the second research question "How can College Station re-zone the eastern area to single family housing without increasing flow of nutrient concentrations to Carters Creek?" the group hypothesized that "Increased single family housing will increase nutrient run-off." A criticism was that the research question and hypothesis were incongruent; the hypothesis was not directly linked to the research question. Also, no data was gathered to analyze or test this hypothesis. It was interesting to note that on the Post-Summer II Questionnaire, when asked if they had a hypothesis in mind when they went into the project, their perceptions were very different. Kyle said "Yes. [We] hypothesized that if College Station grew they would have a serious runoff problem on their hands." Emily stated "We . . . did start out wanting to investigate the water quality of the Brazos watershed and we assumed that land use would drastically affect this." Ken said, "I did not. The hypothesis evolved as we discovered available resources."

This group felt that they collaborated successfully on this project and were engaged in solving the problem together although there was some division of labor according to the skills of each participant. My observations confirm their perceptions and, in fact, I thought they did more actual collaboration than any of the other three groups. Even though each worked on multiple tasks, Emily mainly worked on getting data and doing the report, Ken did much of the mapping, Kyle used the Internet to find supporting materials, and all three worked on the PowerPoint® presentation. This team spent extra time in the SCM-ITS lab working on the project. On the first full day, Emily was still working after everyone else was gone, and on the second day, Ken and Kyle came back after lunch to work for a couple of hours. Kyle attributed their successes to using each others' knowledge and expertise to solve the problem, and Emily felt that success was due to working together to define the problem and constrain the hypothesis, then breaking up to find information and finally reconvening to finish the required components of the assignment. Ken said, "The experience was one of those rare and enjoyable occasions where every team member related to every other in a positive manner."

When asked about difficulties, Kyle commented that lack of knowledge of the area (Brazos County) might have been a contributing factor. Emily opined that, as individuals, some of the group lacked knowledge of some IT tools such as GIS, were inexperienced at forming hypothesis-driven research, and had a diverse knowledge base. She observed that because of various interests it was difficult to focus on a common problem they all agreed was significant. According to Ken, the only perceived difficulty was the time constraint for completing the project. Kyle noted that focusing on a more specific topic would have allowed them to use their time more wisely. Emily pointed out that more training in GIS would have benefited the team, and she would have liked to work on this project in a group that did not have distributed expertise.

*Group 3*. The question asked by Group 3, which consisted of Jodie and Craig (science graduate students), and Kristi (teacher), was "Can we identify soils in the flood plain that have a higher potential for sediment transport/erodibility? On the post-summer II questionnaire, Jodie and Kristi commented that they had a difficult time deciding on a topic and spent a long time on the task. However, the researcher's notes indicate that they made a decision at about the same time as the other groups. The two stated that the group chose to focus on erosion because they felt they could most easily access that data in the short amount of time allowed for the project, and they agreed that it was a group decision. (It was later revealed that Craig had worked extensively with this problem in his graduate studies.) They hypothesized that areas of high erodibility would be found along the shores of the rivers and that use of remote sensing and Soils Survey Geographic (SSURGO) data for Brazos County would enable them to identify those areas. They concluded that there are areas of high erodibility along the Brazos and Navasota Rivers and that identification of these areas can result in ways of minimizing erosion in both agricultural and non-agricultural use areas. A definite dichotomy existed in the scores awarded this project by the evaluators. Two of the three gave this project outstanding ratings overall (33 and 31 out of a possible 36), far higher than any other group scores, while the third evaluator (one of the geographers) gave it only 11 total points, the lowest awarded any project by this evaluator. This evaluator commented "Better use of IT than groups 1 and 2 and at least one individual in the group has good GIS skills and the group presents a clear methodology of what they did. But again, there is no real testable hypothesis other than a qualitative comparison of the two different approaches to identifying erodible land." This group had the highest mean score of any team – 25 – but due to the anomalous rating had a standard deviation of 12.17 and error of 7.02.

Group 3 received mean scores of greater than 3 out of a possible 4 points for the methodology objectives. For *creation of problem/hypothesis* and *data analysis*, the mean was 3.33, with a standard deviation of 1.15 and error of 0.67. One scorer commented in regard to this group's written report, "much better development of problem than Groups 1 and 2." Evaluators agreed that the team did very well on *acquisition of data using appropriate information technology* with a mean score of 3.67, standard deviation of 0.58 and error of 0.33. The score was lower for *project plan/conceptual model*, with a mean score of 2, standard deviation of 1.73, and error of 1.00. One evaluator commented that the group could have considered alternative soil erodibility parameters in creating their project plan.

Attention to a systems approach also was also evident in this team's project. A mean score of 2.33 with a standard deviation of 1.15 and error of 0.67 was received for *consideration of relevant laws/regulations*. A high degree of consensus among the evaluators was evident in recognition of attention paid by the team to *identify possible aesthetic, physiochemical, and biological impacts*, where the mean score was 3.67 with a standard deviation of 0.58 and error of 0.33. *Identify possible socioeconomic impacts/costs* received less attention from the group; its mean score was 1.67, standard deviation 1.53 and error 0.89.

Extreme disagreement among the evaluators existed about the objectives dealing with predictions and implications. Two awarded 4 points for *production of model/predictions*, the highest possible score, while the third gave it no points, resulting in a mean score of 2.67, with a standard deviation of 2.31 and error of 1.33. A mean score of 2.33 with a standard deviation of 2.08 and error of 1.20 resulted for *sustainability of proposed solution* when two judges assigned scores of 3 and 4, respectively, and the third again gave no points.

Team 3 relied heavily on IT, gathering information using the Internet and mapping data with GIS technologies. Kristi referred to GIS as a “powerful, comprehensive tool for analysis and decision making” when used in conjunction with other IT such as search engines paired with powerful databases and GPS and remote sensing. The two team members who replied to the post-summer II survey (Kristi and Jodie) felt that their team both collaborated and cooperated in order to achieve successful completion of their project. Kristi explained, “We collaborated in regards to the inquiry, factors that we needed to address the inquiry, and conclusions from the data we gathered. We cooperated in regards to different areas of expertise.” She mentioned that Craig had a great deal of prior experience mapping with GIS and Jodie with doing work on erosion, the area the team chose for its problem. Jodie observed that the team members had complementary strengths in IT and in knowledge of the subject area.

*Group 4*. The fourth group was the expert group, composed of the four faculty members: Dr. Curtis (biogeochemistry), Dr. Hatcher (environmental engineering), Dr. Morgan (hydrological engineering) and Dr. Matthews (environmental policy). They had some problems deciding on a question, but finally they agreed to ask, “What is the potential environmental impact of reservoir development in Brazos County? The group’s journal and post-summer II survey comments indicate that one group member pushed for this topic because it could result in a publishable paper and the other two who were present at the time simply went along with the idea. Four inquiry questions were posed:

- Is groundwater quality poor enough to justify the costs associated with surface water development?
- What impact will these reservoirs have on water quantity in the county?
- What is the expected water quality in the reservoirs and will that water quality support the intended uses for the reservoirs?
- What are the environmental and social costs associated with reservoir development?

The evaluators' scores had a mean of 14 points out of a possible 36, with a standard deviation of 5.29 and error of 3.06. The engineer who evaluated the projects scored it much higher (20 points) than the two geographers (10 and 12 points).

One would expect higher scores from a group of experts on the methodology objectives. *Creation of problem/hypothesis* and *project plan/conceptual model* received mean scores of 1.67 with standard deviations of 1.53 and errors of 0.88. One geographer who evaluated the projects observed, "The group has a good idea, but it is too large and too unfocused to be useful for the time frame they had." The other commented, "Study group sought to answer too many questions. In the end, none was well developed, 2 questions entirely skipped over, and 1 was not answered/analyzed appropriately." An evaluator also remarked, "I see a good POTENTIAL project, especially if the group could have better articulated a testable hypothesis. One that sprang to mind was to actually determine which of the proposed reservoirs is the best based on a set of criteria chosen." *Acquisition of data using appropriate information technology* had a mean score of 2 with standard deviation of 1.00 and error of 0.58. An evaluator commented on this objective: “Maps produced but not elaborated upon nor linked directly to research questions.” Problems in this area are indicated also in *data analysis,* which scored a mean of 1.33 with standard deviation of 0.58 and error of 0.33.

Evaluators also felt that insufficient attention was paid to the systems approach objectives. *Consideration of relevant laws/regulations* had a mean score of 1.67 with standard deviation of 0.58 and error of 0.33. Although the last inquiry question asked about possible environmental and social cost of reservoir development, *identify possible aesthetic, physiochemical, and biological impacts* rated a mean of 2.33, standard deviation of 0.58 and error of 0.33, and *identify possible socioeconomic impacts/costs* scored even lower, with a mean of 2.00, standard deviation of 1, and error of 0.58. This indicates that the question was not sufficiently addressed in the report or presentation. The appraisals of the project also indicated agreement that little in the way of *model/predictions* was produced, since the mean score was 0.33 with a standard deviation of 0.58 and error of 0.33. An evaluator observed, “The group listed criteria [for the proposed reservoirs] and how things ranked, but drew no real strong conclusions. *Consideration of sustainability of proposed solution* also was only marginally addressed, having received a mean score of 1.00 with a standard deviation of 1 and error of 0.58.

The members of Group 4 had well-defined areas of expertise, and perhaps as a result of that separated the work into individual assignments and proceeded with little collaboration. Dr. Hatcher commented in the post-summer II questionnaire, “I think we worked too independently. We would have benefited greatly from more communication. Work done by some team members occurred primarily outside the classroom, so I didn’t know for sure what they were doing until they brought it in for the final presentation." Dr. Matthews attributed the difficulties experienced by the team to "lack of communication, collaboration, and leadership." Dr. Hatcher felt that the result of their work was four mini-projects rather than one group project, and that all group members should have been available during class time. One evaluator remarked, "One comment in the journal struck me – the people in the team worked independently with little overlap and it shows as the project as presented is disjointed." Dr. Matthews missed the first day entirely, and Dr. Morgan did not arrive until 9:30 the first morning and 9:15 the second. The faculty group did not really get started until about 10:00 the first morning. Dr. Curtis was very disengaged from the process at first but later got into it. Dr. Morgan never wrote his part of the report, but did complete his slides for the presentation. The researcher's observation notes record the comment, "The group which most obviously showed some irritation with each other was the faculty group." In an interview conducted during the spring before the second summer session, Dr. Matthews, referring to the organization of the first summer's ITS session, commented, "The problem from last year is, I think, the problem with interdisciplinary research. I did my thing, Dr. Morgan did his thing, Dr. Curtis did his thing. And we only had one day when we really had a dialog." This is a rather accurate summary of what happened with this group during the second summer's problem-solving activity as well. Even so, the depth of expertise available within the group was readily apparent from their product.

*Results of Final Project*

Using mean scores to rank the projects results in the following: 1) Group 3 – Soil Erodibility, 2) Group 2 – Minimizing Nutrient Runoff, 3) Group 4 – Reservoir Development, and 4) Group 1 – Relationship of Population Growth to River Volume. The purpose of this project was to give the ITS participants practice in using the problem-solving skills they had learned and experience in presenting their findings. With the emphasis in the National Science Education Standards (1996) on inquiry learning and the nature of science, it is imperative that those who teach science have a clear understanding of how science is done. According to the Standards:

> Teachers of science . . . form much of their image of science through the science courses that they take in college. If that image is to reflect the nature of science as presented in these standards, prospective and practicing teachers must take science courses in which they learn science through inquiry, having the same opportunities as their students will have to develop understanding. College science faculty therefore must design courses that are heavily based in investigations, where current and future teachers have direct contact with phenomena, gather and interpret data using appropriate technology, and are involved in groups working on real, open-ended problems. (p. 61)

Whether at the secondary or post-secondary level, all the participants are or will be involved in the teaching of science, so this experience was valuable for each of them.

# Discussion

Although there are no general rules for solving ill-structured problems, problem solving in different contexts and domains utilizes different skills (Jonassen, 1997). The four scientists involved in this project seem to fit into one of two problem-solving perspectives. Two scientists are reductionist – they begin by looking at individual components of a problem and understanding the processes involved; then they move toward looking at the system dynamics. The second two take a systems approach from the beginning, first defining the boundaries of the system and then considering its individual components. The two pairs are also divided along another line – whether or not they consider socioeconomic factors as primary concerns in their problem solving. It is interesting that the two engineers fall on opposite sides; it seems that the division is between enterprises that have environmental/ecological considerations at the forefront and those that do not. Those that do must from the start of the problem-solving process be cognizant of interdisciplinary factors that might affect the outcome.

Whether gender is a factor in the differences between the two engineers is questionable. Faulkner's (2000) discussion of gender and dualism in engineering reflected on the technical/social distinction that is related to stereotypes of masculine, technology-focused instrumentalism and feminine, people-focused expressiveness. These two are sometimes considered to be mutually exclusive and engineers often see themselves as instrumentalists with few social skills. For example, in an interview the civil engineer asked if I knew the difference between an introverted engineer and an extroverted engineer. When I replied that I didn't, he told me, "An introverted engineer looks at his shoes when he talks to you; an extroverted engineer looks at your shoes when he talks to you." Faulkner concluded that the engineers in her study "tend to gender their *descriptions* of what they do more than they gender their actual *practice*" (p. 784). With a sample of only one female and three males, all of whom trained in different fields, it would be presumptuous to conclude that any differences in problem-solving approaches were due to gender.

Since science graduate students comprised the majority of the SCM team, the informed novices had a great deal of expertise in some areas and several had some previous experience in conducting scientific research. Nevertheless, there were some common threads running through the analysis of the results of the final project for Summer II. Consideration of the results reveals more similarities than differences. The three informed novice groups and the expert group all had problems with finding and defining an acceptable problem and then focusing on a testable question. One of the informed novice groups had the best problem development, but they chose a problem that one of the group members had worked on extensively in his graduate studies. The same group also had the best model and predictions development and in general paid more attention to the systems. Two of the novice groups had problems with collecting relevant data, and the expert group, although they collected a great deal of good data, did not link it well to their research questions.

Probably the most pervasive problem throughout all four groups was a lack of collaboration – defined as mutual engagement of participants to solve a problem together (Kneser & Ploetzner, 2001). What went on in all four groups was much more cooperative division of labor among the participants than truly collaborative, and this seemed to be even more of a factor for the expert group than the novice groups. The experts divided tasks according to expertise and then all four never really communicated as a group again, resulting in a failure to share ideas and findings and to build a cohesive product.

There is little doubt that this sort of behavior impedes the success of many so-called collaborative groups composed of experts. Each expert brings to the table his or her perspective and approach to problem solving, and unless true communication of ideas and points of view takes place on a regular basis, collaboration will not occur. The structure of a successful collaborative group requires commitment to the project, effective leadership, purposeful opportunities for communication of ideas and findings, openness among its members to the ideas of others, and a willingness to share.

As the focus in teaching and learning of science moves toward emulating authentic science as practiced in communities of scientists, it is becoming more important to develop an understanding among educators of the type of discussion and collaboration which occurs among scientists and stakeholders in solving complex environmental problems (Coll, France, & Taylor, 2005; R. Duschl & Hamilton, 1998). The traditional model or "physics view" of problem solving shown in Figure 7 (Sarewitz, 2000) portrays a sequential, orderly, very linear relationship purporting to illustrate the process of integrating science and environmental policy. This process suggests that a problem is identified, conceptual models are created, data is collected and analyzed, and predictive models are proposed before there is any consideration of the politics involved. Sarewitz asserts that although “this mental model of how science can contribute to environmental policy-making is consistent with the norms of a culture that places great faith in science and the rationality that science can deliver” (p. 83), in reality it is the powerful political and economic interests that predominate in decision-making. He contends that the principle roles for science are diagnosis and assessment and that they occur only after political consensus has been reached. That environmental laws and regulations have been implemented against the opposition of industry is the result of popular support based on preservation of natural assets such as clean air and water rather than on scientific evidence. Since a linear model of what is a distinctly non-linear process would be inappropriate, Sarewitz proposes a “geologic view” of the relationship among variables involved in environmental controversies (Figure 8) that takes into account the role of political consensus as the driving force behind the search for solutions to environmental problems.

