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Design, Development, and Formative Evaluation of a Geographic Information System-supported Science Web-based Inquiry Module

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DESIGN, DEVELOPMENT, AND FORMATIVE EVALUATION OF A GEOGRAPHIC INFORMATION SYSTEM-SUPPORTED SCIENCE WEB-BASED INQUIRY MODULE

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Dedication

To mom and dad.

Thank you for instilling in me the value of education and hard work.

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ABSTRACT

This study examined how a Web-based module might enhance science inquiry supported by GIS with eighth-grade students. Collaborating with different subject matter experts, we designed a GIS-supported inquiry unit on *Energy* and implemented it in the actual classroom. The study investigated the teacher's fidelity to the design, the strengths and weaknesses of the design, and the students' science content knowledge and attitudes toward science and technology outcomes as a result of the implementation.

Participants included one female science teacher and 108 eighth-grade students from all five of her classes. Data were collected through (1) daily classroom observations; (2) daily reflective meetings with the teacher, and occasionally, the project director; (3) daily researcher journal; (4) students' attitudes toward science and technology pre- and posttests; and (5) content knowledge pre- and posttests.

While the teacher's fidelity to the design was relatively high, she omitted some crucial components of the design pertinent to inquiry. Based on the implementation, the teacher identified the strengths and weaknesses of the design as well as some aspects of the design that needed to be improved. Students' achievement on the science content knowledge assessment increased significantly while their attitudes toward science and technology outcome decreased significantly after the implementation of the unit. Implications for designers and developers who seek to design and implement newer curricular approaches are discussed.

CHAPTER 1: INTRODUCTION TO THE PROBLEM

Science Inquiry

Following the release of *A Nation at Risk* by the National Commission on Excellence in Education (NCEE, 1983), policy makers took up the report's challenge to reverse the "rising tide of mediocrity" that was eroding American education. Numerous educational reform efforts have been proposed by educators with the aim of improving student academic achievement. In science education, calls for restructuring the way students learn in science recommend students be actively engaged in inquiries. Teaching and learning science by inquiry is the central tenet of the *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) and the *National Science Education Standards* (National Research Council [NRC], 1996). The latter states,

> 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 of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)

Swartz (1996) noted that by engaging in inquiry, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills. The Standards (NRC, 1996) also note that inquiry is an active learning process—"something that students do, not something that is done to them" (p. 2). More specifically,

> Students … should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments. (p. 105)

The National Research Council (2007) asserted that current science education tends to overemphasize experimental methods as opposed to presenting science as a process of building theories and models, checking them for internal consistency and coherence, and testing them empirically. Focusing on experimental methods "may exacerbate the difficulties children have with understanding how scientific knowledge is constructed" (p. 182). Inquiry-based teaching and learning is, however, based on the constructivism theory of learning in which knowledge must be individually constructed by the learner and the teacher's role is to facilitate the learning process (Tobin & Tippins, 1993). According to Resnick (1989), constructivism encompasses three interrelated aspects of learning: (1) learning is a process of knowledge construction, not of knowledge recording or absorption; (2) learning is knowledge-dependent; that is, people use current knowledge to construct new knowledge; and (3) learning is highly tuned to the situation in which it takes place. Gil-Pérez et al. (2002) noted that constructivism in science education involves active participation of students in the construction of knowledge and not the simple personal reconstruction of previously elaborated knowledge provided by the teacher or by the textbook. In fact, the National Research Council (2000) asserted that traditional textbooks are not conducive to inquiry-based teaching and learning.

According to Sorenson, Buckmaster, Francis, and Knauf (1996), inquiry helps students develop their own strategies in order to seek out information and solve problems. Haury (1993) contended that inquiry-based teaching and learning strategies promote critical thinking skills, enhance student performance and foster scientific literacy (see also Chiappetta, 1997; Deming & Cracolice, 2004). Windschitl (2000) agreed and asserted that inquiry invokes the intellectual skills of deduction, problem solving, critical thinking, and creative thinking. Further, inquiry guides young learners and scientists to a more complete and coherent understanding of the natural world.

Supporting Science Inquiry with Technology

The *National Educational Technology Standards for Students* called for a classroom that is student-centered, with collaborative work in a multisensory, multimedia-based information exchange, where active inquiry-based learning and critical thinking are fundamental (International Society for Technology in Education [ISTE], 2000). A central component of science inquiry is the appropriate use of technology to support learning goals (AAAS, 1993; Bransford, Brown, & Cocking, 2000; NRC, 1996; 2000). Parks (1997) asserted that learning tools such as computers improve the quality of student thinking and learning. Further, computers offer access to an array of information resources, promote interactivity between people, and allow users to manipulate images and information. Simons and Clark (2004) noted that many researchers have suggested Web-based science inquiry environments can sustain meaningful science inquiry activities and ensure effective teaching and learning. Bodzin (2005) agreed and contended that learning science in today's classroom does not have to be restricted to text-based curricular resources. Web sites present learners with a wide range of science activities in various formats ranging from text-only information to providing authentic, real-time data sets and simulations.

A newer technology that may hold promise in supporting science inquiry in the classroom is Geographic Information Systems (GIS). Baker and Case (2000) noted that the use of a GIS is emerging as an educational technology for developing contextually rich student learning. Bransford et al. (2000) agreed and posited that newer interactive technologies like GIS have the capability to create an environment in which students learn science by doing.

Geographic Information Systems

The Environmental Systems Research Institute (ESRI) defined a GIS as “an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information” (ESRI, 1993, p. 2). A GIS contains maps and associated information in digital form and each category of information is called a “theme” or “layer” (Fazio & Keranen, 1995). Akerson and Dickinson (2003) asserted that educational applications of a GIS are gaining attention and promise to affect classrooms. Students can use a GIS program to simulate real-life situations and to draw on skills that are crucial to developing higher-level thinking and problem solving (Ramirez, 1995). Bull and Mason (1998) agreed and noted that the application of a GIS to authentic learning experiences requires students to research more thoroughly and think more creatively, analytically, and synergistically.

According to Alibrandi (2002), GIS technology enables students to perform research and draw conclusions that can provide authentic benefits to the community while helping students meet educational standards. When using a GIS students have the ability and opportunity to personally apply knowledge using higher-order skills such as problem-solving and synthesis (Sanders, Kajs, & Crawford, 2002). Kerski (2008) noted that use of GIS in education is increasingly viewed as active learning that engages students in critical thinking. According to Holzberg (2006), a GIS encourages students to think and work like real scientists. By manipulating the layers of information contained in a GIS, students can explore complex relationships in meaningful scientific inquiry (Lucking & Christmann, 2003). Thus, a GIS can extend the ability for students to do scientific inquiry as called for by the science education reform efforts. There is, however, a paucity of research on implementing GIS in science classrooms.

Declining Science Achievement in Middle School

The most recent national and international science assessments indicated American students do well at the fourth grade level and scores become lower at higher grade levels. The National Assessment of Educational Progress (NAEP) conducted in 2005 revealed that the average science scores for fourth-grade students was 151 points, eighth-grade students was 149 points, and twelfth-grade students was 147 points (Grigg, Lauko, & Brockway, 2006). On the international scene, the Trends in International Mathematics and Science Study (TIMMS) conducted in 2003 revealed that the average science scores for U.S. fourth-grade students was 536 points and eighth-grade students was 527 points (Gonzales et al., 2004). Further, the performance of U.S. 15-year olds, as measured by the Program for International Student Assessment (PISA) was lower than the average performance for most Organization for Economic Cooperation and Development (OECD) countries. The U.S. performed below the OECD average of 500 points, with a score of 489 points (OECD, 2007). In addition, large achievement gaps between White and minority U.S. students are strong and persistent. Given those achievement results, it appears student science achievement starts declining in middle school.

The Promise of GIS to Promote Environmental Education in Middle School

Bodzin and Anastasio (2006) noted that Web-based inquiry educational modules using GIS maps are ideal for earth and environmental systems education. The field of environmental education is experiencing a period of rapid growth partly because of increasingly more pervasive and global environmental issues, changing societal expectations, and education reform (Hart, 2007). According to Braus and Wood (1994), the aim of environmental education is to develop a world population that is aware of and concerned about the total environment and its associated problems; and which has the knowledge, attitudes, skills, motivation, and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones. Further, environmental education stresses the following five objectives:

1. Awareness – to help students acquire an awareness and sensitivity to the total environment and its problems.
2. Knowledge – to help students acquire a basic understanding of how the environment functions, how people interact with the environment, and how issues and problems with the environment arise and how they can be resolved.
3. Attitudes – to help students acquire a set of values and feelings of concern for the environment and the motivation and commitment to participate in environmental maintenance and improvement.

4. Skills – to help students acquire skills needed to identify and investigate environmental problems and to contribute to the resolution of these problems.
5. Participation – to help students acquire experience in using their acquired knowledge and skills in taking thoughtful, positive actions toward the resolution of environmental issues and problems.

The North American Association for Environmental Education's (NAAEE, 2004) *Guidelines for Learning (pre k-12)* set appropriate expectations for learner performance and achievement at the end of fourth, eighth, and 12th grades. The guidelines for middle school state that in the fifth through eighth grades, learners begin to develop skills in abstract thinking and continue to develop creative thinking skills along with the ability to understand the interplay of environmental and human social systems in greater depth. The NAAEE noted that environmental education can foster that development by focusing on investigation of local environmental systems, problems, and issues. Alibrandi (2002) asserted that providing real learning opportunities in which student research becomes essential to viable, sustainable communities is one of the most important benefits of including GIS among the instructional technologies offered in schools. A GIS is a key feature in some environmental education programs because it is perceived as an ideal tool to create a learning environment in which students can learn by doing (Bednarz, 2004).