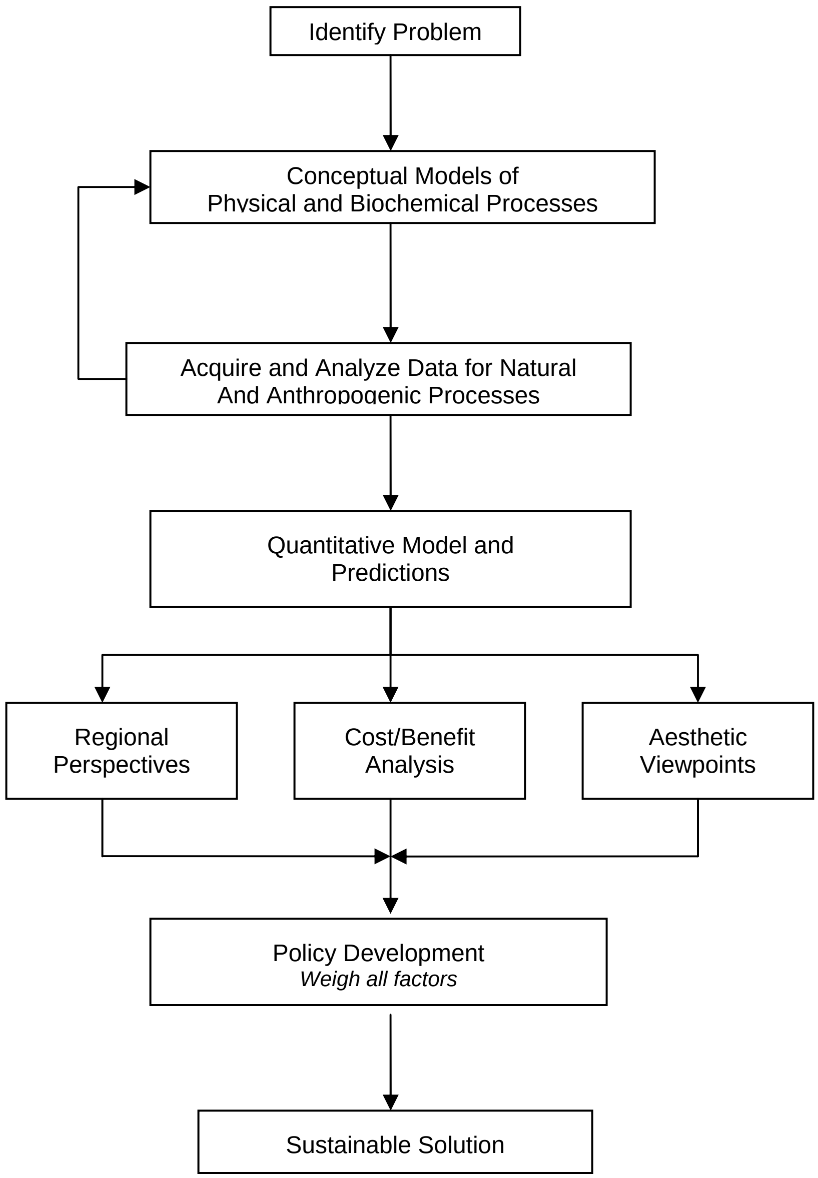


Figure 7. Traditional problem-solving model ("physics view"). (Sarewitz, 2000, p. 82) Frodeman, Robert; Earth Matters: The Earth Sciences, Philosophy and the Claims of Community 1/e © 2000 Reprinted by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

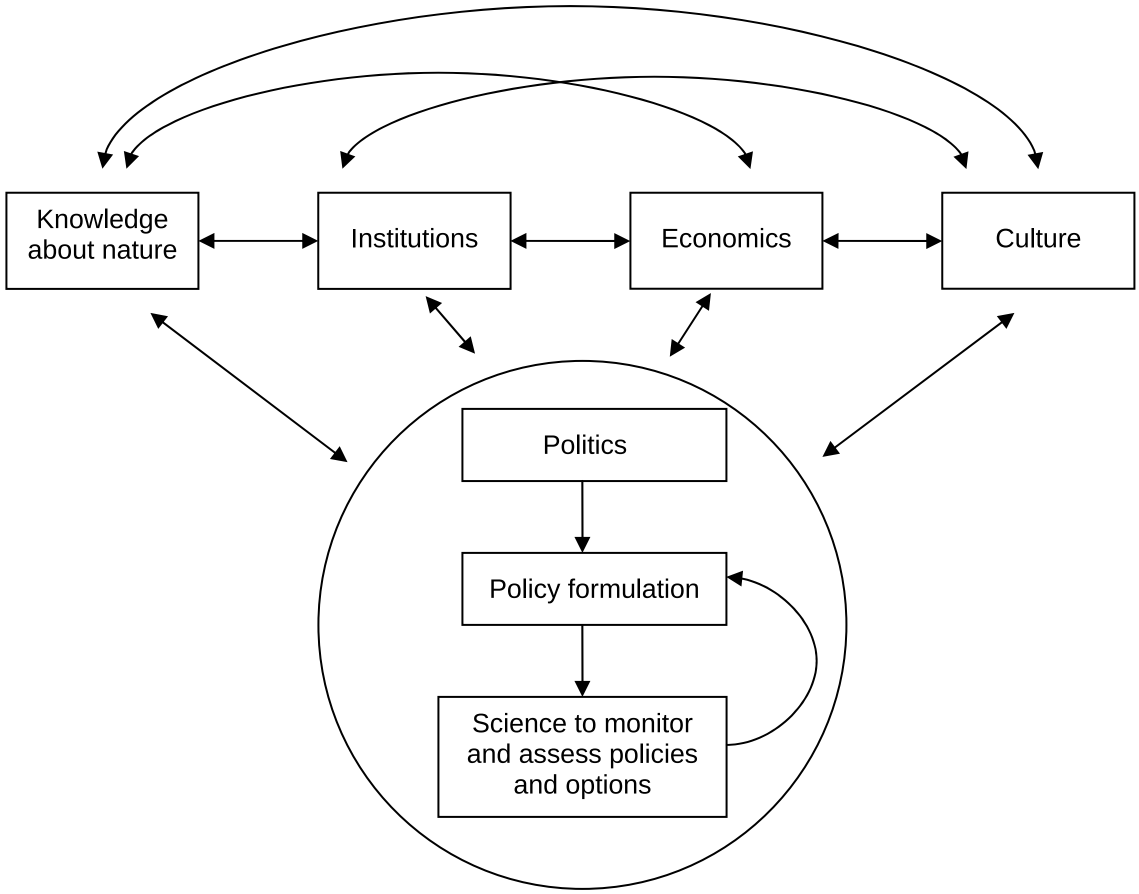


Figure 8. Model of a "geologic view" of environmental problem solving. (Sarewitz, 2000, p. 94) Frodeman, Robert; Earth Matters: The Earth Sciences, Philosophy and the Claims of Community 1/e © 2000 Reprinted by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

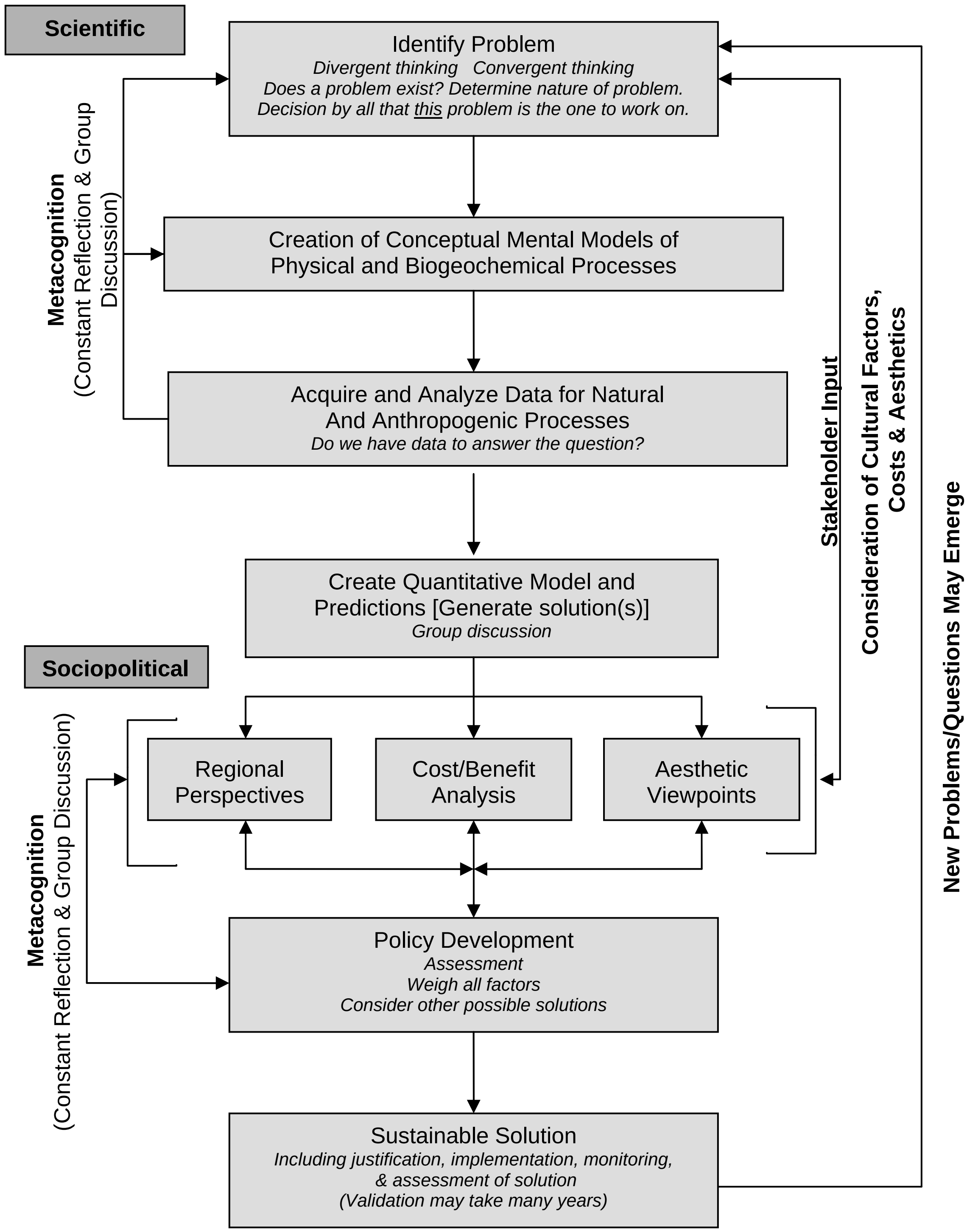


Figure 9. Distributed expert group problem solving for environmental sustainability. (Modified from Sarewitz, 2000)

A careful analysis of information gleaned from the current study suggests some modifications for the “physics view” of problem solving that seem to more closely portray what occurred in the SCM-ITS problem-solving situation in a format that would be more user-friendly for the science classroom and more representative of the reiterative nature of authentic science than Sarewitz’s “geologic view.” This modified model (Figure 9) shows the sociopolitical factors such as stakeholder input and consideration of cultural factors, etc., as contributors to identifying and defining problem parameters. It also emphasizes the role of metacognition (constant reflection, discussion, and assessment) in the process as models are created and revised and as data is collected and evaluated. Sizer (1992) said, “ The real world demands collaboration, the collective solving of problems” (p. 12), and formation of distributed expert groups that effectively collaborate on problem-solving tasks in the classroom requires an understanding on the part of teachers and students of the processes involved. The distributed expert group model portrays in detail the processes inherent in environmental problem solving.

## Research Limitations and Implications

Case studies are by their very nature complex processes, influenced by researcher bias, data collection capabilities, and the setting of the case (Yin, 2003). Problems with data collection were encountered, beginning with a failure to record the scientists’ and participants’ problem-solving discussions on the first morning of class. Several participants did not write in their journals on a regular basis, and only a few were available for interviews during the academic year between Summers I and II. SCM-ITS was originally conceived for a group of participants that would primarily consist of science educators with one or two science graduate students. Instead, there were only a few educators and the majority of participants were science graduate students, some with a great deal of experience and expertise in the topics covered and all with research experience. This greatly changed the expert-novice ratio of the class for many class activities and probably influenced the final projects to a great extent.

Time was a limiting factor in the quality of the final projects, but it affected all teams equally. The rubric used for assessment was based on a discussion of problem solving in the environmental sciences, but may not have been the best means to assess the projects. It was not given to the groups before they began the project, so they did not know the criteria by which the projects would be judged. Although the same instructions were given to all three evaluators, the rubric criteria remain open to interpretation. Having more evaluators from different backgrounds might well have resulted in a different ranking when mean scores were determined.

Despite its limitations, however, this study resulted in some insights into distributed expert and novice group collaborations that can be applied in various situations. For those in education, whether at public school or college level, it becomes obvious that a great deal of scaffolded support is necessary for effective collaborative problem solving. Additional research documenting in depth how participants think during the problem-solving process could help to make classroom implementation of problem-based learning activities more efficient and effective. Understanding how this kind of experience leads to conceptual change is essential for effective science instruction.

# CHAPTER IV

# IMPROVING UNDERSTANDINGS OF AUTHENTIC SCIENTIFIC INQUIRY: DOES WORKING ON A COLLABORATIVE SCIENTIFIC TEAM HELP?

## Introduction

Much of the excitement of science comes when a scientist is involved in creating his/her own research question, designing the research protocol, collecting data and constructing new knowledge. Translating this excitement to the classroom in the form of "authentic" science inquiry is, however, a difficult proposition. Scientific inquiry can be defined as the various ways in which scientists study the natural world and employ the evidence derived from their work to propose explanations (National Research Council, 1996). Roth (1995) describes authentic scientific inquiry as consisting of individual and collaborative construction of knowledge through the framing and solving of ill-structured problems. Perhaps the simplest definition of authentic inquiry is "the activities that scientists engage in while conducting their research" (Chinn & Hmelo-Silver, 2002)

The National Science Education Standards (National Research Council, 1996) state that scientific inquiry in a school setting "refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (p. 23).  The National Science Teachers Association (NSTA) (2004) advises that all K-16 teachers adopt scientific inquiry and is committed to helping educators make it the focus of the science classroom in order to help foster development of a deep understanding of science and scientific inquiry. NSTA also recommends that science teachers provide appropriate content knowledge in an inquiry-based program and use approaches that cause students to ask and answer questions about the natural world. Teachers, with administrative support, should create learning environments that encourage inquiry by providing students with adequate time, space, and resources. Preservice teachers should experience scientific inquiry as a part of their teacher preparation program, and inservice teachers should receive professional development on how to teach using inquiry. Teachers must also learn how to develop questioning strategies and write lesson plans that cultivate the skills and understandings of scientific inquiry.

The Information Technology in Science (ITS) Center for Teaching and Learning, an NSF-funded project, brings teachers, science graduate students, and scientists together for a professional development experience focused on the impact of information technology (IT) on the learning and teaching of science and mathematics (Information Technology in Science Center for Teaching and Learning, 2004). Cohort II ITS participants worked in small groups collaborating with teams of scientists during two three-week summer sessions in 2003 and 2004 on the use of IT tools in scientific inquiry as a means of transferring current scientific research into K-16 classrooms. They also spent time with education researchers learning IT-mediated pedagogical skills and educational research methods and receiving explicit instruction on the nature of scientific inquiry. Participants created IT-mediated inquiry projects for implementation in their own classrooms during the first academic year and refined inquiry projects with an action research component in the second academic year.

The current research project examines in detail one of the small groups of K-12 educators and science graduate students working with a specific team of scientists studying environmental issues affecting the coastal margin of Texas. It proposes that participation in a professional development setting, including explicit nature of science (NOS) instruction, and working with a collaborative scientific team improves K-16 educators' and science graduate students' understandings of the nature of authentic scientific inquiry and impacts their instructional products translating authentic scientific inquiry into their design of classroom experiences.

This study sought to answer two questions:

- How does working in a collaborative scientific team improve informed novices' understanding of the nature of authentic scientific inquiry?
- How does working in a collaborative scientific team impact their instructional products translating authentic scientific inquiry into classroom practice?

## Supporting Literature

Authenticity in science education is stressed because of the relationship between the knowledge and skills that learning activities produce and the situation in which they are learned. Lave and Wenger (1991) call this process "situated cognition" and describe it as taking place in the context and culture in which an activity would normally occur. It involves social interactions in a "community of practice" which move the learner along toward expertise as he/she becomes more engaged in the beliefs and behaviors of the discipline. The growing interest in inquiry teaching as evidenced by the National Science

Education Standards (National Research Council, 1996) and position statements by American Association for the Advancement of Science (1993) and the National Science Teachers Association (2004) holds vast potential for moving science education programs “toward more collaborative inquiry in the context of real world problems” (Comeaux & Huber, 2001). Understanding of the nature of scientific inquiry as practiced by scientists comes from learner experiences in interacting with others in order to construct understandings by making sense of scientific data to solve scientific problems.

Rather than isolate the activity in which knowledge is developed, it is necessary to embed learning within the context in which it is used. J. S. Brown, Collins, and Duguid (1989) compare conceptual knowledge to a tool which may be possessed but lie inert because of lack of knowledge of how to use it. When learners are given the opportunity for on-site observation and practice, they are more likely to become enculturated into the behavioral norms of a community. The logical, relevant, and purposeful activities of a domain are authentic and, therefore, will tend to produce more useful learning. Historically, apprenticeships gave opportunities for learning to occur within the context of a culture. Since school learning activities are often not the activities of practitioners of a domain and do not provide the contextual features that allow for authenticity, meaningful learning often does not occur. A. L. Brown et al. (1997) argue that authentic school activities, at least in the early years, are those which enable students to learn to learn, which induct them into the rituals of scientific discourse and activity. The goal should be to produce students who, although they may not have the basic knowledge needed to succeed in a new field, know how to go about acquiring that knowledge.

There are a number of difficulties inherent in helping students understand the nature of the scientific endeavor and in inducing changes in student epistemology (Carey & Smith, 1993). Sandoval and Reiser (2004) propose a framework for scaffolding epistemic aspects of inquiry that can help students understand inquiry processes in relation to the kinds of knowledge such processes can produce. This framework underlies the design of a technology-supported inquiry curriculum for evolution and natural selection that focuses students on constructing and evaluating scientific explanations for natural phenomena. The design has been refined through cycles of implementation, analysis, and revision that have documented the epistemic practices students engage in during inquiry, indicate ways in which designed tools support students' work, and suggest necessary additional social scaffolds. These findings suggest that epistemic tools can play a unique role in supporting students' inquiry and provide a fruitful means for studying students' scientific epistemologies.

## Theoretical Framework for Analyzing Scientific Inquiry

Moving beyond the suggestions in science standards, Chinn and Malhotra (2002) present an analysis of their research on the features of authentic scientific inquiry. They provide a theoretical framework for analysis of authentic scientific reasoning (Table 1) and then contrast the cognitive processes in authentic inquiry with those simple inquiry processes that normally occur in school science textbooks and classrooms. Secondly, they analyze epistemological dimensions of authentic science (Table 2) and describe the differences in epistemology implied by the differences in cognitive processes of authentic science and school science. The authors argue that inquiry tasks customarily used in schools elicit reasoning processes that are significantly different from the processes utilized in actual scientific inquiry, and that those reasoning tasks seem to be based on an epistemology that is distinct from the epistemology of authentic science. Models-of-data theory is used to explain the existence of differences in cognitive processes and epistemology between authentic scientific inquiry and the types of inquiry tasks commonly used in schools. Chinn & Malhotra assert that the cognitive models underlying authentic inquiry are basically different from those underlying simple experiments, and this helps account for the differences in cognitive processes and epistemology.

Chinn and Malhotra’s (2002) models (See Tables 10 and 11) for evaluation of authentic inquiry processes and epistemology were used as a benchmark to develop an instrument for analysis of ITS participants’ views of the nature of authentic scientific inquiry. Pre- and posttests asking for both objective answers and explanations of those answers were administered and analyzed to determine participants’ views. Second, participants’ inquiry projects for use with their own students were evaluated for the level of authentic science included in their projects.

Table 10. Cognitive processes in authentic inquiry

| Cognitive Process | Authentic Inquiry |
|---|---|
| ***Generating research questions*** | • **Scientists generate their own research questions. (14)** |
| ***Designing studies*** | |
| Selecting variables | • **Scientists select and even invent variables to investigate. There are *many* possible variables. (10)** |
| Planning procedures | • **Scientists invent complex procedures to address questions of interest. (12)**<br>• **Scientists often devise analog models to address the research question. (13)** |
| Controlling variables | • **Scientists often employ multiple controls. (11)**<br>• It can be difficult to determine what the controls should be or how to set them up. |
| Planning measures | • Scientists typically incorporate multiple measures of independent, intermediate, and dependent variables. |
| ***Making observations*** | • **Scientists employ elaborate techniques to guard against observer bias. (4)** |
| ***Explaining results*** | |
| Transforming observations | • **Observations are often repeatedly transformed into other data formats. (9)** |
| Finding flaws | • **Scientists constantly question whether their own results and others' results are correct or artifacts of experimental flaws. (5)** |
| Indirect reasoning | • Observations are related to research questions by complex chains of inference.<br>• Observed variables are not identical to the theoretical variables of interest. |
| Generalizations | • Scientists must judge whether to generalize to situations that are dissimilar in some respects from the experimental situation. |
| Types of reasoning | • Scientists employ multiple forms of argument. |
| ***Developing theories*** | |
| Level of theory | • **Scientists construct theories postulating mechanisms with unobservable entities. (2)** |
| Coordinating results | • **Scientists coordinate results from multiple studies. (3)**<br>• Results from different studies may be partially conflicting, which requires use of strategies to resolve inconsistencies.<br>• There are different types of studies, including studies at the level of mechanism and studies at the level of observable regularities. |
| ***Studying research reports*** | • **Scientists study other scientists' research reports for several purposes. (15)** |

Note. Table adapted from Chinn& Malhotra (2002). Characteristics in bold used in designing questions. Number indicates question number. (Reprinted with permission from John Wiley & Sons, Inc.)

Table 11. Epistemology of authentic inquiry

| Dimension of Epistemology | Authentic Inquiry |
|---|---|
| *Purpose of Research* | • **Scientists aim to build and revise theoretical models with unobservable mechanisms. (7)** |
| *Theory-data coordination* | • **Scientists coordinate theoretical models with multiple sets of complex, partially conflicting data. (6)** |
| *Theory-ladenness of methods* | • Methods are partially theory laden. |
| *Responses to anomalous data* | • **Scientists rationally and regularly discount anomalous data. (8)** |
| *Nature of reasoning* | • Scientists employ heuristic, nonalgorithmic reasoning. |
| *Social construction of knowledge* | • **Scientists employ multiple acceptable argument forms. (1)**<br>• Reasoning is uncertain.<br>• Scientists construct knowledge in collaborative groups.<br>• Scientists build on previous research by many scientists.<br>• Institutional norms are established through expert review processes and exemplary models of research |

Note. Table adapted from Chinn & Malhotra (2002). Characteristics in bold used in designing questions. Number indicates question number. (Reprinted with permission from John Wiley & Sons, Inc.)

## Context of the Study

This study took place during ITS Cohort II within the Sustainable Coastal Margins (SCM-ITS) team. During a two-year period (2003 and 2004), participants were involved in a three-week summer session each summer and additional activities during the academic year. During the summer sessions, participants spent the mornings in small groups led by teams of scientists and the afternoons working with education specialists to develop and revise inquiry projects for use in their classrooms.

### *SCM-ITS Faculty*

Four scientists from diverse fields who were all experienced in environmental research provided leadership:

- Dr. Curtis, a biogeochemist whose primary research interests are in environmental geochemistry, including organic biogeochemistry, geoecology, pollutants in soils, groundwaters, and surface waters,
- Dr. Hatcher, an agricultural engineer concerned with wetlands, nonpoint source pollution control, water quality and hydrologic modeling,
- Dr. Morgan, a civil engineer with expertise in hydrometeorology, remote sensing, land- atmosphere interactions, and hydrology, and
- Dr. Matthews, an environmental planner, whose fields include collaborative ecosystem planning, coastal management and sustainability, environmental dispute resolution, spatial analysis, and natural hazards mitigation.

*SCM-ITS Participants*

The total of ten participants included teachers and science and mathematics graduate students from the SCM-ITS scientific team (Table 12). Some had extensive backgrounds in working as research scientists; others had done little or no work as research scientists. Seven of the participants were science or mathematics graduate students with limited teaching experience and the other three were primarily science teachers/educators. Participants’ original applications to the ITS program and interviews provided biographical data.

Table 12. Participants' backgrounds; educational & research experiences

| | Name* | Degree | Experience | Current work |
|---|---|---|---|---|
| **Science Teachers** | Deanne | BS (Elem. Ed. – Bio.)<br>MEd student (Science Ed.) | Teaching science at elementary and middle school levels<br>Science specialist for region education service center, teacher training | MEd student (Science Ed.)<br>Science specialist for region education service center, teacher training |
| | Kristi | BS (Biology) | Teaching science at secondary level | MS student (Geography Education) |
| | Kyle | BS (Science Education) | Teaching science at secondary level<br>Summer research program in biology | Teaching science at secondary level |
| **Math Teacher** | Larry** | BS (Mathematics)<br>MS (Mathematics) | Teaching secondary and college level mathematics<br>Little science background | Ph.D. student (Mathematics education) |
| **Science Graduate Students** | Catarina | BS (Chemistry)<br>MS (Geology) | Teaching secondary science & teaching assistant for college chemistry, designed curriculum | Biogeochemistry research<br>Ph.D. student (biogeochemistry) |
| | Kayce** | BS (Rangeland Ecology/ Environmental Science) | Teaching assistant for ecosystem management course<br>Environmental research (range management) | Completing MS (Rangeland Ecology/ Environmental Science) |
| | Shane | BS (Renewable Natural Resources Management) | Teaching GIS and GPS classes and workshops<br>Urban planning research | MS student (Urban Planning) |
| | Amanda | BS (Marine Science) | Trainer for seismic acquisition, testing procedures; taught in informal education settings, substitute teacher<br>Weather & oceanography research | MS student (Geoscience) |
| | Kenneth | BS (Biological Systems Engineering)<br>MS (Biological & Agricultural Engineering) | Teaching assistant for agricultural engineering courses<br>Environmental engineering research | Ph.D. student (Biological & Agricultural Engineering) |
| | Emily | BS (Marine Chemistry)<br>MS (Oceanography) | Teaching assistant in chemistry and oceanography | Ph.D. student (Biogeochemistry)<br>Environmental biogeochemistry research |

* Pseudonym **Only participated during Summer I

*Setting*

Participants in SCM-ITS met with their scientific team each morning for three and one-half hours over a three-week period during each session. The first morning's session during Summer I opened with the participants being presented with the complex environmental science issue, "What is the water quality of the Texas Gulf Coast?" They discussed, in small groups, how they would go about solving the problem and reported their results to the larger group. The four scientists then modeled how they would problematize the typical, ill-constrained environmental issue. During the ensuing weeks, participants learned the skills needed to go about solving the issue in an authentic way, with the scientists emphasizing throughout that the techniques and skills being learned were those used in their own research. They learned to create maps and analyze complex data sets using Geographic Information Systems (GIS) technology, create watershed models, manage complex data sets using Excel®, model environmental processes using PowerPoint®, design best management practices for a development, and analyze land and resource use patterns and socioeconomic and demographic patterns. Each afternoon of Summer I, participants met with science education researchers and information technology (IT) specialists for instruction in the nature of science and scientific inquiry, current theories of cognition and pedagogy, and technology-mediated strategies for teaching and learning. The scientific inquiry module required participants to read the Chinn and Malhotra (2002) and Carey and Smith (1993) articles on the nature of scientific inquiry and knowledge and to evaluate web sites for authentic scientific inquiry using Bodzin and Cates' (2003) criteria.

During Summer I, participants used skills and knowledge garnered from the morning scientific teams and knowledge learned in the afternoon education sessions to design inquiry implementation projects to be piloted in their own classroom situations during the upcoming academic year. These implementation projects were to be units of study for their students employing inquiry methods to teach some important concept or concepts for their course. (Those science graduate students who did not have classrooms of their own arranged with a professor in their department to implement their project in the professor's class.) At various times during the academic year, all participants filled out questionnaires for the central ITS office reporting on their inquiry implementations.

Summer II was less structured than Summer I, and participants on the SCM-ITS team began by presenting a PowerPoint® outlining the implementations of their inquiry projects and having them critiqued by the faculty and other participants. Ensuing class times were spent on a variety of activities including modifying and improving the inquiry projects they had piloted during the previous school year. Participants also continued to learn to use GIS applications including spatial analysis. They also performed spatial autocorrelation exercises using Arc-View® and CrimeStat® programs. Dr. Hatcher guided students in developing digital self-guided learning modules to scaffold their inquiry projects. Dr. Morgan taught a lesson on remote sensing, and participants brainstormed ideas for how this type of data could be incorporated into an inquiry project. The four scientists held a group discussion on the nature of science and scientific inquiry from each of their perspectives, and participants discussed how they could incorporate nature of science into their inquiry projects. Presentations on assessment and student motivation were given by education specialists, and participants and team members then used assessment and motivation theories to improve their projects. As the capstone activity of the session, teams of scientists and participants to problematized environmental issues facing the local area and developed solutions for them. During the afternoon education portion of the second summer, participants developed action research projects to assess the effectiveness of their inquiry projects during the coming academic year. (For a more detailed description of the activities for the two summers, see Appendix B.)

## Methodology

I used a mixed-method approach to analyze the views of authentic scientific inquiry of the ten participants involved in the SCM-ITS team and to determine if changes in their conceptions of authentic science carried over into their educational projects. The complexity of the SCM environment could be explored most effectively by using a combination of data collection techniques and both quantitative and qualitative methods of analysis (Creswell, 2003; Frechtling & Sharp, 1997; Tashakkori & Teddlie, 1998).

### *Evaluation Instruments*

The Nature of Authentic Science test (Appendix A) was designed to evaluate participants’ understandings of authentic scientific inquiry processes and epistemologies as described by Chinn and Malhotra (2002). It was composed of fifteen multiple-choice questions, each of which asked for an explanation of the answer chosen. Questions focused on those processes and epistemologies most critical in the project. Construct and content validity were established in consultation with the science educators, scientists and an educational psychologist on the project. The correct answer to each question contains an exact quote or paraphrase of a characteristic of authentic inquiry as described by Chinn and Malhotra (See Tables 1 & 2 and Appendix A). The exception is question 11, where, after discussing the questions with the environmental scientist who led the SCM group, “but in some disciplines, controls are rarely, if ever, used” was added. This change recognized fact that for many complex problems, especially in the environmental and earth sciences, controls are not possible.

I developed a simple rubric modified using some of Chinn & Malhotra’s (2002) terminology from Bonstetter’s (1998) model of inquiry as an evolutionary process for determination of the level of inquiry included in participants’ implementation projects. In this rubric, levels of inquiry were classified according to how much of the activity is controlled by the teacher and how much is controlled by the student. The lowest level, where all parts of the activity are teacher-controlled, is called *traditional hands-on or simple illustrations*. *Structured inquiry* lets the student do some of the data collecting and analysis and draw the conclusions. In *guided inquiry*, the student is also responsible for designing the experimental procedures. The next higher level, *student directed inquiry*, has the student do all of the above as well as obtain the materials and help with the choice of a question to be explored. In the highest level of inquiry, *authentic classroom inquiry*, the student may help choose the topic and is responsible for all the facets of inquiry: research question, materials, procedures and design, results and analysis, and the conclusion.

*Data Collection*

Participants completed detailed applications to the ITS program, giving their educational background and teaching experience. All ITS participants were given identical pre- and posttests (Nature of Authentic Science) administered electronically on the first and last days of the first three-week summer session. I decided to concentrate on the first summer session because experiences in both the science and education components concerned the nature of inquiry, while the second summer experiences were concentrated on improvement of inquiry projects and design of an action research project. Although the tests were given to approximately 60 individuals, only 33 pre- and post- tests could be matched due to some participants' confusion with their ITS identification numbers. The "right" answer on each test question was the one that matched the statement from the Chinn and Malhotra descriptions. For the purposes of this study, the scores of the SCM group were compared to the scores of the whole ITS group to determine test reliability and to compare the significance of pre-post changes in scores. Of the ten SCM team members, the papers from two were unusable because of participants' failures to identify themselves on one or both of the tests so that pre- and posttests from the individuals could not be matched.

Members of the SCM team were interviewed informally throughout the sessions and open-ended interviews were conducted at the end of the first summer session (Yin, 2003). Questions attempted to ascertain participants' understandings of inquiry and problem-solving techniques and how those understandings changed during the SCM-ITS experience. Participants completed PowerPoint® slide presentations about plans for their inquiry projects at the end of Summer I and, at the beginning of Summer II, reported on their implementations. The ITS office provided demographic data about participants from their applications to the program.