Statement of Purpose

Given the paucity of research on implementing geographic information systems in science classrooms and the promising nature of GIS to foster science inquiry, the purpose of this study was to determine how a Web-based module might best be developed to enhance science inquiry supported by GIS with eighth-grade students. This study investigated not only the prototype so developed, but also the implementation of such a module in the actual classroom. Student learning as a result of the implementation of the module was also assessed. To accomplish this, this study employed design-based research methodology. According to Richey, Klein, and Nelson (2004), design-based research methodology combines a formative evaluation of a design and an analysis of the implementation process in naturalistic learning settings (see also Reigeluth & Frick, 1999). This methodology is commonly used in formative evaluation of software where the designer iteratively improves the product until it is successful in terms of appeal and effectiveness (Hawkins & Kurland, 1987). The goal of the iterations is to simultaneously understand how an innovation works while also improving the innovation's design. Instead of rigidly controlling the treatments and observing differences in the outcome, design-based research aims at a particular outcome and observes the process by which the goal is achieved (Newman, 1990). The process is documented to show what path was taken to achieve the goal, what problems were encountered, and how they were handled. The researcher and the teacher collaborate on both the design and analysis of the learning materials and instruction.

Sandoval (2004) wrote that design-based researchers use conjectures (rather than formal hypotheses) about learning within educational designs (design of interventions, including designed technologies and curricular materials). Conjectures are embodied in multiple aspects of the learning design; they predict outcomes and interactions with their contexts of use. This study tested and revised conjectures as informed by ongoing analysis of both the students' learning and the learning environment. According to Joseph (2004), design-based researchers focus on questions that impact the design and questions that address the conjectures embedded in those designs. Further, since design-based research is centered around the evolution of the designed artifact, new questions arise during the implementation of the research study. This study sought to answer five questions.

Research Questions

1. How faithfully was the teacher able to implement the design and what factors account for loss of fidelity?
2. What are the strengths and weaknesses of the design?
3. What improvements should be made to the design?
4. How does a GIS-supported learning unit affect students' attitudes toward science and technology?
5. Does a GIS-supported learning unit affect student science achievement?

Significance of This Study

According to Wanner and Kerski (2000) an increasing number of educators consider GIS to be one of the most promising means for implementing educational reform. Baker and Case (2000) posited that the use of GIS is emerging as an educational technology for developing contextually rich student learning. They contended, however, that there are few empirical studies of using GIS within K-12. Hall-Wallace and McAuliffe (2002) agreed that learning with GIS has great potential for improving students' skills in problem solving, analysis, and spatial visualization. They further noted that little is known about how well GIS-based learning lives up to this potential. Despite the conjecture that GIS can extend scientific inquiry, there is a significant gap in the literature on research about using GIS in the science classroom. If the speculation that

GIS can extend scientific inquiry is to become a reality, educators need evidence of the utility of GIS derived from the science inquiry classroom. Data on how GIS can be used to foster Web-based scientific inquiry is a significant obligation this study attempted to fulfill.

There is little guidance for educators who might have an interest in integrating GIS in their science inquiry classrooms. Audet and Abegg (1996) concluded that “the knowledge base about GIS and education must be expanded, so that a research-supported theory of GIS practiced within school settings can be formulated” (p. 42). Wanner and Kerski (2000) agreed and noted that concrete evidence of the effectiveness of GIS is lacking, and research is needed to move the educational community to an understanding of whether GIS tools can lead to a more effective use of spatial technology to enhance critical thinking skills. Thus, an in-depth investigation of science inquiry classrooms in which GIS is implemented can reveal its effectiveness and the pragmatic issues involved in its implementation. Providing further understanding of the insights regarding how GIS could be implemented in the science inquiry classroom might be useful to other educators.

There is a paucity of research on whether or not GIS has a positive effect on student achievement in science inquiry classrooms. The use of GIS in fostering scientific inquiry proved effective in improving student achievement in this study, thus, educators have an additional technology tool that can be used to support science Web-based inquiry.

CHAPTER 2: REVIEW OF THE LITERATURE

The Weakness of Present Science Instruction

In its 1983 report, *A Nation at Risk: The Imperative for Educational Reform*, the National Commission on Excellence in Education (NCEE, 1983) encouraged educators to improve students' academic achievement. The report warned about the lack of higher-order intellectual skills among students and argued that students need to possess levels of skills, literacy, and training essential to the new era. Educators have emphasized that learning activities should help students become more proficient in higher-order intellectual skills, including solving complex problems that require analyzing, organizing, and synthesizing information, and communicating effectively both orally and in writing (Henke, Chen, & Goldman, 1999; Marshall & Tucker, 1992; Murnane & Levy, 1996). Bransford, Sherwood, Hasselbring, Kinzer, and Williams (1990) argued the basic problem is traditional instruction (for example, textbooks, teacher lectures, and workbook exercises) does not produce transfer to new problem-solving situations.

Studies in science education reveal, however, that teachers depend heavily on textbooks in shaping their science curricula and instructional choices (Driscoll, Moallem, Dick, & Kirby, 1994; Kesidou & Roseman, 2002; Mitman, Mergendoller, & St. Claire, 1987; Weiss, Banilower, McMahon, & Smith, 2001; Yore, 1991). Tobin, Tippins, and Gallard (1994) noted that, in traditional hands-on science activities, students are told what materials to use and what procedures to follow to generate a solution to the question (see also Brown & Melear, 2006 and Llewellyn, 2005). The purpose of such "cookbook-type" laboratories is to verify the information presented is correct. In fact, the American Association for the Advancement of Science (AAAS, 1989) indicted textbooks, saying,

> The present science textbooks and methods of instruction … emphasize learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understandings in context, recitation over argument, reading in lieu of doing. (p. 14)

Raths, Jonas, Rothstein, and Wasserman (1967) argued that following the plan of the textbook is likely to rob students of problem-solving and critical thinking skills. Bransford and Vye (1989) agreed and contended, “many traditional approaches to instruction do not help students make the transition from ‘knowing that’ something is true to ‘knowing how’ to think, learn, and solve problems” (p. 193).

Critical Thinking

Critical thinking has been defined in many ways by many educators. According to Facione (1990), critical thinking is “the process of purposeful, self-regulatory judgment that results in interpretation, analysis, evaluation, and inference. It is the cognitive engine that drives problem-solving and decision making” (p. 5). Ennis (1987) defined critical thinking as “a practical reflective activity that has reasonable belief or action as its goal” (p. 10), while Paul (1995) defined critical thinking as:

1. Disciplined, self-directed thinking which exemplifies the perfections of thinking appropriate to a particular mode or domain of thinking.
2. Thinking that displays mastery of intellectual skills and abilities.
3. The art of thinking about your thinking while you are thinking in order to make your thinking better: more clear, more accurate, or more defensible. (p. 526)

Nickerson (1989) asserted that many educators agree we must help students learn to solve problems and think independently, creatively, and effectively (see also Bransford, Goldman, & Vye, 1991; Chipman & Segal, 1985; Resnick, 1987; Resnick & Klopfer, 1989). According to Raths et al. (1967), critical thinking is important for four main reasons,

- It gives meaning to the learning process and causes students to be active rather than passive learners.
- Learners are prepared for a higher level of study.
- Students are better prepared to enter the work environment; they understand problem-solving and decision making based on sound judgment.
- It develops good citizens because it promotes analytical thought when hearing issues.

The idea that students can think and analyze at a *higher* level stems from the cognitive domain of Bloom's taxonomy of educational objectives (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956). The cognitive domain includes educational objectives that deal with the recall or recognition of knowledge and the development of intellectual abilities and skills. The cognitive domain contains six major classes arranged in a hierarchy; that is, each classification within it demands the skills and abilities that are lower in the classification order. The taxonomy was organized from simple to complex classes of behavior, with the three upper classes addressing objectives that involve critical thinking and problem solving (Anderson et al., 2001). Those classes include,

1. Knowledge – this includes those behaviors which emphasize the remembering, either recognition or recall, of ideas, materials, or phenomena. The student is

expected to store in his or her mind certain information, and the behavior expected later is the remembering of this information.

2. Comprehension – this includes those behaviors which represent an understanding of the literal message contained in a communication. When students are confronted with a communication, they are expected to know what is being communicated and to be able to make some use of the material or ideas contained in it.
3. Application – this includes the use of abstractions in particular and concrete situations. The abstractions may be in the form of general ideas, rules of procedures, or generalized methods. The abstractions may also be technical principles, ideas, and theories which must be remembered and applied.
4. Analysis – this includes the breakdown of the material into its constituent elements or parts such that the relative hierarchy of ideas is made clear and/or the relations between the ideas expressed are made explicit. Such analyses are intended to clarify the communication, to indicate how the communication is organized.
5. Synthesis – this includes putting together elements and parts so as to form a whole. This involves the process of working with pieces, parts, elements, and arranging them in such a way as to constitute a pattern or structure not clearly there before.
6. Evaluation – this includes the making of judgments about the value of material, solutions, works, ideas, and methods for given purposes. The judgments may be either quantitative or qualitative about the extent to which material, solutions,

> works, ideas, and methods satisfy criteria. The criteria may be those determined by the student or those which are given to him or her.

Promoting critical thinking in education is not a new phenomenon. Raths et al. (1967) noted that there was a lack of focus on critical thinking in schools. The authors asserted that in many classrooms students were taught using teacher-centered instruction (lectures) as well as followed along in the textbooks. Students were taught to learn facts rather than understand a process. Teachers often asked "what" type of questions rather than asking more open-ended questions such as "how" or "why." Brooks and Brooks (1993) agreed and argued that when asking questions many teachers seek to find out whether the students know the "right answers" rather than to encourage the students' understanding and critical thinking. Using that approach, students are likely to assume that there is one right answer or that there is only one right way to approach and solve a problem.