## Results

### *Conceptions of Authentic Science*

Although the ITS experience occurred over a relatively short period of time, there were significant differences in participants' conceptions of authentic science before and after the Summer I session. The Nature of Authentic Science test was administered to the entire ITS group at the beginning and again at the end of Summer I. For a total of 41 participants (8 from SCM-ITS, 33 from other ITS scientific teams), it was possible to compare pre- and posttest scores. The change in raw scores obtained from before and after the ITS intervention were subjected to 2x2 factorial with repeated measures on the second factor (time). (See Table 13). The Maunchly's Test of Sphericity was met because there were only two levels of time. The summary table (Table 14) reveals there is not a significant difference in groups at the pre- or posttest. Both groups show a significant difference (.000) in pre- and posttest scores. Figure 10 illustrates that the difference between the two groups is not significant at Time 1 or Time 2, but the mean at Time 1 is significantly different from the mean at Time 2 for both groups. Test reliability for the Nature of Authentic Science Test was determined to be .71 using a Model II estimation of reliability. A Model II approach was used due to the significant difference in the pre- and posttest scores as a result of the intervention.

Table 13. Descriptive statistics

| Group | | Mean | Std. Deviation | N |
|---|---|---|---|---|
| Pr Total | 1 | 8.94 | 1.784 | 33 |
| | 2 | 8.75 | 1.832 | 8 |
| | Total | 8.90 | 1.772 | 41 |
| Po Total | 1 | 10.52 | 2.563 | 33 |
| | 2 | 11.00 | 1.773 | 8 |
| | Total | 10.61 | 2.417 | 41 |

Table 14. Summary ANOVA table for authentic science test scores

| | Source | Sum of Squares | df | Mean Square | F | p | Effect Size (Partial Eta Squared) | Observed Power[a] |
|---|---|---|---|---|---|---|---|---|
| Between subjects | | | | | | | | |
| | Group | .281 | 1 | .281 | .039 | .844 | .001 | .054 |
| | S (Group) | 277.841 | 39 | 7.124 | | | | |
| Within subjects | | | | | | | | |
| | Time | 47.122 | 1 | 47.122 | 23.035 | .000 | .371 | .997 |
| | Time * Group | 1.464 | 1 | 1.464 | .715 | .403 | .018 | .131 |
| | Time * S (Group) | 79.780 | 39 | 2.046 | | | | |

[a.] Computed using alpha = .05

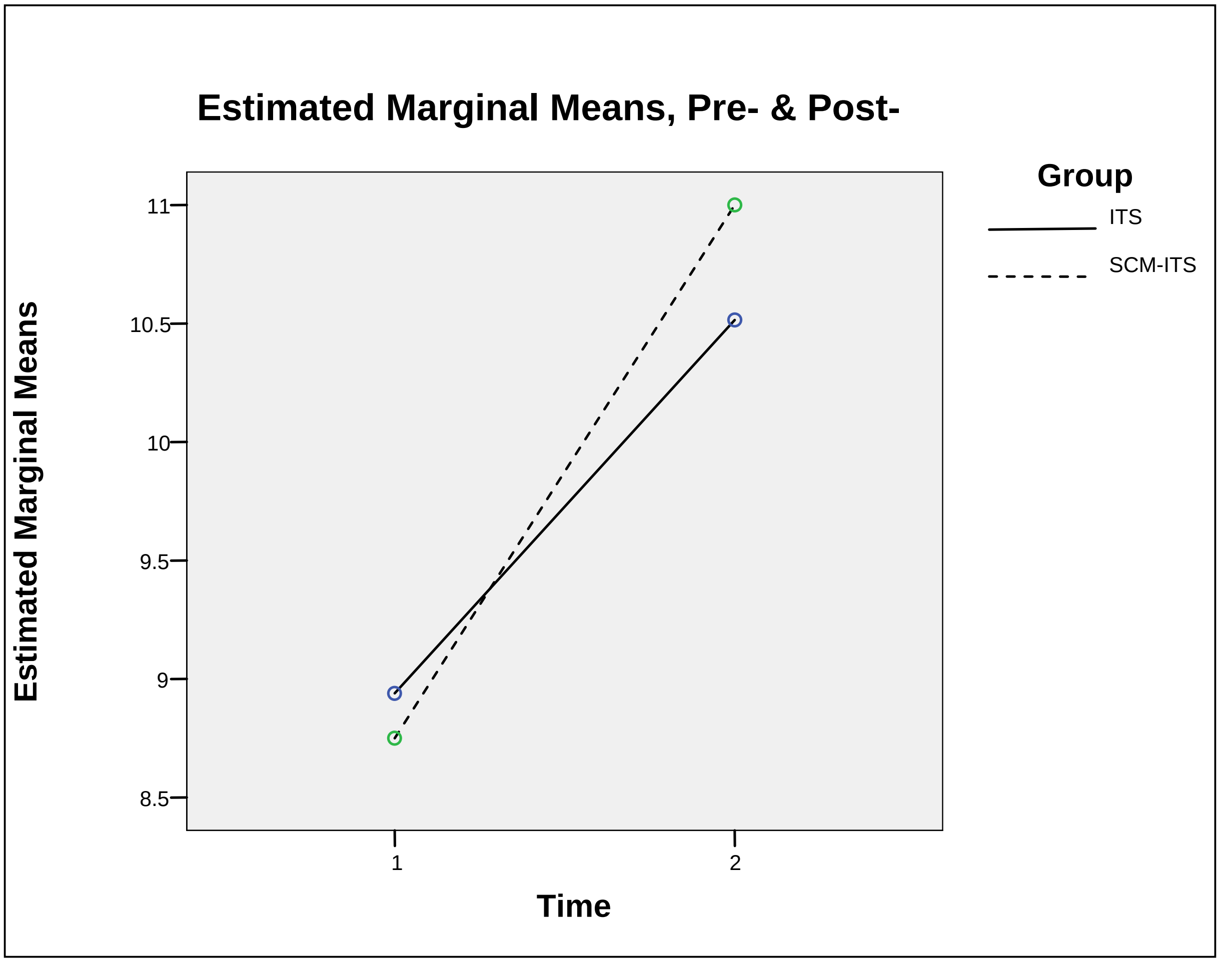


Figure 10. Estimated marginal means for pre- & posttest scores

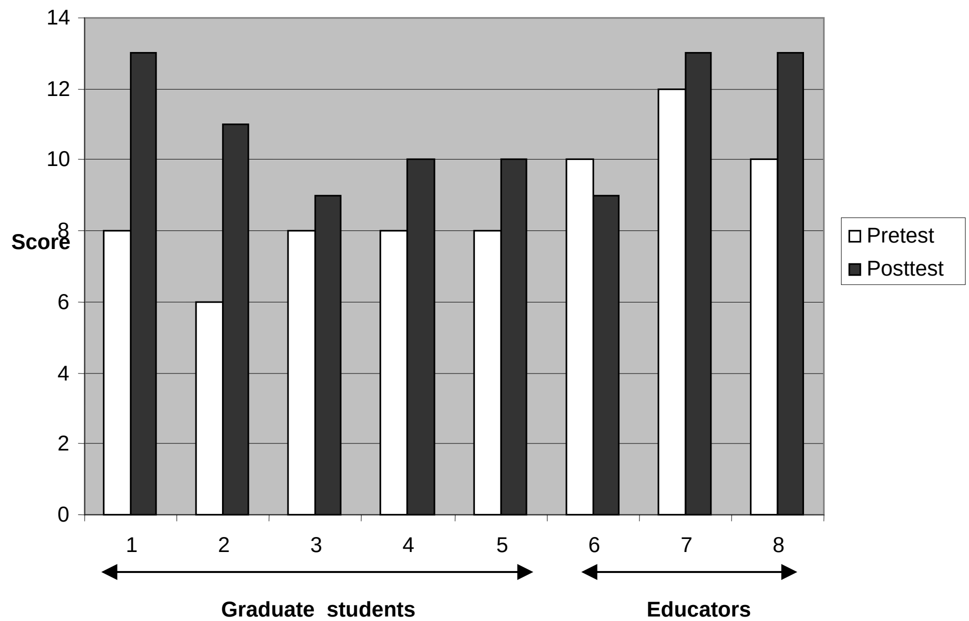


Figure 11. Authentic science pre- & posttest scores (# correct)

Seven of the eight SCM-ITS participants' scores improved on the posttest (Figure 11). It is interesting to note that participants 1-5 are the science graduate students and 6-8 are the educators, and that the three educators all had higher initial scores than any of the science graduate students. Two science graduate students' scores improved from the pretest to the posttest by five questions. The participant whose posttest score decreased by one question was an educator.

The pre- and posttests (Appendix A) began with the instructions "Please select the one answer from each group below that you feel is ***most reflective*** of how authentic science is practiced. Then explain below why you chose that answer, giving examples or elaborating if you can." (Not everyone gave explanations for every answer, and few gave examples.) Eleven of the fifteen questions dealt with the cognitive processes (CP) described by Chinn & Malhotra (Table 10) and the remaining four dealt with the epistemology of authentic science (Table 11). I will discuss the results of the questions in the order each process or concept appears in Tables 10 and 11 and Figure 12 rather than by question number (Figure 13). Correct responses according to Chinn and Malhotra's authentic inquiry framework can be found in bold type in the right column of tables I and II and in bold type in the Nature of Authentic Science test in Appendix A.

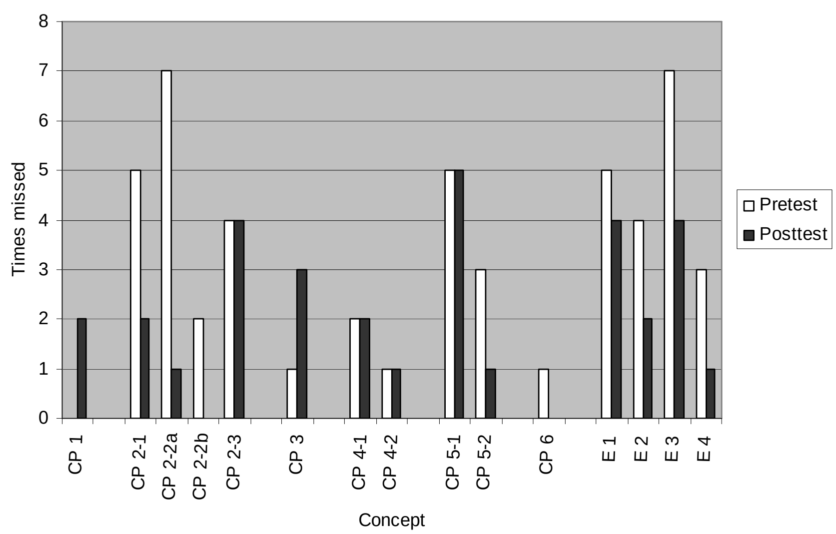


Figure 12. Times authentic science questions missed, grouped by concept. (CP = Cognitive Processes, E = Epistemologies)

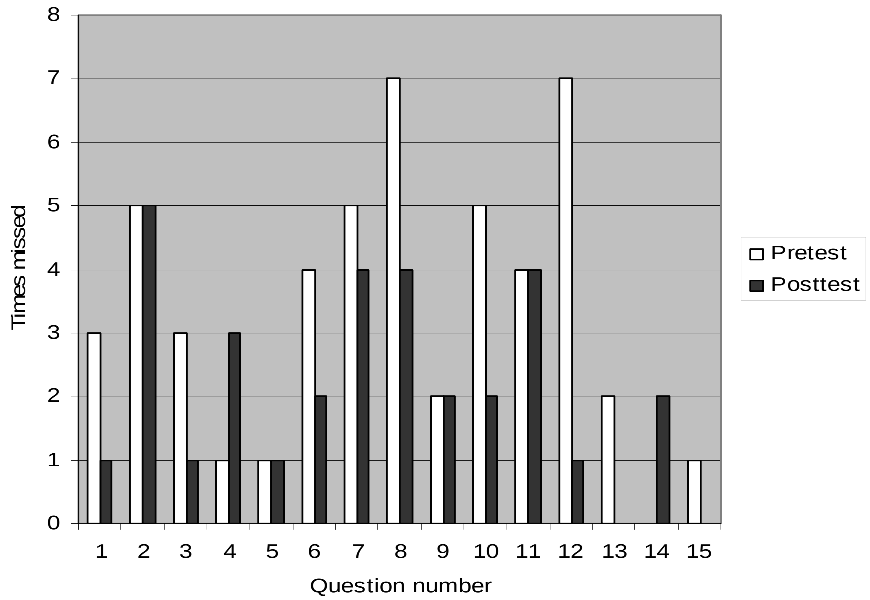


Figure 13. Times authentic science questions missed

*Cognitive processes questions.* The question concerning how scientists generate research questions (Q 14, CP 1) gave the following answer choices: “a) almost always rely on questions provided by their funding agencies, b) almost always use questions provided by the universities or companies that employ them, c) generate their own questions, sometimes in collaboration with other scientists, and d) always generate their own questions individually in order to prevent competition.” On the pretest, 100% chose the “correct” answer according to the article (“c”), but on the posttest, two of the eight (both science graduate students) missed it with both choosing answer “a”. Perhaps during the course they became more aware of scientists’ reliance on outside funding to carry out their research agendas. One wrote, “In a perfect world, scientists would generate research questions on their own. However, in the imperfect world that we do live in questions are provided or encouraged strongly by funding agencies or employers. [When] scientists do come up with their own research question, they have to prove to the funding source that it is worthwhile and in their benefit to fund these research questions."

Four questions pertained to the design of studies, including variable selection (Q 10, CP 2-1), planning by inventing complex procedures (Q 12, CP 2-2a), planning by devising analog models (Q 13, CP 2-2b), and controlling variables (Q 11, CP 2-3). The following were the answer choices to the question on variable selection: "a) investigate only one variable at a time, b) may select and even invent variables to investigate, since there are many possible variables, c) investigate only, at the most, two variables at a time, and d) may select but never invent variables to test." On the pretest, two participants, both teachers, thought that scientists would investigate a single variable at a time. The three science graduate students who missed the question recognized that multiple variables may be investigated at a time but, as one commented, "There are usually enough natural variables one must choose from and [one] usually can not measure all of them; I am not sure why one would invent a variable." On both the pre- and post- tests, another science graduate student mentioned in her explanation the large number of variables she is studying in her research. Although she changed her answer on the posttest to indicate that variables may be invented, she was still reluctant to acknowledge that that might be true, remarking, "I don't think they invent variables, but they may construct variables that have not been historically tested." The two who missed this question on the posttest did not give an explanation for their answers.

The second study design question (Q 12, CP 2-2a) concerned planning investigative procedures, and the possible answers were: “a) almost always follow traditional, proven methods in order to answer questions, b) often invent complex procedures to address questions of interest, c) rarely invent complex procedures to address questions of interest, and d) first use traditional, proven methods followed by invented complex procedures.” The large number of wrong answers on the pretest possibly had to do with design of the distractors for this question; seven of eight missed the “correct” answer (b), with six of the seven choosing answer d. One of the teachers explained her choice, “It depends. If the traditional methods have not been used yet, then I think the scientist would want to start with the most simple straight-forward method needed. If the traditional methods have already been done and documented and the question still has not been answered, then a more complex procedure may be needed.” By the posttest, all but one participant selected the “correct” answer choice. As can be seen on the graph in Figure 3, this question showed the greatest change in number choosing the correct answer of any of the fifteen questions.

The third question examining study design (Q 13, CP 2-2b) also dealt with planning procedures for research projects, giving the following answer choices: “a) scientists often devise analog models or model systems to address a research question, b) analog models are sometimes used in solving a problem, but scientists do not consider the appropriateness of the analogy, c) analog models are rarely used by scientists in solving a problem, and d) analog models are always used by scientists in solving a problem.” Two science graduate students missed this question on the pretest, both answering “b,” but with no explanation for why they chose that answer. On the posttest, this was one of two questions answered correctly by everyone, perhaps reflecting the amount of class time spent making models using ArcView® and other formats and discussing their importance in doing science.

50% of the participants missed the question on control of variables (Q 11, CP 2-3) on both the pre- and post- tests. Possible answers were: “a) control of variables is never an issue in experiments, b) there is always a single, simple control group in experiments, c) scientists often employ multiple controls, but in some disciplines, controls are rarely, if ever, used, and d) control of variables is always an issue in experiments, no matter the discipline.” On the pretest, one educator responded that there is always a single, simple control group, and two science graduate students and one educator answered that control of variables is always an issue, no matter the discipline. On the posttest, all four who missed the question answered “d.” The confusion is understandable, since the Chinn and Malhotra (2002) article – and most probably the afternoon class discussion – indicated that controls are always an issue. The scientists of the SCM team disagreed with Chinn and Malhotra, pointing out that the point of view espoused in their article fails to consider the wide range of inquiry used in scientific investigations – from classic experiments requiring controls to descriptive inquiries where there are no controls.