Science Education Reform

In answer to the call for reform sounded by *A Nation at Risk* (NCEE, 1983), *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NRC, 1996) recommended using inquiry-based teaching as the central strategy for students to learn science.

Inquiry is a general process in which human beings seek information or understanding (Welch, Klopfer, Aikenhead, & Robinson, 1981). More specifically, the Standards note,

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light

> of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

Those science education reform documents recommend that students be actively engaged in inquiry into authentic questions generated from their own experiences. According to the Merriam-Webster online dictionary (2005), “authentic” means real, actual (not false or imitation). By engaging in “inquiry into authentic questions,” the authors mean doing science in ways that are similar to what practicing scientists do (Chinn & Malhotra, 2002; Dunbar, 1995; Minstrell & van Zee, 2000). “Authentic inquiry,” according to Chinn and Hmelo-Silver (2002) means activities scientists engage in while conducting their research. In authentic inquiry, the learner observes scientific phenomena, manipulates materials, asks questions, designs investigations, conducts experiments, analyzes data, and reports results (Brown & Melear, 2006). When combined with other words, “authentic assessment” means that progress is measured in ways that match the instructional method or are related to some real-life task (McComas, 2005). “Authentic assessment exercises” according to the National Research Council (1996) “require students to apply scientific knowledge and reasoning to situations similar to those they will encounter in the world outside the classroom, as well as situations that approximate how scientists do their work” (p. 78). Authentic inquiry is important because the knowledge and skills that learning activities produce are tied to the situation in which they are learned (Edelson, 1998).

Efforts to engage students in inquiry-based instruction are not new, several authors have stressed using inquiry-based instruction in the classroom. Dewey (1956) wrote that children learn from being engaged in activities that provide experiences in real-world problem-solving and from discussion with others. Schwab (1962) also advocated for the teaching of science as inquiry to be a priority, and that teachers should instruct students on how to conduct investigations in inquiry and to view science itself as a process of inquiry. He argued that through discussion, students can learn that some questions do not have a single right answer, but rather answers are more or less justifiable based upon the available evidence. DeBoer (1991) posited that “if a single word had to be chosen to describe the goals of science educators during the 30-year period that began in the late 1950s, it would have to be *inquiry*” (p. 206). More recently, *Before It’s Too Late,* the Glenn Commission report, also envisioned the kind of instruction in mathematics and science that can be called “high-quality teaching.” The report notes,

> In high-quality teaching, the process of *inquiry,* not merely “giving instruction,” is the very heart of what teachers do. Inquiry not only tests what students know, it presses students to put what they know to the test. It uses “hands-on” approaches to learning, in which students participate in activities, exercises, and real-life situations to both learn and apply lesson content. It teaches students not only what to learn but how to learn. (U.S. Department of Education, 2000, p. 22)

Edelson, Gordin, and Pea (1999) posited that the first opportunity for learning provided by inquiry is the opportunity to develop general inquiry abilities. General inquiry abilities include posing and refining research questions, planning and managing an investigation, and analyzing and communicating results. Secondly, inquiry provides the opportunity to acquire specific investigation skills by engaging in those skills.

The Promise of Inquiry-based Science Instruction

Colburn (2000) defined inquiry-based instruction as "the creation of a classroom where students are engaged in essentially open-ended, student-centered, hands-on activities" (p. 42). The National Research Council in *Inquiry and the National Science Education Standards* (NRC, 2000) synthesized inquiry teaching and learning into five essential features:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations. (p. 25)

Llewellyn (2002) posited that essential scientific questions require students to analyze, synthesize and evaluate information they encounter. These three actions are in concert with the three higher levels of intellectual behavior in the cognitive domain of Bloom's taxonomy discussed earlier, namely, analysis, synthesis, and evaluation. Inquiry-based learning according to Blumberg (2000) nurtures critical thinking skills and essential information processing skills that are required in an information-abundant society by practicing search, categorization, analysis, and evaluation of the information.

Various studies have been conducted to investigate inquiry's promising role in science teaching and learning.

Smith (1996) conducted a meta-analysis of studies that compared differences in outcomes produced by teaching of science as inquiry and teaching of science by traditional methodology (lectures and textbooks). The population of studies for that meta-analysis consisted of the empirical literature, published and unpublished, which reported the effects of the inquiry approach compared to the traditional methodology of the teaching of science on student achievement, critical thinking, process skills, or laboratory skills. Seventy-nine studies were identified using predetermined criteria. The final sample consisted of 35 studies which produced a data set based on 7,437 students. The researcher constructed a coding instrument for the meta-analysis. Two evaluators randomly selected five studies and analyzed them for inter-rater reliability. Inter-rater agreement percentages ranged from 92% to 95% for all five studies. The effectiveness of the inquiry approach as compared to the traditional methodology in teaching science was determined by calculating the effect size estimates. T-tests were performed for values of the effect sizes. Based on the overall effect size estimates, the findings revealed that teaching science as inquiry increased students' mastery of science content [$d = 0.33$, $t(18) = 8.46$, $p<.001$], improved critical thinking skills [$d = 0.77$, $t(6) = 10.86$, $p<.001$], and improved laboratory skills [$d = 0.14$, $t(24) = 28.11$, $p<.001$], all at a significantly higher level than was the case for students taught science by the traditional methodology. Teaching of science as inquiry did not help students develop process skills more than did the traditional methodology [$d = 0.05$, $t(6) = 0.76$, $p>.05$]. Smith concluded that these findings justified the continued use of inquiry approach in the teaching of science. This meta-analysis consisted, however, only of studies that involved students in seventh grade through college. It is difficult to determine whether those findings can be generalized to other grade levels.

Mao, Chang, and Barufaldi (1998) compared the effects of inquiry-based teaching and traditional teaching on secondary students' learning of earth science concepts. The researcher employed a quasi-experimental non-equivalent control-group design to identify any significant gains in achievement. The sample consisted of one earth science teacher and 232 ninth-grade earth science students enrolled in six earth science classes at a public junior high school. Three intact classes (n=116) were randomly assigned to the inquiry-based instruction group and the remaining three classes (n=116) were randomly assigned to the traditional lecture-type instruction group. The experimental group received two weeks of inquiry-based instruction, whereas the control group received two weeks of traditional lecture-type instruction taught by the same teacher using the same text. The instrument contained 27 test items that were used as both pretest and posttest measures of student achievement. The content validity of the instrument was verified by a panel of experts who determined that the test items corresponded with important concepts introduced in the textbook. The Cronbach's alpha reliability coefficient was 0.61 for the pretest and 0.83 for the posttest. Individual items in that instrument were classified into three categories (factual, comprehension, and integrated) corresponding to Bloom's taxonomy of knowledge (factual), comprehension, and application (integrated) levels.

The data were analyzed by employing an analysis of covariance (ANCOVA) on posttest scores with pretest as the covariate. The results indicated that students taught using the inquiry-based instructional method scored significantly higher than those taught using the traditional teaching approach [$F(1, 229) = 6.75$, $p<.05$]. Most notably, there were significant gains in achievement, especially on the comprehensive level items [$F(1, 229) = 3.94$, $p<.05$] and integrated level items [$F(1, 229) = 6.47$, $p<.05$]. There were no significant gains in student achievement at the factual level among the experimental groups compared to the control groups [$F(1, 229) = 3.43$, $p>.05$]. The authors concluded that inquiry-based instruction can produce positive outcomes on student concept learning, especially at higher levels of Bloom's taxonomy. One concern about this study was whether it could be generalized to other populations. The authors did not provide demographics on the teacher and students, so there is no way of determining whether that sample was representative of other populations.

Gibson (1998) conducted a repeated measures analysis of variance (ANOVA) to examine the long-term impact of the Summer Science Exploration Program (SSEP), an inquiry-based science camp, conducted in 1992-1994, whose goal was to stimulate greater interest in science and scientific careers among middle school students entering grade seven and eight. One hundred and fifty-seven students were randomly selected from a pool of applicants to attend SSEP. Two quantitative surveys, the *Science Opinion Survey* developed by the National Association for Educational Progress (NAEP) and the *Career Decision-Making System Revised* (CDM-R), were administered to 79 out of those 157 SSEP students and to several students who applied to the program but were not accepted. The concurrent validity of the CDM-R had previously been verified by its authors (Harrington & O'Shea, 2000). Pre-surveys were administered to students at the beginning of the first day of the program, and then the two-week summer program was offered. Twenty-two out of 79 participants were randomly selected to participate in follow-up interviews during the fall of 1996, two years after administering the summer program. Thirty-five students who applied to the program but were not accepted also completed the post surveys. In addition, over 500 non-SSEP students in grades seven through 12, from the public schools the SSEP students attended, were also pre- and post-surveyed. A two-sample *t*-test found that there was a statistically significant difference between SSEP and non-SSEP students' attitude [SSEP: $M = 0.9$ (1992-1994), $M = 0.8$ (1996-1997); Non-SSEP: $M = 0.3$ (1992-1994), $M = -0.1$ (1996-1997), $p<.0001$] and interest in science careers [SSEP: $M = 22$ (1992-1994), $M = 19$ (1996-1997); Non-SSEP: $M = 14$ (1996-1997), $M = 10$ (1996-1997), $p<.0001$]. A higher mean (M) meant students had a high attitude toward science and a high interest in science careers. Both SSEP and non-SSEP students' average attitude toward science and interest in science careers decreased from 1992-1994 to 1996-1997. It appeared that both those student groups lost some interest in science careers as they went from junior to senior high school.