The third cognitive process dealt with making observations (Q 4, CP 3), and answer choices included:  “a) employ elaborate techniques to guard against observer bias, b) do not have to guard against observer bias since it never enters into scientific work, c) do not need to explicitly address observer bias, since it is rarely a problem in scientific investigations, and d) are concerned with possible effects of observer bias only in certain unusual situations." Although one person missed this on the pretest, she qualified her answer by stating, "A scientist may be biased in trying to answer a question. But usually by following the scientific method this is less common since it is very objective." The same person missed it again on the posttest, this time saying, "Bias in scientific knowledge cannot be disregarded. Scientists try to guard against bias but sometimes it is inevitable." In addition, two other participants missed this on the posttest, but their written explanations also indicated that they were aware of the need to guard against bias. This may have been one of those situations where careless reading or misunderstanding of answer choices led to some people missing the question.

Two questions were concerned with the fourth cognitive process, how scientists explain the results of their research. The first (Q 9, CP 4-1) of these referred to how scientific observations are handled: "a) occasionally transformed into other data formats such as straightforward graphs, b) never transformed without substantial alteration, c) seldom transformed into other data formats except perhaps drawings, or d) often repeatedly transformed into other data formats." On the pretest, six participants realized that data is often repeatedly transformed, and the two who did not both selected answer "a" and commented that data is transformed into graphs. One of those people missed the question again on the posttest but did not give an explanation. The second person who missed it on the posttest had gotten it correct on the pretest, saying "Scientists will . . .

transform their observations into other tools," but on the posttest he only mentioned graphs.

The second question (Q 5, CP 4-2) was in regard to how scientists deal with experimental flaws in explaining their results, and one person missed it on the pretest and another on the posttest. Answer choices were: "a) rarely have to consider flaws in experiments because they are seldom salient (important), b) constantly question whether results are correct or artifacts of experimental flaws, c) assume they did the experiment incorrectly if they do not obtain the expected outcome, or d) typically consider flaws to be important only if human subjects are involved." The science graduate student who missed this question on the pretest chose answer "a" and commented that she didn't think any of the answers were correct since good experimental design and quality control would take care of any problems. Although she changed her answer to "b" on the posttest, she said, "I still would not say scientists constantly question their experiments only because you prepare your experiment the best you can and have controls etc. so you do not question your results." The science graduate student who missed the question on the posttest said, "Doing an experiment you should trust that what you are doing is correct. Double guessing yourself is saying that you are not confident in what you are doing."

The fifth cognitive process involved theory development and the first question (Q2, CP 5-1) was "The level of theory development usually results in scientists: a) uncovering empirical regularities, not theoretical mechanisms, b) constructing theories postulating mechanisms with unobservable entities, c) uncovering empirical irregularities, not theoretical mechanisms, or d) doing experiments that illustrate theoretical mechanisms but do not investigate theories." The misconceptions or misunderstandings held about this concept proved to be resistant to change, as this question was missed five times on both the pretest and posttest. All three of the educators missed this question on both tests. One of the graduate students who chose the correct answer on both tests explained on the posttest, "Theory development is the construction of models that postulate mechanisms for unobservable phenomena."

The other question concerning theory development (Q3, CP 5-2) asked whether scientists usually: "a) do only a single experiment at a time, b) make only a certain range of observations at one time, c) do only a single demonstration of scientific principle at a time, or d) coordinate results from multiple studies." Three participants, all science graduate students, missed this question on the pretest, but on the posttest only one did not choose "d", and she wrote, "They can either look at one thing at a time or several. It depends on what they are looking at."

The final cognitive process (Q15, CP 6) regarded scientists studying other scientists' research reports and was only missed by one person on the pretest and by no one on the posttest. Explanations of answers showed awareness of peer review functions as well as the importance of keeping abreast of current research.

*Epistemology questions.* The four questions concerning the epistemology of authentic inquiry on the whole showed greater misunderstandings on both the pretest and posttest than for the questions on cognitive processes. The question dealing with the purpose of research (Q7, E 1) was very similar to the cognitive processes question about theory construction both in content and in number of times missed. It was also missed five times on the pretest but only four times on the posttest. It read: “The best description of the purpose of research is that scientists aim to: a) understand a pre-existing theory or model, b) observe structures of objects or models, c) uncover simple surface-level regularities, or d) build and revise theoretical models with unobservable mechanisms.” One participant related her explanation to the work done in class, “Research usually builds on a theory in place. In building models as we did using ArcView, we could not observe all the mechanisms but we could make inferences about the mechanisms.”

The second epistemology question (Q6, E2) said: “The best description of theory-data coordination is that scientists: a) coordinate theoretical models with multiple sets of complex, partially conflicting data, b) record and use only what they can see and measure quantitatively, c) coordinate one set of observable results with conclusions about those observable results, or d) do not attempt to use theory-data coordination if there are any conflicts in data.” This question was missed four times on the pretest, and each who missed it either did not put an explanation or said their answer was a guess. It was only missed twice on the posttest, and one participant who did not understand what the question was referring to on the pretest but got it right on the posttest commented “We did this in our morning session!” Another showed a deep understanding, saying, “Multiple data sets are examined, which may contain some data conflict, before theories are offered. Data sets are negotiable and subject to interpretation, so conflict is inevitable.”

In regard to responding to anomalous data, the third epistemology question (Q8, E3) asked if scientists: “a) may regularly and rationally discount anomalous data or change their theory, b) never discount anomalous data; all data are equally important in judging a theory, c) always reject data as erroneous if results contradict the expectations, or d) typically start an experiment over because the anomalous data aren’t reliable.” This question, missed by seven on the pretest and four on the posttest, also revealed a high level of misconceptions. On the pretest, several indicated that all data is equally important. On both tests it seemed that those who missed the question ignored the “or change their theory” part of answer “a.” One who put answer “b” said, “Anomalous data is important to research. It could lead to other questions and answers.” Another said “I think this is what we have discussed the past three weeks, but I am not sure if I agree. I think scientists usually discount anomalous data. There are ways to ‘fix’ data and outliers are often excluded in stats.”

The final question in this group actually fits into both the Cognitive Process section under “Types of reasoning” and the Dimension of Epistemology section under “Social construction of knowledge.” It asked about the reasoning methods employed by scientists in explaining their results, and answer choices included: “a) simple deductive reasoning, b) simple inductive reasoning, c) multiple acceptable argument forms, and d) simple contrastive argument forms.” Three participants – all science graduate students – answered “simple deductive reasoning” on the pretest, while everyone else recognized that scientists use multiple acceptable argument forms. As one commented, “There are many ways to arrive at an answer or understanding.” This question was missed only one time on the posttest (by one who had also missed it on the pretest) and that person did not give a reason for her answer.

*Levels of Inquiry*

During Summer I, each participant completed a plan for a technology-mediated inquiry project to be implemented during the following academic year in their personal teaching situation or a borrowed classroom. There was a wide variation in targeted age levels and specific inquiry topics, but all dealt in some way with environmental issues. They gave detailed plans for their implementations in PowerPoint® presentations on the final day of class, and at the beginning of Summer II presented a report on the results of their implementation. During this second presentation, participants' projects were evaluated for inquiry level using the Inquiry Level Rubric (Figure 14) and critiqued by the faculty members present and by each of the other participants. Participants also did self-evaluations after their presentations. The faculty and participants discussed the meaning of the categories used on the rubric before evaluating inquiry projects with it. Self scores, mean faculty scores, and mean participant scores are reported in Table 15 and Figure 15. (Larry, the mathematics education graduate student, and Kayce, a science graduate student, did not return for the second session and, therefore, are not included in these evaluations.)

| Type of Inquiry / Inquiry Task | Traditional Hands-on/ Simple Illustrations | Structured Inquiry | Guided Inquiry | Student Directed Inquiry | Authentic Classroom Inquiry |
|---|---|---|---|---|---|
| **Topic Choice** | Teacher | Teacher | Teacher | Teacher | Teacher/ Student |
| **Question Choice** | Teacher | Teacher | Teacher | Teacher/ Student | Student |
| **Materials** | Teacher | Teacher | Teacher | Student | Student |
| **Inquiry Design/ Procedures** | Teacher | Teacher | Teacher/ Student | Student | Student |
| **Results/Analysis** | Teacher | Teacher/ Student | Student | Student | Student |
| **Conclusions** | Teacher | Student | Student | Student | Student |
| **Score** | 1 | 2 | 3 | 4 | 5 |

Figure 14. Inquiry level rubric (Modified from Bonstetter, 1998. Reprinted with permission from the Electronic Journal of Science Education.)

Table 15. Inquiry project data

| **Name*** | **Implementation Level & Course** | **Evaluator** | **Score for Level of Inquiry** |
|---|---|---|---|
| Deanne | Teacher professional development | Self | 3.5 |
| | | Faculty Mean | 3.67 |
| | | Student Mean | 3.14 |
| Kristi | 7th grade (Integrated science) | Self | 3 |
| | | Faculty Mean | 3.33 |
| | | Student Mean | 3.0 |
| Kyle | 7th grade (Integrated science) | Self | NS |
| | | Faculty Mean | 3.0 |
| | | Student Mean | 2.64 |
| Catarina | University freshmen (Geology) | Self | 3 |
| | | Faculty Mean | 3.75 |
| | | Student Mean | 3.0 |
| Shane | Graduate students (Environmental planning) | Self | 1 |
| | | Faculty Mean | 2.5 |
| | | Student Mean | 2.29 |
| Amanda | University freshmen (Geology) | Self | 4 |
| | | Faculty Mean | 3.5 |
| | | Student Mean | 3.86 |
| Kenneth | Upper level university (Agricultural engineering) | Self | NS |
| | | Faculty Mean | 2.33 |
| | | Student Mean | 2.64 |
| Emily | Upper level university (Geology) | Self | 4 |
| | | Faculty Mean | 2.67 |
| | | Student Mean | 3.9 |

*Pseudonym

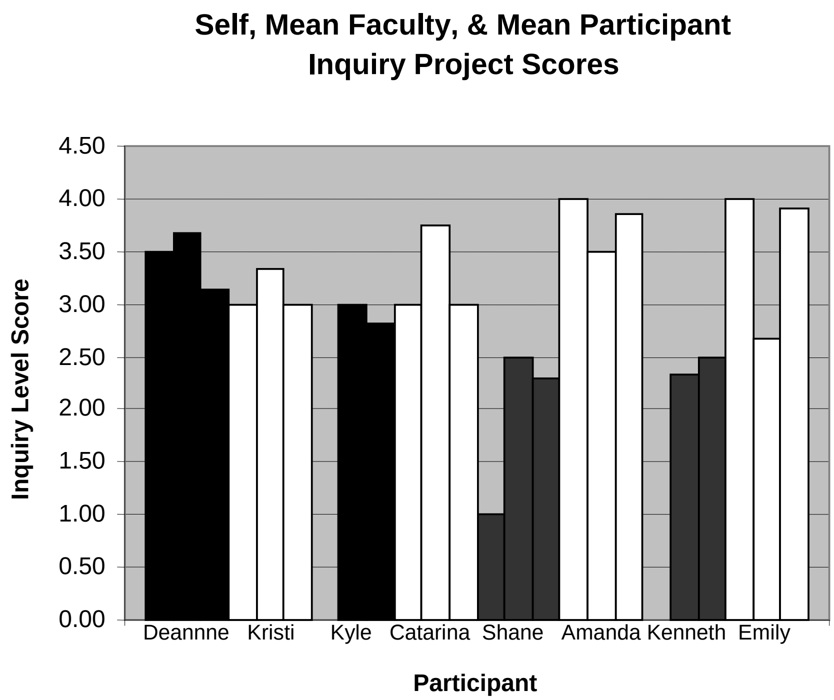


Figure 15. Level of inquiry scores

Deanne is a former classroom teacher who is currently a professional development specialist at a Region Education Service Center. Her targeted learners were K-12 teachers who were currently receiving GLOBE training and had little experience using imaging and modeling data and little experience using authentic inquiry in their classrooms. The inquiry question they were to investigate over two GLOBE protocols was “What causes fluctuations in dissolved oxygen levels and how does that relate to the environmental health of the Texas Coastal Margin?” Deanne’s goals were for the teachers to experience inquiry by using technology to access information and data and create visualizations using GLOBE imaging, MultiSpec© or GIS. They would use actual data to construct a model of the effect of dissolved oxygen in regard to new information about factors affecting dissolved oxygen and present their solutions to the inquiry question to the other group members. In actuality, constraints from the school districts regarding high-stakes testing and budget cuts resulted in cancellation of the scheduled GLOBE training sessions. As a result, Deanne implemented a greatly modified framework in a workshop setting (one day) for teachers of $6^{th}$-$9^{th}$ grades. The first half of the day involved a teacher/presenter discussing how he uses hand-held data recording devices in his classroom. During the second half of the day, teachers first explored projects posted at the HOBO® datalogger web site (http://www.iscienceproject.com/) and then in small groups determined an inquiry question they could answer by using the datalogger. After collecting the necessary data, the teachers downloaded it from the HOBO® onto the computer, graphed their data, and shared their conclusions with the entire group. They were then shown how to access data sets on the web and asked to model how temperature and day length are related along a given latitude and create a representation using Excel®. Finally, each group shared its data source, chosen latitude, and final graph with the rest of the groups.

Deanne scored her implementation between guided inquiry and student directed inquiry (3.5), and the faculty and participant assessments were in the same realm (3.7 and 3.1, respectively). This experience is an example of how inquiry does not have to consist of elaborate, time-intensive projects. After learning how to collect data using the handheld dataloggers, participants designed simple questions such as “Is the hot water the same temperature in all the school restrooms?” and “What part of the room is the hottest?” It is obvious that students at a relatively young age could learn to use technology to answer questions that they design themselves.

Although Kristi left the middle school classroom that summer to become a full time graduate student in geography education, she developed a module to be implemented with “borrowed” 7$^{th}$ and 8$^{th}$ grade science students at a local private school on each Friday throughout a semester. Because she had experienced a particular challenge in teaching osmosis, she designed an implementation project for students to investigate the following questions: 1) What is osmosis? 2) What types of things does osmosis cause? 3) What does osmosis have to do with equilibrium and salinity? and, What are some examples of osmosis in action in the real world? Because these students had not studied science as a separate subject until 6$^{th}$ grade, she did not expect them to have experience with or understanding of science inquiry methods. She planned to introduce the topic with a model, a toy fish that can absorb water, make observations of absorption using fresh and salt water, and use Excel® to record and graph their data. They would then do a scaffolded Internet search for a model to explain their observations. After they discovered a model for what they observed (osmosis), they would test the model in a lab station setting, first making a hypothesis based on their model. Finally, they would use GIS to map the salinity of the Texas Gulf Coast and predict the effects of high or low salinity on a bay using their understanding of osmosis and water regulation in fish. The final learning product would be models representing a real world example of equilibrium due to osmosis in a system or organism, planned and designed by small groups of students.

Kristi began the implementation of the project with the toy fish exercise followed by the guided Internet search and creation of PowerPoint® animations using a template she provided. Then microscopes were used to investigate osmosis on a cellular level in *Elodea*, onion peels, and pond water. Finally, students conducted a guided Internet search investigating environmental impacts related to salinity and osmosis and made group presentations of research questions based on the information collected in the search. Kristi and the other participants rated her inquiry level as guided inquiry (3.0), while faculty members rated it slightly higher (3.3). Students were able to participate in some of the design of their inquiries but were not involved in determining materials to be used.

Kyle designed his instructional sequence for use in a 6th grade advanced science class to have students answer the question "How does non-point source pollution affect the water quality in Cameron County, Texas?" His goals included implementing the TEKS (Texas Essential Knowledge and Skills) standards for using scientific inquiry methods in investigations, critical thinking and problem solving, and technology applications. The students would work on the question as a six-week project alone or in pairs. Background information on the topics of non-point source pollution, watersheds, groundwater and GIS mapping skills were to be taught in class, and students would produce a three-dimensional model of a watershed and map local watersheds and river systems using GIS technologies. They would also use the Project WISE web site (http://wise.berkeley.edu/) water quality investigations to practice inquiry problems. The final student product would be a PowerPoint® presentation of findings to the class.

Kyle's teaching assignment was changed before the beginning of school, so he implemented his module in 7th grade science classes. His students participated in a laboratory exercise demonstrating that pollutants (fertilizer, food peelings, and washing detergent) would cause algal blooms in water. Tutorials on GIS software (two one-hour sessions) and PowerPoint® were presented and students did the "Creek Detectives" project from the WISE web site to practice solving inquiry-based problems. Kyle found challenges in providing adequate computer access and training in GIS for his students and discovered that the water quality data available for the area is limited. He did not score his own inquiry level, but the mean faculty member classification was guided inquiry (3.0) and participants as between structured and guided (2.6). Kyle planned to implement his module again the following year at an increased level of inquiry, having the students first use the WISE web site to explore scientific inquiry problems and then create their own scientific inquiry problem concerning local water quality.

Catarina, a geology graduate student, had more extensive teaching experience than the other science graduate students, having taught secondary science and served as a teaching assistant for college chemistry classes. She planned for learners in an introductory Geology lecture setting to select and analyze data to explain the environmental effects of mercury contamination in the Gulf of Mexico and its potential impact on humans. They would graph data from The Gulf of Mexico Program Mercury Analysis Project using Excel® and use a simulation model for aquatic ecosystems (Aquatox®) to explore the effects of water quality on aquatic organisms. Catarina planned to work with the professor (her advisor, who was not involved in ITS) throughout the semester to acquaint students with the IT used in the project. Students would work on the inquiry individually or in small groups over a three-week period from their home computers with virtual assistance from her through a web page. The final learning product would be a written report answering the problem and providing evidence to support their conclusions.

In the actual implementation students used complex databases from the USGS and EPA as well as the Gulf of Mexico Program websites and selected which variables to test and the data to use to answer some aspect of the research question. Catarina found that, in addition to having IT problems, students were discouraged and did not understand the purpose of the project. As a result, she planned for a new approach to a future implementation that would include a greater emphasis on the importance of scientific inquiry as well as a semester-long timeline for the project. She would also give them more explicit instructions for their final product: it would include an exposition of the data collected, analysis of tendencies and trends, and an explanation of the potential consequences of the trends. I think this would give Catarina the opportunity to explain the components of authentic scientific inquiry, including the need for justification and reporting of results and the possible influence on environmental policy decisions. Catarina and the other participants rated her implementation as guided inquiry (3.0), while the faculty mean score was 3.75, moving it closer to student-directed inquiry. Although the teacher gave an overall question, the students chose an aspect of the question to explore, designed their procedures and gathered data needed in for exploration.

Shane, a science graduate student in urban planning, had some experience in teaching GIS and GPS classes and workshops. He originally planned to have students use land use, land cover, and sociodemographic variables data to answer the question: What is the relationship between land use and non-point source pollution in the watershed you have chosen? Upper level undergraduates would use GIS operations (data extraction, projection and/or image registration), a runoff model, and analysis of runoff changes in relation to land use change in order to answer the question over a four-week period at the end of the semester. They would turn in a project proposal shortly after the assignment was given and turn in a project plan halfway through the time period. Students' final products would be PowerPoint® presentations with the results of their analyses, recommendations, and limitations of their studies and written reports with data sources, analysis procedures, recommendations and limitations.

Had this plan been implemented, it would have been student-directed inquiry since although the teacher determined the topic, both teacher and students would have had input into the question and all of the rest of the inquiry tasks would have been student-determined. It would have been an excellent opportunity to give students control and have them experience how environmental research is often done by scientists. In actuality, Shane implemented a much different plan in only one class period, addressing the question, "Is ozone pollution normally distributed across population characteristics? Why or why not?" in a classroom with only one computer. He used GIS, statistical software and data from the U.S. Census Bureau and air monitoring stations to demonstrate how scientists would look at ozone pollution data and relate it to demographic characteristics such as race, age, income, education, and housing. He discussed the results from an environmental and social justice point of view, emphasizing the importance of this type of correlational analysis to local-level planning efforts. He involved the students in discussion, but due to computer limitations there was no hands-on component to the class. Shane rated his project in the traditional hands-on/simple illustrations category (1) while both the faculty and participant mean scores (2.5 and 2.3, respectively) placed this implementation slightly above the structured inquiry level. This is logical in the sense that teacher and students were involved in the results and analysis and the students drew conclusions, but Shane's self-assessment seems to be more accurate. In actuality, since students had no hands-on involvement, it should probably not even be classified as inquiry, but as a demonstration.

Amanda, also a geology graduate student with some teaching experience, planned an instructional sequence for a beginning physical geology laboratory class to have students answer the question "What dynamical changes have humans caused on sediment transport on the Texas Gulf Coast?" She originally planned a guided inquiry, but in the actual implementation she moved toward a more student-directed inquiry. Before the lab, students were asked to read an introduction to the topic, and at the beginning of the class she gave a short lecture and discussion. As an IT component, they viewed data sets collected on the beach profiles of several areas in Texas and made inferences from that data. They then worked with a wave-sand table in small groups. Each group had to make an assessment of a barrier island using the physical model, and in the process, create a hypothesis, design an experiment, collect data and make observations, and report on their results. After this experience, they each did an individual written report assessing the importance of adding a seawall to the Outer Banks barrier island system. Amanda rated her level of inquiry as student-directed inquiry (4), while the faculty and other participants scored the project as between guided inquiry and student-directed inquiry (3.5 and 3.86, respectively). Problems with her implementation included having to implement in an environment where she was not the regular laboratory teaching assistant, using a different structure for the lab than the usual cook-book experiences students were used to and a lack of scaffolding on the topic by the lecture component of the course. This emphasizes the need for students to be comfortable in their laboratory situation with the instructor and to be trained in the inquiry process.

Kenneth, a biological and agricultural engineering doctoral student, planned his implementation for a five-week period of two-hour lab classes per week and a target audience of upper level undergraduate students with a focus on environmental or water resources engineering. The inquiry problem was “To what extent does the orientation of spatially distributed curve numbers influence runoff calculations within a watershed?” and students were to formulate and test a hypothesis for a case study using both “lumped” and distributed analysis techniques. The final learning product for each student was to be a presentation and a project web site containing a formal engineering report representing the integration of smaller individual inquiries made over the course of three lab sessions. The students were to apply techniques learned (GIS for visualization and manipulation of data and MatLab Release 13® to simulate and visualize outputs) to a study area of their choice. Kenneth implemented his module as designed, but found that it took ten weeks instead of five to complete. He felt that students realized the value of the experience and developed skills that would be important to them in the future. He did not rate his own inquiry level, but the faculty and participants rated the module between structured and guided inquiry (2.3 and 2.6, respectively). Although his students were able to choose their study area, other components of the inquiry were determined by the teacher.

The final science graduate student, Emily, had some experience as a teaching assistant in chemistry and oceanography. She planned an ambitious implementation project for use with university juniors and seniors in an environmental geochemistry class. The inquiry problem to be investigated was “How does the damming of Texas watersheds affect the water quality in different Earth systems and the associated sedimentary biogeochemistry?” She planned to have students collect data from model sediment cores created in Winogradsky columns, map complex data sets using GIS, analyze the data, determine data trends and hypothesize, use external models to make explanations, create their own animated models using PowerPoint®, and draw conclusions about the Earth systems explored, all in a one-week time period.

Emily field tested her plan during the fall semester in an upper-level environmental geology class with 15 students over a three-week period of time. Scaffolding for the inquiry-based learning module included PowerPoint® lectures, assignment of background reading materials, and technology tutorials. Emily’s students created physical models (Winogradsky columns) where they determined the setup and treatments – soil type (marine or wetlands sediments), the type of organic matter added to the columns (oil or molasses) and whether to make the column hypoxic or anoxic by choosing whether or not to aerate. They also decided how they would measure changes in the column. Suggested methods were the use of a dissolved oxygen meter, a microvolt meter, addition of non-galvanized nails, or a digital camera to track color changes. They created information technology models using geographic information systems (GIS) and Excel® to model and analyze large-scale data sets and link human impacts to the environment and used PowerPoint® to illustrate their mental model of eutrophication processes and sediment biogeochemistry. In rating the degree of inquiry used, Emily and the other students rated her project as student directed inquiry (4), while the faculty mean score (2.67) placed her project between structured inquiry and guided inquiry. The module seems to fit well into the category of guided inquiry (3) since for this level the teacher determines topic, question, and materials and the teacher and student together determine the inquiry design and procedures. By limiting the materials, Emily effectively took away some of the choices and moved the project away from student-directed inquiry.

Problems in consistent rating of inquiry level by the individuals, participants, and faculty members probably have several causes. First of all, I did not do sufficient training of raters to ensure that everyone would be on the same page about terminology. In some cases, a part of the implementation project was student-directed but the majority of it was not, so raters used different criteria for determining a score. In other cases, what was planned was far different from what was actually implemented and no clear instructions were given on which part of the project to score. For the most part, however, scores on these implementation efforts fall in the range of structured inquiry to guided inquiry, with some movement toward student-directed inquiry. None provide examples of what Bonstetter (1998) or Chinn and Malhotra (2002) would consider the highest level of authentic classroom inquiry, where students have input or control over every part of the project. Furthermore, teachers of older students did not consistently implement at a significantly higher level of inquiry than teachers of middle school students. Most reported problems with trying to do sufficient scaffolding in a limited time frame for students to truly be in charge of their learning. Results seem to confirm the idea that students need to be "trained" in inquiry in order to feel comfortable with using it.

## Discussion

Results of the Nature of Authentic Inquiry pre- and posttests revealed a statistically significant difference in scores. All three SCM-ITS educators' initial scores were higher than any of the science graduate students' scores. It is possible that educators were more aware of NOS concepts in the beginning because of prior exposure and the specific inclusion of NOS concepts in the Texas Essential Knowledge and Skills (TEKS). Posttest scores improved for seven of the eight SCM-ITS participants; the one participant whose score decreased (by one correct answer) was an educator. Two of the graduate students' scores improved by five correct answers, indicating an openness to change and new ideas.

NOS concepts were addressed explicitly in the education portion of the ITS experience that first summer and the four SCM-ITS scientists were aware of the push toward of teaching NOS concepts and tried to address them explicitly whenever possible. This supports the assertion that NOS concepts must be taught explicitly (Abd-El-Khalick & Lederman, 2000), since one would expect the science graduate students who were at least somewhat experienced in scientific research to have scored at least as high as the educators on the pretest if NOS concepts could be easily learned by experiencing authentic scientific research.

Questions which caused the most difficulty dealt with the varied facets of “scientific method.” Misunderstandings of the nature of theories, laws, and hypotheses as well as the idea of one inductive, atheoretical “scientific method” are pervasive myths or misconceptions concerning the nature of science (McComas, 1998; Windschitl, 2004). Windschitl’s “folk theories” of inquiry include the idea that different forms of scientific inquiry are, to a greater or lesser degree, prescribed (as in THE scientific method), social, differently directed and differently enacted. Since the meaning of scientific inquiry is situated by culture and discipline and is constantly changing as it is practiced, the enactment of inquiry occurring in classrooms depends on the teacher and reinforces various aspects of the folk theories. These are often simplistic and linear and obscure the complexity and reiterative nature of authentic science as it is practiced by scientists in the field.

Since teachers and science graduate students are products of schools – and even college science classes – that use typical classroom inquiry rather than authentic scientific research experiences, it is not surprising that there would be misconceptions about the cognitive processes and epistemologies of authentic inquiry. The experiences of doing environmental science in an authentic manner in the SCM-ITS group and of reading and receiving instruction about authentic science resulted in a positive change in the participants' understanding of authentic inquiry as shown by the improvement in test scores over the course of Summer I. At the end of Summer II participants had the opportunity to practice authentic science as they solved real-life environmental problems affecting the local area.

The inquiry incorporated in the modules written by the participants was predominantly guided inquiry, where the teacher chooses the topic and question and selects and provides the materials used. The student and teacher both have input into the design and procedures used, and the student has sole responsibility for collecting and analyzing data and drawing conclusions. Approximately the same level of inquiry occurred at all levels represented by participants (6-16 and adults). The challenge for educators is to "develop simpler tasks that can be carried out within the limitations of space, time, money, and expertise that exist in the classroom. The goal is to develop relatively simple *school inquiry tasks* that, despite their simplicity, capture core components of scientific reasoning" (Chinn & Malhotra, 2002). The first step in the task is to acquaint teachers with authentic science, and the SCM-ITS experience was a step in the right direction.

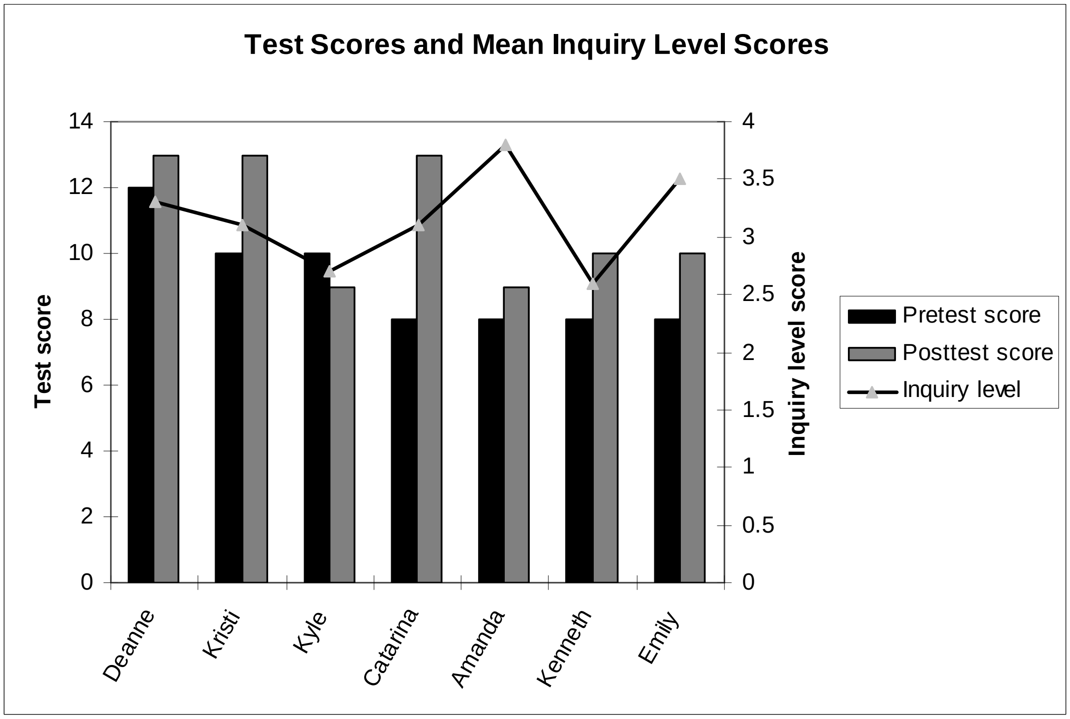


Figure 16. Authentic science scores compared to inquiry level scores

An examination of the scores on the Nature of Authentic Science pre- and posttest compared with the total mean inquiry levels for each participant reveals no consistent relationship. (See Figure 16.) The person with the highest inquiry level score, Amanda, had one of the lowest test scores, while those with the highest posttest scores, Deanne, Kristi, and Catarina, had mid-level inquiry scores. Inquiry level was far less “controllable” than the scores on the Authentic Science instrument; too many variables affected the inquiry projects. A combination of factors influenced it, including the grade/level at which the project was implemented and how ambitious the project was. If the teacher had to spend a great deal of time scaffolding the skills necessary to accomplish the project, the inquiry rating was lower. Thus, it is not unexpected that high test scores do not translate into high inquiry-level projects. The inquiry project assignment was not modeled after the Chinn and Malhotra criteria for authentic inquiry; a better fit of the assignment and assessment results might have occurred if the two had been intentionally aligned.

## Implications

Although there is a great deal of confusion and disagreement among “experts” about what inquiry means, most science teachers would agree that it involves asking questions and constructing explanations. According to the *National Science Education Standards*, “Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities in which [students] develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (p. 23). Inquiry provides opportunities for students to experience the nature of science by engaging them in the practices of scientists. Through inquiry, students learn how to obtain and make sense of data and to generate their own knowledge and understandings. Decisions about the degree of inquiry to be implemented in a given situation depend on a variety of factors, including:

- student maturity, cognitive development, and experience with inquiry,
- subject matter,
- time constraints, and
- resource availability.