The post surveys also revealed that there was a statistically significant difference in students' science attitude [SSEP: $M = 0.8$ (1996-1997); Control: $M = 0.5$ (1996-1997), $p = .02$] and interest in science scores [SSEP: $M = 19$ (1996-1997); Control: $M = 0.9$ (1996-1997), $p< .001$] between those who attended camp (SSEP) and those who had applied but were not accepted (referred to as control). The post surveys indicated that over the years, SSEP students maintained a more positive attitude towards science and a higher interest in science careers than students who applied to the program and were not selected. Qualitative data suggested that SSEP may have increased students' interest in science and students liked more hands-on science that is relevant to their lives, the chance to discuss issues and the time to explore issues in-depth. Gibson concluded that the inquiry-based SSEP program had a positive long-term impact on students' attitude towards science and interest in science careers. The program may have helped middle school students with a high level of interest in science maintain that level of interest through their high school years. This study did not, however, provide demographics for either population or sample, so there was no way to determine whether those middle school students were representative of other populations. It appears that there was experimental mortality because post surveys were administered to only SSEP students who could be located. Statistical findings for this study were not written in their entirety; *t* values and degrees of freedom were not reported.

Von Secker and Lissitz (1999) conducted a study to estimate direct and indirect effects of instructional practices recommended by the *National Science Education Standards* on individual student achievement. The researchers used data from the 1990 High School Effectiveness Study (HSES) collected as part of the second wave of the National Education Longitudinal Study (NELS). National Education Longitudinal Study focuses on the personal and academic experiences of students as they progress from eighth grade to high school and beyond. The High School Effectiveness Study was designed to support investigation of school effects issues including direct and indirect associations of instructional practices with student achievement. The HSES comprised a national probability sample of all regular public and private tenth-grade schools in the 1989-1990 academic year. The total sample included 7,642 students representing 790,810 tenth-grade students enrolled in 247 urban and suburban schools in the 30 largest metropolitan school districts. Within each school, science teachers and one administrator completed questionnaires that provided information about classroom instruction and school demographics. The researchers selected for analysis 2,018 tenth-grade students in 163 schools based on student achievement data, student demographic data, science teacher questionnaire data, and at least four students per school.

Science achievement was measured with a standardized science test developed by the Educational Testing Service (ETS) with the express purpose of measuring higher order thinking as well as understanding of fundamental concepts and mastery of basic skills. Von Secker and Lissitz created three composite variables that reflected instructional practices recommended by the *Standards,* namely, providing more opportunities for laboratory inquiry, increasing emphasis on critical thinking, and reducing the amount of teacher-centered instruction. The researchers used the hierarchical linear modeling (HLM) method to estimate the influence of those three instructional practices on science achievement. The between-schools results revealed that mean achievement was significant [$x^2(159) = 1211.367$, $p = .0001$]. Emphasis on teacher-centered instruction and emphasis on laboratory inquiry had moderate direct associations with science achievement. Teacher-centered instruction was negatively associated with achievement ($d = -0.472$, $p = .0001$); that is, mean achievement was almost 0.5 standard deviations lower in schools where the emphasis teachers place on teacher-centered instruction is 1 standard deviation above average. Providing more opportunities for laboratory inquiry was positively associated with science achievement ($d = 0.388$, $p = .0001$) and emphasizing critical thinking was not significant ($d = 0.059$, $p = .545$). The authors concluded that instruction matters: school excellence can be positively or negatively affected by the way science is taught. The 2,018 out of 7,642 students were selected to participate in this study based on, among other factors, student achievement data. The researchers did not, however, give details on what the achievement data entailed. It is possible that only students who had a high achievement were selected. The validity and reliability of the instrument were not provided. Von Secker and Lissitz used a standardized science test developed by the ETS, which was likely previously validated.

Von Secker (2000) investigated whether and to what extent inquiry-based instruction influences science achievement of all students regardless of students' social context (gender, minority status and socioeconomic status). Data for this analysis were obtained from the second wave of the National Education Longitudinal Study (NELS) of 1990. The survey comprised a national probability sample of all regular public and private tenth-grade schools in the 1989-1990 academic year. The sample consisted of five teachers and 4,437 students in 1,406 classes. Science achievement was measured with a standardized science test developed by the Educational Testing Service (ETS) with the express purpose of measuring higher order thinking as well as understanding of fundamental concepts and mastery of basic skills. Measurements of teacher practices were selected from items on the NELS teacher questionnaire that asked teachers to report how much emphasis they placed on an inquiry approach that combined five practices, namely, (a) eliciting student interest and engagement, (b) using appropriate laboratory techniques, (c) problem solving, (d) conducting further study, and (e) scientific writing.

The researcher used the hierarchical linear modeling method to estimate the individual and combined effects of those five teacher practices on the science achievement of students. The findings revealed that the influences of inquiry-based teaching practices were significant when all five teacher practices were combined (d = 0.58, p =.0001) and when each teacher practice was considered individually: eliciting student interest and engagement (*d* = 0.22, *p* =.0001), using appropriate laboratory techniques (*d* = 0.28, *p* =.0001), problem solving (*d* = 0.33, *p* =.0001), conducting further study (*d* = 0.36, *p* =.0001), and scientific writing (*d* = 0.22, *p* =.0001). The researcher concluded that greater emphasis on inquiry-based teaching increases science achievement. Those five teachers, however, were not randomly sampled and demographic data on those teachers including their attitudes towards and beliefs about inquiry-based instruction were not provided. It is possible that the influence of those five teachers affected the findings. The validity and reliability of the instrument were not provided. Von Secker used a standardized science test developed by the ETS, which was likely previously validated.

Parker and Gerber (2000) conducted a study to investigate whether a science intervention program, which included inquiry-based curriculum with real-world applications, would promote middle school students' science achievement and positive attitudes toward science. The sample consisted of 11 African American students from a summer academic enrichment program. All of the students were from economically disadvantaged families and were eligible for free or reduced lunches. Their academic performance in reading and mathematics during the regular school year was often below average. The researchers developed the intervention program that consisted of 10 physical science lessons for fifth through eighth grades. A criterion-referenced test and an attitude toward science survey were administered to participants at the beginning of the science intervention program and at the completion of the program. The criterion-referenced test, constructed by the researchers to measure science achievement, consisted of 15 multiple choice items. Content validity of the test was determined by two science researcher-educators who analyzed the relatedness of the test items to Georgia's Quality Core Curriculum (QCC) instructional objectives. The test was judged to have high content validity. The Cronbach's alpha reliability coefficient was 0.52 for the pretest and 0.47 for the posttest. All participants completed the *Attitude Toward Science Survey* (ATSS) which had a reliability coefficient of 0.79 for the pretest and 0.83 for the posttest. Science lessons from the intervention program were presented twice a week during two-hour class periods for five weeks. During each class lesson, the students were shown slides of local business people, and they were told how the science concepts of the lesson were used in those businesses. In addition to slide presentations, students participated in science investigations characterized by the learning cycle approach to instruction, specifically exploration, term introduction, and application.

Parker and Gerber recorded observations, such as student behaviors, and teacher-student interactions. The findings showed a significant difference for students' science achievement [$t(10) = 5.52$, $p < .001$] and a significant difference for students' attitudes toward science [$t(10) = 2.68$, $p = .023$]. Data from the observations revealed that students' attitudes toward science improved. The authors concluded that the quality of science curricula is a major variable that influences students' achievement and attitudes toward science. Although the findings showed an improvement in students' achievement and attitudes toward science, the authors acknowledged those findings could not be generalized to a wider population. They recommended replicating the study with heterogeneous populations and larger class sizes. It is possible that taking the pretest influenced the students' performance on the posttest. The reliability coefficients for the pretest and posttest were not particularly high. The authors attributed that, however, to the small number of items on the criterion-referenced test. It is also possible that there was statistical regression in this study because the participants were low achievers. The improvement in students' achievement and attitudes toward science might have been, in part, due to the Hawthorne effect because the researchers are the ones who developed the intervention program, taught the lessons, and carried out the observations. The researchers might have played up the value of the program.

Reger (2006) conducted a qualitative study to investigate whether participation in inquiry-based activities increased higher-level questioning and statements made by fifth-grade, gifted, science students. The school in that study was one of 11 elementary schools in a large urban metropolitan school district. The school was one of two schools that provided self-contained classes for the gifted and talented students. The teacher selected for this study had completed her endorsement in gifted education and was also very supportive of, in fact, favored inquiry-based instruction. Nineteen students, who had not received inquiry-based lessons in science during the previous school year, participated in the inquiry-based lessons. Purposeful sampling of four students, who were to be the focus of that study, was done by gender and ethnicity. During the two-week study, the teacher presented three separate inquiry-based forensics lessons to the class. The teacher helped direct some questioning, encouraged student investigation and interpretation of data, and guided further investigation.

Reger examined the types of questions and statements students made as the students progressed through those lessons. The lessons were placed into a sequence of increased complexity. In each lesson the students applied the principles of forensic science to solve a hypothetical crime using scientific processes. Students formulated strategies and questions that were implemented to complete the investigation with the teacher acting as the facilitator. Data were collected using teacher interviews, field notes, and logs that recorded students' observations, questions, and thoughts. Lessons were videotaped. Detailed descriptions of observations were recorded in a coding instrument that comprised of the six categories of Bloom's cognitive taxonomy. During observations, ideas for new categories emerged beyond the six levels. To confirm the objectivity of the researcher, a peer reviewer coded some sections of the transcripts for inter-rater validation. Internal validity and reliability were also ensured by using multiple sources of data such as journals, videotapes, field notes, and interviews.