This research suggests that implementation of inquiry in the classroom at all levels (K-16) also depends on the teacher's understanding (or lack of understanding) of scientific inquiry. The model-based, theoretical nature of inquiry proved difficult, and even the science graduate students evinced naïve assumptions about inquiry. Disciplinary background also influenced graduate students' understandings. A required course in philosophy of science might be in order for both future scientists and science teachers.

Ideally, as teachers become more comfortable with authentic inquiry they are more likely to relinquish control of learning to the students. As students develop and gain experience with inquiry, teacher direction decreases and student self-direction increases. The results of this study indicate that working on a collaborative team in an authentic scientific setting can help educators to become more aware of the nature of authentic scientific inquiry and to incorporate inquiry into their lesson plans and learning modules.

# CHAPTER V

# SUMMARY, CONCLUSIONS, AND IMPLICATIONS

## Introduction

Scientific inquiry as a way of investigating and learning lies at the heart of this dissertation. Its purposes are to enhance the understanding of how inquiry is carried out in collaborative teams, how adult learners come to an understanding of inquiry, and how working in collaborative teams can enhance educators' use of inquiry in the classroom. Four research questions drove this study: 1a) How do members of a collaborative team of informed novices with various levels of distributed expertise problematize and solve a complex environmental science issue using web-based information and IT analysis tools? 1b) What are the similarities and differences in the way a collaborative team of scientists with distributed expertise and collaborative teams of informed novices with various levels of distributed expertise problematize and solve complex environmental science issues? 2a) How does working in a collaborative scientific team improve informed novices' understanding of the nature of authentic scientific inquiry? and 2b) How does working in a collaborative scientific team impact their instructional products translating authentic scientific inquiry into classroom experiences?

Inquiry-based education had its beginnings in the educational theories of pragmatist philosopher John Dewey (1859-1952), who, in a 1909 speech before the American Association for the Advancement of Science (AAAS), asserted that science teaching emphasized the accumulation of facts and information and neglected science as a manner of thinking and a method of investigating (National Research Council, 2000). He emphasized the importance of students learning the processes by which science is conducted by scientists rather than just memorizing a body of knowledge. Driven by Sputnik and the space race, development of curriculum materials that involved students in doing science began in the 1950s and 1960s. Today, however, almost a century after Dewey's address to the AAAS, educators are still struggling with incorporating the use of inquiry in the classroom in an authentic manner.

The remainder of this chapter is divided into three sections. The first section presents a summary of the purpose of the study and its methods. Section two recounts the findings and conclusions relating to each of the research questions and discusses the basis for those conclusions. The final section reflects on the implications of this study.

## Summary of the Study

The goals of this study were a) to reach a deeper understanding of how collaborative teams composed of experts and novices with distributed expertise interact to problematize complex problems in the field of environmental science and (b) to determine the effect of working in this collaborative team environment on participants' understandings of the nature of authentic scientific inquiry and their ability to translate these understandings into the science classroom at secondary and college levels. In order to achieve these goals, the study used mixed methods including both qualitative and quantitative data analysis to look at one scientific team – Sustainable Coastal Margins (SCM) – participating in the NSF-funded Information Technology in Science (ITS) program at Texas A&M University. Participants included four scientists/faculty members from diverse departments in the university, seven science graduate students and three science educators who met together half-days for two three-week sessions over a period of two summers. The goal of the SCM-ITS team was to use information technology (IT) to improve understanding of the environmental problems of the Texas Gulf Coast. This setting offered an opportunity to study collaborative problem solving involving distributed expertise in a group of experts and in groups of informed novices during a professional development experience. It also offered a context for observing how this experience affected the novices' perceptions of the nature of scientific inquiry and how they translated these perceptions into their classroom products.

During Summer I, SCM faculty modeled complex problem solving and provided scaffolding for the skills needed to perform this type of problem solving in each of their disciplines: geology/biogeochemistry, agricultural/environmental engineering, civil engineering/hydrology, and environmental/ecosystem planning. Participants worked together in collaborative groups to practice these skills. They also spent one-half of each day working with education research faculty on improving IT skills, exploring NOS concepts, and developing an understanding of inquiry methods. During the three weeks, they used the skills they were learning from science and education research faculty to design an inquiry project to implement in their classrooms during the subsequent academic year.

Summer II began with SCM-ITS participants reporting the results of piloting their implementation projects in their classrooms. Throughout the remainder of the session, they revised and improved the design of these projects for use in an action research study in their classrooms the following year. They spent SCM team time further scaffolding the scientific skills and NOS understandings they gained the previous summer, participating in a field trip to the Texas Gulf Coast, and learning about motivating students and assessment techniques for science teaching. The culminating activity of the session was for interdisciplinary collaborative teams of experts and novices to select environmental issues and develop solutions for them.

Data of various types were collected from a number of sources. Participants completed questionnaires before the program began and kept journals during the first summer session, and both participants and faculty members were interviewed. The researcher took field notes, collected classroom artifacts, and administered surveys. During Summer I, pre- and posttests were given to assess participants' views of the nature of authentic scientific inquiry. Implementation projects were self-evaluated and rated by faculty and peers, and final projects from Summer II were evaluated by a team of outside experts.

## Conclusions

In response to the first research question, "How do members of a collaborative team of informed novices with various levels of distributed expertise problematize and solve a complex environmental science issue using web-based information and IT analysis tools?" a number of conclusions can be drawn from the results of this study. In order to problematize complex environmental issues, each group had to first generate a significant problem for investigation through reflection, brainstorming, and collaboration (Radinsky et al., 1999). Then they had to agree on common conceptual models of the processes involved, collect data, and finally generate a proposed solution. Constant reflection and discussion (metacognition) as well as consideration of financial and cultural factors had to occur throughout the process, and sometimes required groups to reconsider and change their strategies. Familiarity with information technology (IT) tools, including the computer, the Internet with its associated complex databases, and geographic information systems and other software, proved to be essential to the successful completion of the project. Participants found working collaboratively or cooperatively in groups with distributed backgrounds and levels of expertise to be a generally positive experience. Group members learned to consider different points of view and different approaches to solving complex problems. They found that collaboration generally saved time and that having groups with distributed expertise enabled them to learn from each other, especially in regards to software skills. They also learned that it is necessary to actually teach scientific inquiry skills.

The approaches taken by experts to solving complex, ill-structured problems varies somewhat depending on discipline. Scientists from different disciplines have different points of view, use different methodologies, and make different assumptions about facets of the problems. The process of defining the problem was a sticking point for the four scientists/faculty members in this project, who describe their approaches in different ways influenced by their perspectives:

- Reductionist moving to systems standpoint. This natural scientist begins solving a problem by reducing it to its component parts and identifying the individual variables that influence the problem and reaching an understanding about each process involved. He then looks at the processes as a system operating in space and time, interacting and influencing each other.

- Focused, empirically data-driven approach. This applied scientist/civil engineer collects data before defining the problem parameters. He would begin with specific processes in mind (in the case used in this situation, water quality and quantity).
- Practical, environmental engineering design approach. This applied scientist/environmental engineer begins by defining the system being dealt with while looking at the big picture, including the specifics of what needs to be measured and the limitations of the problem. She would then consider the constraints and priorities, including budget.
- Interdisciplinary ecosystem planning approach. This social scientist considers the boundaries of a system as defined by ecological/environmental factors (not human-imposed factors) and then the interaction between natural resources and socioeconomic factors.

Although there are no general rules for solving ill-structured problems, problem solving in different contexts and domains utilizes different skills (Jonassen, 1997). These four scientists seem to fit into one of two problem-solving perspectives. The first two described above are reductionist – they begin by looking at individual components of a problem and understanding the processes involved; then they move toward looking at the system dynamics. The second two take a systems approach from the beginning, first defining the boundaries of the system and then considering its individual components.

The two pairs are also divided along another line – whether or not they consider socioeconomic factors as primary concerns in their problem solving. It is interesting that the two engineers fall on opposite sides; it seems that the division is between enterprises that have environmental/ecological considerations at the forefront and those that do not. Those who do must from the start of the problem-solving process be cognizant of interdisciplinary factors that might affect the outcome.

The role of gender in science began to be studied in the last part of the twentieth century as feminists began to highlight the association of masculine qualities with science (Keller, 1995). Faulkner's (2000) discussion of gender and dualism in engineering reflected on the technical/social distinction that is related to stereotypes of masculine, technology-focused instrumentalism and feminine, people-focused expressiveness. These two are sometimes considered to be mutually exclusive and engineers often see themselves as instrumentalists with few social skills. For example, in an interview the civil engineer asked if I knew the difference between an introverted engineer and an extroverted engineer. When I replied that I didn't, he told me, "An introverted engineer looks at his shoes when he talks to you; an extroverted engineer looks at your shoes when he talks to you." Faulkner concluded that the engineers in her study "tend to gender their *descriptions* of what they do more than they gender their actual *practice*" (p. 784). With a sample of only one female and three males, all of whom trained in different fields, it would be presumptuous to conclude that any observed differences in problem-solving approaches were due to gender.

Successful collaborative problem solving requires building an element of trust, especially in interdisciplinary situations where different perspectives are brought to the table. There seemed to be a resistance to change and to different perspectives at the beginning of the ITS program. As trust grew, however, openness to other approaches and awareness of different perspectives increased.

The second part of the first research question asked, “What are the similarities and differences in the way a collaborative team of scientists with distributed expertise and collaborative teams of informed novices with various levels of distributed expertise problematize and solve complex environmental science issues?” Since there was a large percentage of science graduate students on the SCM team, the informed novices had a great deal of expertise in some areas and several had some previous experience in conducting scientific research. Nevertheless, there were some common threads running through the analysis of the results of the final project for Summer II – to identify an environmental problem and develop a solution to it.

Consideration of the results of the final project reveals more similarities than differences. The three informed novice groups and the expert group all had problems with finding and defining an acceptable problem and then focusing on a testable question. The group that had the best problem development was one of the informed novice groups, but they chose a problem that one of the group members had worked on extensively in his graduate studies. The same group also had the best model and predictions development and in general paid more attention to the systems. Two of the novice groups had problems with collecting relevant data, and the expert group, although they collected a great deal of good data, did not link it well to their research questions.

Probably the most pervasive problem throughout all four groups was a lack of collaboration, which Kneser and Ploetzner (2001) define as mutual engagement of participants to solve a problem together. Two elements are common to most definitions of collaboration: working together toward a mutual goal and knowledge sharing (Bronstein, 2002; Hara et al., 2003). What went on in all four SCM-ITS groups was often more cooperative, with labor divided among the participants, than collaborative, and this seemed to be even more of a factor for the expert group than the novice groups. The experts divided tasks according to expertise and then all four never really communicated as a group again, resulting in a failure to share ideas and findings and to build a cohesive product.

There is little doubt that this sort of behavior impedes the success of many so-called collaborative groups composed of experts. Each expert brings to the table his or her perspective and approach to problem solving, and unless true communication of ideas and points of view takes place on a regular basis, collaboration will not occur. This research supports previous findings that the structure of a successful collaborative group requires effective leadership, purposeful opportunities for communication of ideas and findings, openness among its members to compromise, and a willingness to share responsibility (Bronstein, 2002; Hara et al., 2003).

The Sarewitz (2000) model of the “geologic view” of environmental problem solving provided inspiration for the revised model proposed by the researcher in Chapter

3. The recursive interactions among the variables were observed to occur in the SCM-ITS problem solving experiences, although on a smaller scale and over a shorter period of time. Recognition of the role of metacognition during both the scientific and sociopolitical phases and the cyclical structure of the process is essential to an understanding of what goes on in distributed expert group problem solving. Environmental science research is unique in its inclusion of aspects of many other sciences and the complexity and "messiness" inherent in environmental science are portrayed in the non-linear nature of the model.

The second research question dealt with nature of science (NOS) concerns. The first part of the question asked "How does working in a collaborative scientific team improve informed novices' understanding of the nature of authentic scientific inquiry?" To answer this question, I designed and gave as a pre- and posttest the Nature of Authentic Science Test based on the authentic science processes and epistemologies as described by Chinn and Malhotra (2002). They define authentic scientific inquiry as "the research that scientists actually carry out" (p. 177). Their premise is that classroom inquiry activities usually fail to capture the cognitive processes and epistemologies of authentic inquiry. This test was given at the beginning and end of the first summer session, when there was a concentration of activities related to the nature of science both in the morning and afternoon sessions.

The test was given to the entire ITS cohort and the results of the SCM-ITS participants were compared to those of the entire group for purposed of validation. There was a significant difference (.000) found in the pre- and posttest scores of both groups.

The SCM-ITS group showed a greater pre- to posttest gain (8.75 to 11.00 mean score) than the entire group (8.94 to 10.52 mean score) but this difference was not statistically significant.

It was interesting to note that all three SCM-ITS educators' initial scores were higher than any of the science graduate students' scores. It is possible that educators were more aware of NOS concepts in the beginning because of prior exposure and the specific inclusion of NOS concepts in the Texas Essential Knowledge and Skills (TEKS). Posttest scores improved for seven of the eight SCM-ITS participants; the one participant whose score decreased (by one correct answer) was an educator. Two of the graduate students' scores improved by five correct answers. NOS concepts were addressed explicitly in the education portion of the ITS experience that first summer and the four SCM-ITS scientists were aware of the push toward teaching NOS concepts and tried to address them explicitly whenever possible. This supports the assertion that NOS concepts must be taught explicitly (Abd-El-Khalick & Lederman, 2000), since one would expect the science graduate students who were somewhat experienced in scientific research to have scored at least as high as the educators on the pretest if NOS concepts could be easily learned by experiencing authentic scientific research.

On the Nature of Authentic Science test, the eleven questions dealing with cognitive process showed mixed results from pre- to posttest. Five questions were missed fewer times on the posttest than on the pretest, two were missed more times on the posttest, and four showed no change from pre- to posttest. The question about scientists generating their own research questions was not missed on the pretest but missed by two of the science graduate students on the posttest, perhaps due to an increasing awareness of the influence of funding issues on research topics.

The four questions concerning study design showed improvement, including questions dealing with selecting variables, planning methodologies and using models, but no change was seen on the question dealing with controlling variables. The "correct" answer to the variables question was different than the answer given by Chinn and Malhotra (2002). The SCM-ITS scientists often use forms of inquiry that are more descriptive than experimental; thus no control is used. The SCM-ITS participants had read the Chinn and Malhotra article during the session, and even though they received experience in a discipline where controls are rarely, used, the differences in the types of inquiry used by scientists were not apparent to them.

The topic of observer bias was addressed in a question that was missed only once on the pretest and three times on the posttest. Every time it was missed, however, the written explanation of the answer given indicated that the participant was aware of the problem with observer bias. It is possible that the wording of the question or answer choices led to misunderstandings.

The cognitive process of explaining results was focused on by two questions. They both concerned transformation of observations and finding experimental flaws, and were missed the same number of times on the pre- and posttests (twice and once, respectively).

In the "Developing theories" portion, the question that caused the most trouble referred to scientists constructing theories postulating mechanisms with unobservable entities and was missed five times on both the pre- and posttests. This is a very abstract concept, and the misconceptions are apparently very persistent. Misunderstandings of the nature of theories, laws, and hypotheses as well as the idea of one inductive, atheoretical “scientific method” are pervasive myths or misconceptions concerning the nature of science (McComas, 1998; Windschitl, 2004). The usual type of inquiry experiences practiced in school science simply serve to demonstrate easily observable regularities and do not encourage students to develop theories to explain underlying mechanisms (Chinn & Malhotra, 2002). Windschitl describes the oversimplified, rigid way of doing science as “folk theory” and points out that it fails to portray science as a way of thinking and knowing the world. To aid preservice teachers in reaching a theoretically grounded understanding of inquiry, he advocates using inquiry experiences that are based on theoretical models in methods courses and including class discussions that “make explicit the tenets of model-based inquiry that remain invisible in the protocol of the traditional scientific method” (p. 508).

Awareness that scientists coordinate results from multiple studies increases from one test to the next (missed three times and one time respectively).The fact that scientists study other scientists’ research for several purposes was very clear to the participants. Only one missed it on the pretest, and everyone got it correct on the posttest. Written answers showed an appreciation for the role of peer review in the inquiry process and for keeping current with other scientists’ research.

Four questions were related to Chinn and Malhotra’s Dimensions of Epistemology; answers to these questions were also influenced by the widely-held idea of a single “scientific method.” The first concerned the purpose of research, which states that scientists aim to build theoretical models with unobservable mechanisms. This question was missed five times on the pretest and four times on the posttest. Again, this is a rather abstract concept closely related to the theory-building question discussed above and misconceptions were persistent. This result was probably to be expected, based on the findings of previous research (McComas, 1998; Windschitl, 2004). The second question pertained to theory-data coordination and the coordination of theoretical models with multiple sets of complex, sometimes partially conflicting, data. This question, missed four times on the pretest and twice on the posttest, was clarified, at least for some participants, by the activities of the SCM-ITS group. They became aware of the complexity of data sets used by environmental scientists and the inevitable conflicts that arise. The third epistemology question related to how scientists deal with anomalous data by discounting it or changing their theories. This question was missed seven times on the pretest and four times on the posttest; again some misconceptions seemed to persist despite instruction and experiences. During Summer I, students were not involved in gathering their own data, but were given data sets by the scientists and possibly never had anomalous data to be discounted. One of the nature of science tenets that is often misunderstood is the tentativeness of science; many people feel that scientific knowledge is absolute and never changes (McComas, 1998). Research has shown, however, that explicit nature of science (NOS) instruction combined with authentic research experiences and reflection enables participants to move from naïve views of NOS to more enhanced understandings (Schwartz et al., 2004). The fourth question on this topic dealt with the "Social construction of knowledge," and applied equally well to the Cognitive Process section relating to types of reasoning employed by scientists in explaining results since both stated that scientists employ argument forms as a method of authentic inquiry. This question was missed three times on the pretest and once on the posttest. All who missed it were science graduate students, and they took the position that scientists use simple deductive reasoning instead of multiple argument forms. Again, the influence of the concept of a single scientific method is evident.

Chinn and Malhotra (2002) categorize most of the hands-on research activities used in schools as simple experiments, simple observations, and simple illustrations. They argue that these classroom inquiry tasks do not reflect the essential characteristics of authentic scientific inquiry. In a footnote to his discussion of folk theories of inquiry, Windschitl (2004) explains:

> Around the middle of the 20$^{th}$ century, the Scientific Method was offered as a template for teachers to emulate for the activity of scientists (National Society for the Study of Education, 1947). It was composed of anywhere from five to seven steps (e.g., making observations, defining the problem, constructing hypotheses, experimenting, compiling results, drawing conclusions). Despite criticism beginning as early as the 1960s, this oversimplified view of science has proven disconcertingly durable and continues to be used in classroom [sic] today (DeBoer, 1991), thus dismissing the complex, creative, and imaginative nature of the scientific endeavor (Abd-El-Khalick & BouJaoude, 1997; Lederman, 1992). (p. 509)

Since graduate students are products of schools – and even college classes – that often at best use naïve classroom inquiry for teaching science and our teachers rarely have authentic scientific research experience, it is not surprising that there would be misconceptions about the cognitive processes and epistemologies of authentic inquiry. The experiences of doing environmental science in an authentic manner in the SCM-ITS group and of reading and receiving instruction about authentic science resulted in a statistically significant change in the participants' understanding of authentic inquiry as shown by the improvement in scores on the Nature of Authentic Science test. At the end of Summer II participants had the opportunity to practice authentic science, albeit in a very limited time frame, as they solved real-life environmental problems affecting the local area.

The final research question was "How does working in a collaborative scientific team impact their instructional products translating authentic scientific inquiry into classroom experiences?" Participants designed inquiry modules using the information they learned in ITS and piloted them in their classrooms. They reported on their modules and the implementation at the beginning of Summer II, and the level of inquiry used in the modules was rated by the individual, the faculty, and by the other students. The rubric used was based on a modification of Bonstetter's (1998) inquiry levels. The level descriptors and scores were:

- Traditional hands-on/simple illustrations (1),
- Structured inquiry (2),
- Guided inquiry (3),

- Student directed inquiry (4), and
- Authentic classroom inquiry (5).

There was a variation in the levels of inquiry incorporated in the modules. Most scores fell into the area of guided inquiry. At this level of inquiry, the teacher chooses the topic, question, and selects and provides the materials used. The student and teacher both have input into the design and procedures used, and the student is responsible for collecting and analyzing data and drawing conclusions from the results. The design of the inquiry modules reflects Chinn and Malhotra's (2002) description of inquiry and the difficulties of designing authentic classroom inquiry.

> Authentic scientific inquiry is a complex activity, employing expensive equipment, elaborate procedures and theories, highly specialized expertise, and advanced techniques for data analysis and modeling (Dunbar, 1995(Kevin Dunbar, 1995); Galison, 1997; Giere, 1988). Schools lack the time and resources to reproduce such research tasks. Instead, educators must necessarily develop simpler tasks that can be carried out within the limitations of space, time, money, and expertise that exist in the classroom. The goal is to develop relatively simple *school inquiry tasks* that, despite their simplicity, capture core components of scientific reasoning. (p. 177)

Even at the university level, it is not easy to incorporate authentic inquiry into the classrooms, especially for graduate students who are working within someone else's classroom. Class size, limited computer access, equipment availability, and time constraints affect the teaching of science in an authentic manner at all levels. Most inquiry activities found in textbooks reflect few or none of the cognitive processes from authentic science and, as a result, these tasks espouse an epistemology in conflict with that of science as practiced by scientists (Chinn & Malhotra, 2002). Due to this, until a person works as a research scientist, many of the features of authentic science remain obscure. The need to develop classroom science activities that incorporate authentic cognitive processes and epistemologies becomes imperative in order for our students to begin to understand authentic science. The SCM-ITS experience was a step in the right direction for its participants.

There were several limitations to this research. It was conceived as a study of one segment of the ITS program and therefore all components had to be prepared at the beginning of the first summer session of Cohort II. As a result, time to prepare was limited. Due to operator errors, the discussions of problem solving by faculty and participants on the first day were not recorded for later analysis. Ideally, the Nature of Authentic Science test should have been given again at the end of Summer II. Interview questions and guiding questions for the journals could have been more helpful if they had been less generic. Several of the group who were graduate students in science or education were not required to complete their inquiry projects because they served as mentors for others in Summer II and this limited the sample size, but the rich data collected from those remaining offered important insights into how inquiry is implemented in classrooms.

## Implications

The Sustainable Coastal Margins scientific team met the goals of ITS through its activities. The interaction between the faculty scientists, science graduate students, and science educators was stimulating and productive. Team members profited from the distributed expertise within the group; the educators learned about the discipline and the scientists learned about teaching and learning. The benefits to both groups can have far-reaching impacts on secondary and post-secondary learners. Research projects by SCM team members that were outgrowths of ITS include a study of laboratory experiments in an introductory geology course and a study of simulation experiments in an undergraduate agricultural engineering class. These projects have added to the knowledge base on learning and teaching science.

Learning science doesn't have to be restricted to textbooks – if teachers learn to use technology to do science collaboratively themselves and then use that knowledge to support inquiry learning, they can transform their teaching to include those components. According to Bybee (2000), "To implement inquiry in the classroom, we see three crucial ingredients: (1) teachers must understand precisely what scientific inquiry is; (2) they must have sufficient understanding of the structure of the discipline itself; and (3) they must become skilled in inquiry teaching techniques" (p. 30). The SCM-ITS experience gave participants the opportunity to understand one mode of scientific inquiry by having them experience it firsthand through using complex databases to solve environmental problems. Faculty members helped them reach an understanding of the structure, techniques and methodologies of the discipline of environmental science. It also gave them the opportunity to design and practice inquiry teaching techniques and to receive feedback on their efforts. The ITS program was able to accomplish its goals of producing education specialists and disseminating quality professional development experiences.

Science education activities that are currently available could be easily modified to include more of the components of authentic inquiry. For example, asking questions that encourage reflection and metacognition within an activity would increase its authenticity. Preservice teacher training should include experience in authentic scientific inquiry as well as instruction in how to increase the authenticity of classroom science activities. Professional development for experienced teachers should also include opportunities for them to participate in authentic scientific inquiry with scientists through programs like ITS.

For true interdisciplinary collaboration to be successful there needs to be a willingness to participate in the activity and trust among the collaborators. There is a need for more research to aid in understanding the differences in problem solving approaches among the various scientific disciplines and the effect of these differences on collaborative activities. Further research is needed to determine if the model of “contested collaboration” described by Sonnenwald (1995) as occurring among information system designers is applicable to the type of group interaction and interdisciplinary collaboration that occurs among scientists working on environmental issues. The effects of gender differences on the interactions between collaborative group members, whether gender influences problem-solving strategies employed by scientists and engineers and whether single-sex groups interact differently than mixed groups are other areas needing study. Another avenue of research would to compare how distributed groups of environmental scientists build models in solving problems to the findings of Dunbar's (1999) research on how groups of molecular biologists and immunologists collaborate and use distributed reasoning in model building.

SCM-ITS offered an excellent context for study of the effects and processes of distributed interdisciplinary collaboration in solving environmental problems. Despite the presence of various roadblocks resulting in more cooperation than true collaboration in some of the groups, primary benefits of interdisciplinary collaboration observed in this setting include the synergy that occurred among participants, creativity brought to the projects, networking opportunities, and shared work load. Exposure of the SCM-ITS faculty, science graduate students and educators to the practice of inquiry in a collaborative setting was a growth opportunity for some that could lead to better research and teaching in the future. Inquiry science necessitates discussion, working collaboratively with others and sharing ideas, all of which are important skills to learn. Participating in dialogue and gathering and sharing information in a social setting is also a powerful means toward problem solving and building individual conceptual understanding (Kluger-Bell, 1999). Both experts and novices who have experienced and are comfortable in a collaborative setting are more likely to use those techniques in their own work and/or classrooms.

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# APPENDIX A

# AUTHENTIC SCIENCE PRE- AND POSTTEST

## Nature of Authentic Science

Please select the one answer from each group below that you feel is ***most reflective*** of how authentic science is practiced. Then explain below why you chose that answer, giving examples or elaborating if you can.

1. Scientists reason by employing:
   a. simple deductive reasoning.
   b. simple inductive reasoning.
   *c. multiple acceptable argument forms.
   d. simple contrastive argument forms.

Explain your answer and provide example if possible:

2. The level of theory development usually results in scientists:
   a. uncovering empirical regularities, not theoretical mechanisms.
   *b. constructing theories postulating mechanisms with unobservable entities.
   c. uncovering empirical irregularities, not theoretical mechanisms.
   d. doing experiments that illustrate theoretical mechanisms but do not investigate theories.

Explain your answer and provide example if possible:

3. In developing theories, scientists usually:
   a. do only a single experiment at a time.
   b. make only a certain range of observations at one time.
   c. do only a single demonstration of scientific principle at a time.
   *d. coordinate results from multiple studies.

Explain your answer and provide example if possible:

4. When making observations, scientists
   *a. employ elaborate techniques to guard against observer bias.
   b. do not have to guard against observer bias since it never enters into scientific work.
   c. do not need to explicitly address observer bias, since it is rarely a problem in scientific investigations.
   d. are concerned with possible effects of observer bias only in certain unusual situations.

Explain your answer and provide example if possible:

5. In explaining results, scientists:
   a. rarely have to consider flaws in experiments because they are seldom salient (important).
   *b. constantly question whether results are correct or artifacts of experimental flaws.
   c. assume they did the experiment incorrectly if they do not obtain the expected outcome.
   d. typically consider flaws to be important only if human subjects are involved.

Explain your answer and provide example if possible:

6. The best description of theory-data coordination is that scientists:
   *a. coordinate theoretical models with multiple sets of complex, partially conflicting data.
   b. record and use only what they can see and measure quantitatively.
   c. coordinate one set of observable results with conclusions about those observable results.
   d. do not attempt to use theory-data coordination if there are any conflicts in data.

Explain your answer and provide example if possible:

7. The best description of the purpose of research is that scientists aim to:
   a. understand a pre-existing theory or model.
   b. observe structures of objects or models.
   c. uncover simple surface-level regularities.
   *d. build and revise theoretical models with unobservable mechanisms.

Explain your answer and provide example if possible:

8. In responding to anomalous data, scientists:
   *a. may regularly and rationally discount anomalous data or change their theory.
   b. never discount anomalous data; all data are equally important in judging a theory.
   c. always reject data as erroneous if results contradict the expectations.
   d. typically start an experiment over because the anomalous data aren't reliable.

Explain your answer and provide example if possible:

9. In explaining results, scientific observations are:
   a. occasionally transformed into other data formats such as straightforward graphs.
   b. never transformed without substantial alteration.
   c. seldom transformed into other data formats except perhaps drawings.
   *d. often repeatedly transformed into other data formats.

Explain your answer and provide example if possible:

10. In designing studies, scientists:
   a. investigate only one variable at a time.
   *b. may select and even invent variables to investigate, since there are many possible variables.
   c. investigate only, at the most, two variables at a time.
   d. may select but never invent variables to test.

Explain your answer and provide example if possible:

11. In the design of scientific studies,
   a. control of variables is never an issue in experiments.
   b. there is always a single, simple control group in experiments.
   *c. scientists often employ multiple controls, but in some disciplines, controls are rarely, if ever, used.
   d. control of variables is always an issue in experiments, no matter the discipline.

Explain your answer and provide example if possible:

12. In designing studies, scientists:
   a. almost always follow traditional, proven methods in order to answer questions.
   *b. often invent complex procedures to address questions of interest.
   c. rarely invent complex procedures to address questions of interest.
   d. first use traditional, proven methods followed by invented complex procedures.

Explain your answer and provide example if possible:

13. In designing studies,
  *a. scientists often devise analog models or model systems to address a research question.
  b. analog models are sometimes used in solving a problem, but scientists do not consider the appropriateness of the analogy.
  c. analog models are rarely used by scientists in solving a problem.
  d. analog models are always used by scientists in solving a problem.

Explain your answer and provide example if possible:

14. In generating research questions, scientists
  a. almost always rely on questions provided by their funding agencies.
  b. almost always use questions provided by the universities or companies that employ them.
  *c. generate their own questions, sometimes in collaboration with other scientists.
  d. always generate their own questions individually in order to prevent competition.

Explain your answer and provide example if possible:

15. Scientists:
  a. should not read others' research reports in order to prevent bias in their own work.
  b. study other scientists' research reports in order to critique their work.
  c. are not interested in other scientists' research reports.
  *d. regularly study other scientists' research reports for several reasons.

Explain your answer and provide example if possible:

* Indicates answer from the article cited below.
Previous questions based on the work of:

Chinn, C. A. and B. A. Malhotra. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. Science Education 86(2), 175-218.

# APPENDIX B

## ITS COHORT II

## SUSTAINABLE COASTAL MARGINS SCIENTIFIC TEAM SCHEDULE

### Summer I

*Mornings*

| | |
|---|---|
| Day 1 | Introduction, Problem solving discussion, Pretest |
| Day 2-3 | Introduction to concepts & terms, Landscapes, GIS, Laboratory field trip |
| Days 4-6 | Hydrology, transport, runoff, Watershed & soil models in GIS |
| Days7-9 | NPS pollution, erosion, Digital assignments (mass loading estimations, PowerPoint® animation) |
| Days10-12 | Environmental policy, Socioeconomics & Demographics, Role play |
| Day 13 | Work on implementation projects w/ scientists' help, Individual interviews of participants |
| Days 14-15 | Presentations of plans for inquiry implementation projects |

*Afternoons*

Instruction on nature of scientific inquiry

Preparation of inquiry implementation project

**Summer II**

*Mornings*

| | |
|---|---|
| Day 1 | Preparation of report on inquiry implementation projects |
| Day 2-3 | Presentation of report on inquiry implementation projects |
| Day 4 | Modules on GIS applications, assessment in science teaching |
| Day 5 | Tutorial/scaffolding development project |
| Day 6 | Students received GPS units, learned to use them |
| Day 7 | Scientists discuss scientific inquiry from each of their points of view; assignment: to incorporate nature of scientific inquiry (as practiced by environmental scientists) concepts into implementation projects |
| Day 8 to | Presentation on motivation, case study, assignment: use motivation theory improve implementation projects |
| Day 9 | Field trip to Matagorda Bay |
| Day 10 | Presentation on spatial analysis for social scientists, assignment: spatial analysis inquiry questions |
| Day 11 | Presentation on remote sensing, practiced downloading data |
| Day 12 | Individual work on scaffolding projects |
| Days 13-14 | Preparation of final digital inquiry project in teams: Identify and answer a question related to sustainable development in Brazos County |
| Day 15 | Teams present final projects |

*Afternoons*

Instruction on action research

Individuals design action research project to use with implementation of inquiry project

# VITA


| | |
|---|---|
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