The researcher found that all the gifted students seemed to exhibit growth in higher-order thinking. The group dynamics enhanced the construction of analytical skills as the students seemed to stimulate each other's ideas. The teacher also facilitated the growth of higher-order thinking in the students by modeling higher-order thinking and soliciting it through her questioning techniques. Reger concluded that the interplay between the curriculum complexity, the student interactions, and the teacher's modeling behavior all influenced the increased cognitive development of the students. The findings may not be generalized to other classroom settings, however, because while the students exhibited growth in higher-order thinking, the participants in that study were only gifted students. It is possible that the experimenter effect and the Hawthorne effect accounted for the findings. The teacher's role in this study as facilitator and the fact that the teacher favored inquiry-based instruction may have influenced the findings. Given that the participants were gifted students, they might have perceived how they were expected to perform leading them to exhibit the growth in higher-order thinking.

This section presented studies on the effects of inquiry-based instruction on science learning. One concern is that some of the previous research has been with specialized programs (for example, two-week science summer camp), specialized populations (for example, under-achieving African American students and "gifted" students) and lots of different levels of learners (for example, seventh-grade through college students). It is unclear how these studies' findings might generalize to different populations and settings.

Types of Inquiry

According to the National Research Council (2000), inquiry-based teaching can vary in the amount of structure, guidance, and coaching the teacher provides for students engaged in inquiry (see also Chinn & Hmelo-Silver, 2002; Colburn, 2000; Schwab, 1962). Some teachers engage students in the investigation process with little or no guidance while others stress directing students throughout inquiry. The more responsibility the learners have for posing and responding to questions, designing investigations, and extracting and communicating their learning, the more "open" the inquiry. The more responsibility the teacher takes, the more "guided" the inquiry. Accordingly, three types of science inquiry teaching have been devised to identify the extent of teacher direction,

- Structured inquiry – the teacher provides students with a problem to investigate, as well as the procedures, and materials.
- Guided inquiry – the teacher provides the materials and problem to investigate. Students devise their own procedure to solve the problem.

- Open inquiry – gives students the freedom to formulate their own problem to investigate as well as to devise the ways and means to come up with the solutions.

In conversations with teachers who were participating in summer workshops that emphasized inquiry, Pierce (2001) noted that many teachers were hesitant to teach an actual inquiry unit because inquiry takes too much time, when students develop their own questions the questions don't relate to the required curriculum, teachers are uncomfortable sorting questions, and teachers feel unprepared to help students with difficult questions due to a lack of background knowledge. Pierce found that teachers were looking for more structure than an open-ended inquiry. Crawford (2000) contended that true inquiry-based teaching and learning involves the teacher building on students' experiences so they can revise their understandings. Thus, inquiry-based approach to science is strongly based on constructivism, a theoretical perspective of learning that assigns primary importance to the way in which learners attempt to make sense of what they are learning.

Constructivism

The basic tenet of constructivism is that understanding is developed through a constructive process in which students modify and refine what they know (von Glaserfeld, 1995). According to Brooks and Brooks (1993), constructivism has its roots in the work of Jean Piaget. Piaget viewed constructivism as a way of explaining how people come to know about their world. Constructivism is a theory of knowing; knowledge has to be actively built up by each individual knower (von Glaserfeld, 1993). Individuals construct meanings by forming connections between new concepts and those that are part of an existing framework of prior knowledge (Mintzes & Wandersee, 1998).

In a constructivist classroom, the teacher typically takes account of what students know, maximizes social interaction between learners such that they can negotiate meaning, and provides a variety of sensory experiences from which knowledge is built (Shapiro, 1994; von Glaserfeld, 2005).

In the constructivist theory of learning, there is a shift from traditional views of learners as passive receptors of knowledge to learners as active meaning-makers. The goal is to transform teachers from lecturers into facilitators and students from passive observers into active participants in the learning process (Ahern-Rindell, 1998). Brooks and Brooks (1993) posited that a constructivist framework challenges teachers to create environments in which they and their students are encouraged to think and explore, and that constructivism has five guiding principles:

1. Pose problems of emerging relevance to students –A good problem is one in which students make a testable prediction, make use of accessible resources, is complex enough to elicit multiple problem-solving approaches, benefits form group effort, and must be relevant to the students.
2. Structure learning around primary concepts – Students are most engaged when problems and ideas are presented holistically rather than in separate isolated parts. Many students are unable to build concepts and skills from parts to wholes. Learners become more engaged by concepts introduced by the teacher and constructed by the learner whole-to-part rather than part-to-whole.
3. Seek and value students' points of view – Students' points of view can reveal their reasoning, and it helps the teacher challenge the students and ask for elaboration.

4. Adapt curriculum to address students' suppositions – Some sort of relationship must exist between the demands of the curriculum and the suppositions that each student brings to a curricular task. If students' suppositions are not addressed, most students will find lessons lacking meaning.
5. Assess student learning in the context of teaching – Authentic assessment, like learning, occurs when it is in a meaningful context and when it relates to authentic concerns and problems faced by students.

According to Jonassen (1994), learners in a constructivist learning environment construct their own reality or at least interpret it based upon their perceptions of experiences, so an individual's knowledge is a function of one's prior experiences, mental structures, and beliefs that are used to interpret objects and events. Purposeful knowledge construction may be facilitated by a learning environment that,

- Provides multiple representations of reality, thereby:
- Avoiding oversimplification of instruction by representing the natural complexity of the real world;
- Focusing on knowledge construction, not reproduction;
- Presenting authentic tasks (contextualizing rather than abstracting instruction);
- Providing real-world learning environments, rather than pre-determined instructional sequences;
- Fostering reflective practice;
- Enabling context and content-dependent knowledge construction ; and
- Supporting knowledge through social negotiation, not competition among learners for recognition.

Constructivists emphasize situating cognitive experiences in authentic activities. They contend instruction should develop the skills of the learner to construct (and reconstruct) knowledge to situational demands and opportunities. Instruction should provide contexts and assistance that will aid the individual in making sense of the environment as it is encountered. Knowledge must be constructed, tested, and revised as a function of one's particular encounters in the environment (Duffy & Jonassen, 1992). According to Gil-Pérez et al. (2002), science learning is conceived not as a simple conceptual change, but as a procedural change as well as a process of oriented research that enables students to participate in the (re)construction of scientific knowledge, thus favoring more efficient and meaningful learning. Oriented research is a process of research training similar to the initial training of future researchers.

The Promise of Technology to Enhance Science Inquiry

The science education reform efforts (AAAS, 1993; NRC, 1996) also advocated for effective science learning environments to provide the opportunity for students to use contemporary technology as they develop their scientific understanding. According to Linn (1998), technology refers to a wide array of tools used in the science classes including,

1. Laboratory equipment such as measuring devices.
2. Video materials such as movies, films, filmstrips, television, scientific visualizations and computer animations.
3. Interactive media such as computer tutors, microworlds, programming environments and scaffolded learning environments. Microworlds are tiny artificial worlds inside which a student can explore alternatives, test hypotheses,

and discover facts that are true about the world. Scaffolds refer to temporary support teachers and/or technology provide for learners that can gradually be removed as the learners develop their expertise.

4. Electronic communication methods such as electronic mail, bulletin boards and discussion environments. (p. 265-266)

Edelson et al. (1999) noted that computer technologies were receiving increased attention from the science education community because of excitement about their potential to support new forms of inquiry. A survey by the U.S. Census Bureau revealed that households with a computer had risen from 37% in 1997 to 62% in 2003, while, households with Internet access had risen from 18% in 1997 to 55% in 2003 (U.S. Census Bureau, 2003). Correspondingly, Internet connectivity in schools has also risen. According to the National Center for Education Statistics (Parsad & Jones, 2005), in fall of 2003, nearly 100 % of public schools in the United States had access to the Internet compared to 35 % in 1994. Owston (1997) contended that the World Wide Web is likely to bring new learning resources and opportunities into the classroom, provide teachers and students access to more resources, and promote improved learning. Hoffman, Kupperman, and Wallace (1997) agreed and posited that online resources have potential for supporting inquiry-based learning.

Owston was not alone in advocating the Web's potential role in supporting science teaching and learning. Many writers praise the rich instructional resources the Web offers to enhance student science learning (see Alloway, et al.; Bodzin 1997; Bodzin, 2005; Bodzin & Cates, 2003; Clark, Hosticka, Kent, & Browne 1998; Friedman, Baron, & Addison, 1996; Haury, 2001; Haury, 1993; Haury & Milbourne, 1999;

Nachmias & Tuvi, 2001). According to these authors, the Web can facilitate interactions by offering collaboration on projects and discussion among students. Communication can be facilitated via email, group conferencing, and listservers. In addition, the Web offers an extensive array of information sources. Students can analyze real-world data using current and archived research findings, and some sites extend classroom activities by nurturing self-directed learning to promote the learner's interest and understanding. The Web offers simulations, virtual reality, animations, video clips, sound, and scientific visualizations unavailable in text-based instructional materials. Bodzin, Cates, and Vollmer (2003) contended that the Web may provide a context for authentic learning by presenting learners with authentic real-world tasks that require problem solving and reasoning to achieve a collaborative goal. Various descriptions of technology-supported inquiry-based projects and research studies that have examined technology's potential role in supporting science inquiry are presented in the following paragraphs.

Global Learning Observations to Benefit the Environment (GLOBE) is an international science and education program designed to increase environmental awareness of people throughout the world, and to contribute to an improved understanding of the local, regional, and global environment (de La Beaujardière et al., 1997; Finarelli, 1998). The program aims to improve student achievement in science, mathematics, geography, and use of technology. Students in grades K-12 measure environment quantities in the vicinity of their schools and submit their data to a central computer. Scientists actively participate as research collaborators with the students and teachers. The visualization server disseminates daily images of both students and environmental data collected by students. Using the visualizations, students can learn how the environmental conditions at their site relate to the regional and global environment, how conditions change with time, and how student measurements compare with the forecast model results. Access to the World Wide Web allows for the collection and storage of data in GLOBE archives, and a ready means to provide a variety of graphical, visualization, and technical tools for students to examine and manipulate the data.

Butler and MacGregor (2003) noted that from the perspective of teachers, the evaluations found that students have a very high interest in GLOBE activities. GLOBE has empowered students to take a greater interest in science exploring the world around them. Teachers noted that the GLOBE approach had greatly improved students' science inquiry abilities, such as observational, measurement, and technological skills, along with the ability to work cooperatively in groups and to be more analytical. An examination of students' opinions showed that their special interest was expressed in the use of computers, working with satellite images and taking measurements. Students were also encouraged by knowing that their data will help people better understand earth, and enjoy their collaboration as "real scientists" with their research colleagues. Selected samples showed that students exposed to GLOBE scored better on tests than their counterparts in non-GLOBE classes. Students' ability to interpret data and apply science concepts was also superior, and they appeared to make more science-based inferences about the natural world than their non-GLOBE peers. The writers did not, however, provide the reported data.

Computers as Learning Partners (CLP) is a partnership of classroom teachers, cognitive researchers, natural scientists, technology experts, and middle school students, all of whom contribute ideas and refinements to the curriculum for a semester-long science course (Linn & Hsi, 2000). The founding tenets of the partnership are for students to achieve deep understanding of science, take advantage of the technological tools that scientists regularly use, and create instruction that equitably serve students from all cultural groups. In CLP students are offered experiments, peer discussions, class discussions, prototypes, pragmatic science principles, visualizations, everyday problems, simulated online problems, and teacher tutoring as learning partners.

Geology Explorer (http://oit.ndsu.edu/~mooadmin/PLANET/wwwic-ge.html) is a multi-user virtual environment intended to teach the concepts of physical geology. The players visit a simulated world and compete for points by undertaking a goal-directed exploration where they perform simple experiments in order to identify rocks and minerals. The players then create a geologic map that highlights the locations of different outcrops in the virtual environment. The simulated environment has been developed in order to simulate authentic geosciences experiences. Players are engaged in processes that promote their acting like and thinking like a geologist, thus, learn-by-doing geology.

BioKIDS: Kids Inquiry of Diverse Species (http://www.biokids.umich.edu/) is a technology-rich curricular program that was designed to teach upper elementary students about biodiversity through inquiry. BioKIDS creates innovative, inquiry-based science curricula that utilize current technologies such as CD-ROMS, personal digital assistants (PDAs) and the World Wide Web for interactive study (Huber, Songer, & Lee, 2003). Students use current technologies such as PDAs to collect scientific data in a manner similar to professional scientists. Once data are collected, students analyze data and generate scientific claims, explanations, and hypothesis based on their data. The primary goal of BioKIDS is to support fifth- through eighth-grade students to demonstrate complex reasoning in science and technological fluency as a result of their interaction with a challenging coordinated science program (Parr, Jones, & Songer, 2004).

Investigating and Questioning our World through Science and Technology (IQWST) (http://hice.org/iqwst/Index.html) develops middle school curricula designed to enable teachers with diverse knowledge and experiences to teach science effectively to students with a variety of backgrounds and strengths. IQWST materials align with national standards, are rooted in principles of project-based scientific inquiry, focus on science's "big ideas", and employ research-based practices shown to promote students' science and science literacy learning. The instruction is sequenced to build upon students' prior knowledge and experiences in the real world. Students learn complex scientific ideas by engaging in practices that include working with models, constructing scientific explanations, engaging in argumentation and debate, analyzing data gathered either from students' own investigations or captured within complex datasets, and presenting ideas to peers.

The *Technology Enhanced Learning in Science* (TELS) investigates the impact of technology on science learning and instruction. TELS embeds highly interactive and dynamic visualizations in inquiry projects to enable students develop integrated understanding (Linn, Husic, Slotta, & Tinker, 2006). Twelve topics that perplex students, align with standards, and could benefit from powerful visualizations were selected for investigation. TELS designed knowledge integration assessments for the 12 topics and administered the assessments as a baseline in participating schools to establish the knowledge of students studying the traditional curriculum. TELS then formed 12 multidisciplinary teams to design inquiry activities for each of the 12 topics. All 12 projects were iteratively designed with reviews by at least eight different groups. The designs were informed by the benchmark performance of the students following the traditional curriculum. The 12 TELS projects were pilot-tested, taught, and studied during the school year. Overall, 16 schools, 16 principals, 49 teachers, and over 5,000 students in more than 200 classes participated in the research. Teachers used pretests, posttests, and embedded assessments to establish student progress in knowledge integration. All those items were scored using knowledge integration rubrics. To ensure construct validity, the assessments were aligned with the knowledge integration construct and designed to measure the multiple levels of competence described by the construct. To establish content validity, items were aligned with national standards and reviewed by content experts. Cronbach's alpha for the tests ranged from 0.75 to 0.81.

In the spring of the first year, TELS teachers administered the benchmark assessments to establish baseline performance levels on the 12 topics for their students. In the spring of the second year, TELS teachers administered the benchmark assessments to the new cohort of students who used TELS projects during that year. The cohort-comparison design enabled the researchers to find out if students using TELS projects benefited compared to similar students who did not use TELS projects. The projects revealed that students benefited from interactive visualizations embedded in inquiry projects. Data from one middle school project revealed that students made significant gains in understanding of the concepts even after the concepts had already been taught in their science classes [$t(150) = -11.61$, $p<.001$]. In addition, students of low, medium, and high prior knowledge going into the projects all made progress in understanding. Students with the least prior knowledge benefited the most.

Hoelscher and Walker (1995) implemented a project in middle school whose goals were to improve students' attitudes toward science, improve students' understanding of science concepts and principles, increase the richness of science and technology instruction, and to expand the range of classroom tools available to science teachers. The project was based on the *Newton's Apple Multimedia Collection,* a series of interactive videodiscs for middle school science developed by a team of television series producers, instructional designers, and a national advisory board. The collection is an interactive means of integrating video, software, and print materials to supplement traditional ways of learning middle school science (for example, textbooks, teacher lectures, and workbook exercises). Each 30-minute video features several short segments led by a host and a variety of science experts, where a science question is explored through a simple demonstration, series of models, or graphic illustrations. The team developed two videodiscs, one for physical science and the other for life science. Each videodisc contained eight motivational video segments that invited students to examine a life science or physical science topic. When prototypes of the videodisc, software, and print materials were ready for classroom use, formative and summative evaluations were conducted.

Four hundred and fifty-five students participated in the evaluations at 134 middle school sites selected to provide diversity in gender, ethnicity, age, grade level, language, and geographic region. During the evaluations, 134 middle school teachers and the 455 students provided feedback on how to increase appeal, comprehension, utility, and potential learning effectiveness of those two products. Classroom print materials supported each video segment with student activities such as questions to stimulate thought before the video segment, and lesson activities to encourage further investigations after the video segment. Computer software accompanied the videodisc program, designed for students to develop their own projects or presentations. Both the physical and life science video products were quite favorably received by teachers and students in that study. Teachers reported positive reaction to the ability of the products to meet science objectives, stimulate questions from students, enhance student responses, and support teaching. Teacher-reported student learning included the following: factual information, principles of science, conceptual understanding, abstract to concrete understanding, process skills, relationships, procedural information, how scientists work, and enjoyment of science. Student attitude toward participation in that project was positive. When the students' ideas were reinforced through the results of the activities and follow-up video, students reported they were as good at science as anyone. Although this study reported positive reactions towards the project from both teachers and students, there are a few concerns about the study. It is unclear how long this study was conducted, how the sample was selected, the demographics of the population and sample, and the instruments used for the evaluations. It is therefore difficult to determine the validity and reliability of the evaluation instruments, and also to determine whether the sample was similar to other populations in order to generalize the findings. Since this study did not have a control group, it is possible the formative evaluation influenced the participants' responses on the summative evaluation.

Christmann and Badgett (1999) conducted a study to compare the contributions of computer-assisted instruction (CAI) to student achievement in science across different educational settings (urban, suburban, and rural). The authors conducted a meta-analysis of studies that compared science students who were taught using traditional methodology (textbooks, classroom questions, laboratory experiments) with those who were taught using traditional methodology supplemented with CAI. The population consisted of over 500 studies and the sample consisted of 11 studies. Those 11 studies met four predetermined criteria, namely, they were conducted in an educational setting, they included quantitative results in which academic achievement was the dependent variable and microcomputer-provided computer-assisted instruction was the treatment, they had experimental, quasi-experimental, or correlational research designs, and the sample sizes had a combined minimum of 20 students in the experimental and control groups. The majority of those CAI studies that did not meet the above criteria did not statistically analyze the reported data. A total of 2343 students had participated in the 11 studies. The sample size in those 11 studies ranged from 43 to 300, and the mean sample size was 98 students.

The overall mean effect size of the meta-analysis was $d = 0.266$. That number was positive because higher scores were attained by those students receiving CAI. Tallying the mean effect sizes across educational settings revealed that CAI had its strongest effects among science students in urban settings ($d = 0.685$), weaker effects among suburban settings ($d = 0.273$), and weakest effects among rural settings ($d = 0.156$). The authors also found that students receiving traditional instruction supplemented with CAI attained higher academic achievement than did 60.4% of those receiving only traditional instruction. Christmann and Badgett concluded that CAI positively affects the achievement of science students. This study did not, however, provide information on the different types of CAI used in the individual studies analyzed. Given the time frame in which this study was conducted, CAI likely included tutorials, drill-and-practice, simulations, instructional games, tests, problem-solving environments, teaching tools, computer games, intelligent computer-assisted instruction, and computer-controlled video among others (Alessi & Trollip, 1985; Gibbons & Fairweather, 1998). It could be argued that these different types of CAI are not equal; that is, not all types of CAI affect student achievement in the same way. Kozma (1991) argued that learners will benefit most from the use of a particular medium with certain capabilities as compared to the use of a medium without those capabilities if the capabilities are employed by the instructional method. It is possible that CAI might have been designed using better instructional design than traditional face-to-face instruction.

During the 2001-2002 academic year, Bentley (2003) taught several online undergraduate courses at two different institutions that delivered degree programs entirely online. In the first institution, enrollments in five sections of introductory biology course ranged between eight and 22 students, while the second institution had 23 students. Online tools used for teaching included the drop box for students to deliver their assignments, the message board for student-teacher and student-student communication, online seminars via a chat room, and an email listserv to deliver notes and images. Other tools included Web-posted PowerPoint presentations, video clips, and/or sound files, online office hours, and online quizzes and exams. Examinations and assignments involved Web-based inquiries, such as locating and interpreting data, maps, graphs, or whole research studies found on particular Web sites. The findings indicated that overall student feedback was positive. Students reported that they learned a lot in those online courses. Many Web postings indicated that students searched beyond what was required of them in the assignment. Bentley concluded that a computer-mediated learning environment can effectively facilitate student knowledge construction. This study did not, however, provide demographics on population or sample. It is unclear whether the students who participated were similar to students in other populations in order to generalize the findings. Since there was no control group and the study was conducted for a whole academic year, it is possible that events outside the study (for example, using computers at home) contributed to the students' positive feedback. There was no information provided on the reliability and validity of any instrument used in this study.

As part of larger urban systemic reform efforts, Marx et al. (2004) investigated whether an inquiry-based and technology-infused curriculum could help middle grade students in an underperforming urban district learn important science content that addressed national standards. Fourteen schools involved in that study represented the broad range of schools and neighborhoods in the city, ranging from inner city schools serving communities with high poverty to schools in more suburban and somewhat more affluent neighborhoods. Across the district, 91% of the students were African American, 4% Latino, 4% White, and 1% Asian. That distribution characterized the student sample in this study. In most of the 14 schools one to three faculty participated based on interest or because they were selected by their school administration. Four curriculum projects, each lasting between eight and 10 weeks, were designed to engage students in inquiry-based learning activities supported by embedded learning technologies; one project in the sixth grade, two in the seventh grade and one in the eighth grade. Three projects were implemented for three academic years and the fourth project, which was developed after the other three, was implemented for two academic years. Thus, there were a total of 11 implementations. The curriculum projects used extensive software tools that feature modeling, visualization, and information-searching.

Written test instruments were administered to all students participating in the curriculum projects to assess their understanding of the curriculum content and science process skills. The tests, developed by science educators, content specialists, educational psychologists, and classroom teachers, consisted of a combination of multiple choice and free response items. Content validity of the tests was ensured by creating items based on a matrix of topics that reflected the relative importance of the content and processes in the curriculum materials. Total score reliability (Cronbach's alpha) for each of the test instruments fell in the range of 0.63 to 0.78 with the exception of one test whose reliability coefficient was 0.5. The tests were administered to all the students participating in a curriculum project at the start of the first week (pretests) and the same tests were administered at the conclusion of the last week (posttests) of the curriculum project. Three years of outcomes were assessed to examine whether outcomes improved over time. The findings revealed that nine out of 11 tests were statistically significant at $p < .001$, one test was significant at $p < .01$, and one test was not significant. The researchers acknowledged that though the findings revealed increasing gains on student achievement, it was difficult to separate the effects of the components of the systemic reform efforts and attribute causality to one or another. A number of causes may have influenced the gains on student achievement. Since this study spanned three years and there was no control group, it is possible that in the course of time other factors outside the curriculum projects (for example, working at home with computers) increased student achievement. It is also possible that the students, say sixth graders, matured physically and psychologically as they went on to higher grades leading to higher achievement. Lastly, the pretests and posttests administered to the students were exactly the same test for each project, thus, it is possible that the students were able to answer the test better on seeing it a second time (posttest).

The *Web-based Inquiry Science Environment* (WISE) provides an Internet-based platform for middle and high school science activities where students work collaboratively on inquiry projects making use of evidence from the Web. In WISE activities, students learn to use the Internet for inquiry, critiquing Web sites, designing approaches, or comparing arguments. WISE activities can also incorporate java applets that enable students to visualize data, create casual maps, graph their predictions, or design an argument based on evidence that links to the Web. The activities also include pop-up windows for reflection notes and cognitive hints. The WISE authoring software supports knowledge integration through its technology features and curriculum design patterns (Linn, Clark, & Slotta, 2003; Slotta, 2002). Stephens (2004) used a mixed methods research design to investigate students' and teachers' perceptions of their classroom learning environment, and the students' achievement after participating in selected WISE activities. The study was conducted in a midsize urban school district. The researcher obtained a purposeful and convenient sample from the teachers and students who volunteered to participate in the study. The participants consisted of 16 science teachers and 474 students from eight high schools who were randomly assigned to either an experimental group (n = 234) or a control group (n = 240). The experimental group accessed resources on the Internet, logged their ideas and thoughts in a personal notebook in the WISE environment, and collected evidence in order to support or reject different hypotheses. The control group participated in inquiry-based activities in the physical science curriculum without using the Web. Most of the physical science classes in the district participated in more traditional classroom activities like readings and doing exercises from the textbook. Students in both groups took a pretest and posttest survey, and a pretest and posttest achievement test. Classroom observations and focus group interviews were conducted using the researcher-developed protocols.

A one-way analysis of variance revealed that there was no significant difference [$F(1, 472) = 0.733$, $p = .392$] in academic performance as measured by the posttest scores of the students who participated in science Web-based inquiry activities and those who participated in more traditional classroom science activities. Qualitative findings revealed an increase in Internet usage and group work. Stephens concluded that although the Web-based inquiry activities did not have any effect on students' achievement, they promoted collaboration among students. Sixteen out of 100 teachers and 474 out of 864 students consented to participate in this study. It was unclear whether the sample of students was similar to other populations since there were no demographics provided on the population and sample. It turned out that 25% of the teachers and 24% of the students who participated were from one particular school. There was no information provided about that particular school (for example, student performance, student demographics, socioeconomic status) that might have helped to account for the findings. Lastly, there was no way to determine whether the researcher-developed protocols used in the interviews and the qualitative findings were reliable and valid.

The *Kids as Global Scientists* (KGS) weather program consists of a systematic, curricular, approach to fostering students' deep conceptual understanding of weather content through the use of a suite of learning tools designed specifically with inquiry science in mind (Songer, Lee, & McDonald, 2003). The program is designed to foster inquiry thinking among middle school science students and teachers. The KGS program includes activities that culminate in inquiry-oriented real-time predictions, use of real-world scientific phenomena, and a set of software tools that guide students towards salient data and productive construction of explanations with others. Students do a real-time forecast of weather in target cities across the country, modeled and guided by online content experts and peers. KGS software consist of CD-ROM that houses both archived imagery and a Web browser for the retrieval of real-time imagery, as well as a separate Internet-available, Web-based threaded discussion board. The KGS program was implemented for eight weeks in 230 classroom settings with approximately 230 teachers and 13,000 fourth-ninth grade students from 40 states to investigate students' performance on content and inquiry assessments. A common profile of a KGS site was an urban classroom with a high percentage of minority students and poor Internet reliability. While the majority of the classrooms were in urban settings (41%), some were located in rural (31%) and suburban (28%) settings. Two groups of teachers participated in that study: "Maverick" teachers and urban teachers. Maverick teachers were teachers distributed across the nation who customized the KGS program to their needs and who did not receive systemic professional development, while urban teachers were teachers from high-poverty urban school districts who were provided with targeted professional development.

Data on student learning were gathered from 17 teachers and their students, from which five classroom groups (n = 225) were chosen for detailed analysis: two classrooms represented maverick groups and three classrooms represented urban groups. The students from the five focus groups were chosen because they were all in sixth grade and they demonstrated significant content gains from pre- to posttests measuring weather content and inquiry. Because of those demonstrated student gains, the five selected classrooms were defined as "successful." Evaluations of science learning were made using instruments of both multiple-choice and open-ended items about weather and scientific inquiry content. Multiple-choice items included released National Assessment Educational Progress (NAEP) items and the Michigan Education Assessment Program (MEAP) items measuring understandings of temperature, weather data collection and interpretation, fronts, pressure, and inquiry. The Cronbach's alpha for the MAEP test was 0.89 while the content validity was ensured by a content advisory committee which verified that each item met the objective it was supposed to measure. For the multiple-choice items, repeated measures ANOVAs were used to illustrate changes in students' content knowledge development from pretest to posttest. The researchers developed qualitative coding rubrics for the open-ended items. A team of three researchers met several times to determine inter-rater reliability of 91% on open-ended items. Open-ended posttests showed that all focus students showed significant gains and high effect size difference between pre- and posttests ($p < .01$). All samples of focus students made significant gains in multiple choice pre- and posttests ($p < .01$), except one group that had demonstrated a very high pretest score. The authors concluded that KGS helped focus students demonstrate greater and more developed understandings of complex science inquiry-focused thinking related to weather concepts. These findings may not, however, be generalizable to other populations because only data from "successful" students were analyzed. It is unclear how the other 12,775 students (98%) performed.

The studies presented in this section provide examples of classroom-based successful science inquiry that utilized innovative technology. Another newer technology that may hold promise in supporting science inquiry is a Geographic Information System (GIS), a spatial thinking tool, which is discussed in the next section.

Geographic Information Systems

Gersmehl (2005) defined spatial thinking as thinking about locations, conditions, and connections. According to the National Research Council (2006), spatial thinking is the knowledge, skills, and habits of mind to use concepts of space, tools of representation, and processes of reasoning in order to structure problems, find answers, and express solutions to those problems. Spatial thinking serves three purposes. It has 1) a descriptive function, capturing, preserving, and conveying the appearances of and relations among objects; 2) an analytic function, enabling an understanding of the structure of objects; and 3) an inferential function, generating answers to questions about the evolution and function of objects. Spatial thinking uses representations to help us remember, understand, reason, and communicate about properties of and relations between objects represented in space. *The National Geography Standards* (Geography Education Standards Project, 1994) on spatial thinking require each student to know and understand,

1. How to use maps and other geographic representations, tools, and technologies to acquire, process, and report information from a spatial perspective;
2. How to use mental maps to organize information about people, places, and environments in a spatial context; and
3. How to analyze the spatial organization of people, places, and environments on earth's surface.

Alibrandi (2003) asserted that a Geographic Information System (GIS) can put students' spatial abilities to significant learning tasks. Spatial ability is the ability of people to organize the space around them (Potegal, 1982). Many definitions of a GIS have been proposed. Broda and Baxter (2002) defined a GIS as a system that is designed to store, retrieve, manipulate, and display geographic data. Walker, Casper, Hissong, and Rieben (2003) stated that a GIS involves powerful, complex computer databases that organize information around a specific location, while DeMers (2005) defined a GIS as a tool that allow for the processing of spatial data into information, generally information tied explicitly to, and used to make decisions about, some portion of the earth. DeMers further summed up how a GIS operates as a series of the following subsystems within a larger system:

1. A data input subsystem that collects and preprocesses spatial data from various sources, and is largely responsible for the transformation of different types of spatial data.
2. A data storage and retrieval subsystem that organizes the spatial data in a manner that allows retrieval, updating, and editing.

3. A data manipulation and analysis subsystem that performs tasks on the data, aggregates and disaggregates, estimates parameters and constraints, and performs modeling functions.
4. A reporting subsystem that displays all or part of the database in tabular, graphic, or map form. (p. 9)

According to Schuurman (2004), the roots of Geographic Information Systems date back to the 1960s. In 1962, Ian McHarg, a landscape architect was searching for the optimal route for a new highway, a route that would involve the least disruption of other “layers” of the landscape including forest cover, pastoral valleys, and existing semirural housing. He took multiple pieces of tracing paper, one representing each layer, and laid them over each other. By using visual intersections, he was able to “see” the only logical route. McHarg’s method of “overlay” was later to become the methodology of a GIS. One of the earliest GIS was developed in 1964 in Canada, a brainchild of Roger Tomlinson and Lee Pratt. The Canadian ministry of agriculture wanted to compile land use maps that would describe multiple characteristics including agriculture, forestry, wildlife, recreation areas, and census divisions. Tomlinson and Pratt pioneered a computerized system in which land use zones were digitally encoded so that they could be overlaid with other relevant layers such as urban/rural areas, soil type, and geology. In the 1970s, researchers from the Harvard graphics laboratory contributed to the dissemination of GIS in the U.S., especially into the private sector.

A GIS stores geographic data as a collection of thematic layers (for example, overlays of a map showing human population distribution, hydrology, transportation, soils, geology, and land cover) that are linked to a common georeferencing system (NRC, 2006). Each thematic layer has two information components: the location of a place in geometrical terms and a description of the attributes of that place. The layers of information one combines depends on his or her purpose; for example, finding the best location for a new store, analyzing environmental damage, viewing similar crimes in a city to detect a pattern, and so on (Lucking & Christmann, 2003). Stacking those themes or layers of information allows new patterns to emerge for scientific consideration (Walker et al., 2003). According to the Environmental Systems Research Institute (ESRI, 1993), there are five generic questions that a sophisticated GIS can answer:

1. What is it …? Seeks to find out what exists at a particular location.
2. Where is it …? Seeks to find a location where certain conditions are satisfied.
3. What has changed since …? Seeks to find the differences within an area over time.
4. What spatial patterns exist …? One might seek to find out, for example, whether cancer is a major cause of death among residents near a nuclear power station.
5. What if …? One might seek to find out, for example, what happens if a new road is added to a network.

Rapidly declining computer hardware costs have made Geographic Information Systems affordable to an increasingly wider audience (ESRI, 1993). Epidemiologists use a GIS to identify clusters of infectious disease, archaeologists use a GIS to map sites, and Starbucks® is reputed to use a GIS to site its coffee shops (Schuurman, 2004). Fire departments use a GIS to enhance their routing capabilities to ensure rapid response in emergencies; the military could use a GIS to determine appropriate battle plans and to organize troop movements; and businesses are using a GIS to market products and even to develop mailing lists based on selected spatial criteria. Real estate companies are using a GIS to isolate available housing on the basis of customer criteria such as proximity to schools, types of neighborhood, or access to highways; and police departments use a GIS to compile information to characterize movements and operational settings of suspected serial killers (DeMers, 2005). Other users include resource managers who rely on a GIS for fish and wildlife planning, management of forested, agricultural, and coastal lands, and energy and mineral resource management. Local governments use a GIS for planning and zoning, property assessment and land records, parcel mapping, public safety, and environmental planning. Last but not least, demographers use a GIS for target market analysis, address matching, as well as product profiles, forecasting and planning (ESRI, 1993).

GIS in K-12 Education

Geographic information systems have been in general use for many years but are more recently appearing in the education sector (Parker, 1999). The decreasing cost of technology and the concurrent increasing availability of powerful computers in schools have made GIS technologies viable tools for many teachers. Holzberg (2006) noted that K-12 educators are harnessing the power of GIS technology to support standards-based math, science, and social studies curricula. Some factors that impact the implementation of GIS at the K-12 level are,

1. Hardware and software – appropriate hardware and software must be available and accessible to the teachers and students. Recent advances in hardware capabilities and relative reduction in costs have made available powerful, affordable, computers that can be used to run GIS software and manipulate large

spatial data sets (McClurg & Buss, 2007). In addition, several of the major producers of GIS software have produced software bundles designed for K-12 at affordable educational prices (see also Meyer, Butterick, Olkin, & Zack, 1999).

2. Data availability – data acquisition, according to Audet and Paris (1997), is a problem that varies according to the nature and scope of the instructional applications. Baker (2005) suggested that classrooms wishing to work with GIS could consider joining established online networks that use collaborative Internet-based mapping applications to explore and/or analyze data (for example, the GLOBE project, PathFinder Science network). Imagery and data sets from such agencies such as the National Aeronautics and Space Administration (NASA), the United States Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA) are available to K-12 students via the World Wide Web (McClurg & Buss, 2007).
3. Professional development – the complex nature of GIS training makes it imperative that ample professional development occur (Audet & Paris, 1997). Donaldson (2001) agreed and asserted that successful use of GIS in classrooms depends not only on the required hardware and software infrastructures but also the provision of teacher training. Meyer et al. (1999) contended that professional development and on-going support are critical elements to successful implementation of a GIS. Training is required for teachers, students, and technical support personnel so that the GIS system can be successfully integrated into appropriate situations (Sanders et al., 2002). Bednarz (2000) posited that teachers integrating GIS into their classrooms may need to change their teaching styles

from a teacher-centered to a more student-centered approach like problem-based learning.

4. Time – according to McClurg and Buss (2007), GIS software is more sophisticated than many of the application programs used in schools. The teacher needs time to master the use of the new technology and time within the existing curricula to introduce a new learning experience (see also Meyer et al., 1999). Baker (2005) agreed and noted that GIS requires a substantial commitment of time from educators to learn the software, the complexity of data, and the development or modification of instructional materials supported by GIS.

A GIS creates a learning environment in which students can visually explore, analyze, and make decisions about problems in an interactive and challenging manner (Audet & Ludwig, 2000). Descriptions of an interactive visualization project and research studies on implementing a GIS in K-12 classrooms in different subject areas are presented in the following paragraphs.

The *Geographic Data in Education* (GEODE) *Initiative* at Northwestern University (http://www.geode.northwestern.edu/index.html) supports a middle school and a high school curriculum initiative. Both initiatives integrate scientific visualizations into an inquiry-based program of hands-on labs, group work, and discussions to enhance students' understanding of the scientific and social issues associated with our changing environment. Most of the GEODE Initiative's curricula are organized around a real-world case. GEODE Initiative's research has shown that scientific visualization, incorporated into inquiry-based learning, can enable students of diverse abilities to develop an understanding of complex phenomena in the Earth and environmental sciences.

Keiper (1998) conducted a case study to investigate the outcomes of using a GIS to teach geography in an elementary school classroom. Twenty-nine fifth-grade students participated in that study. The teacher described those students as “above average,” and highly interested in and motivated by computer technology. The school had some use of computer technology but no knowledge of a GIS. A GIS computer module was developed for use in that study and a rubric was created to assess skill development. Internal validity and reliability were ensured by triangulating the data; that is, using multiple sources of data. Data were collected through observations, interviews, survey results, and performance assessment results. The study found that the GIS module was extremely motivating and well received, and it afforded the students a great opportunity to practice the geographic skills outlined in the national standards. The GIS module did not, however, appear to lead to a positive attitude toward geography.

The insights Keiper gained with regard to strategies for implementing the GIS included the GIS module should be used within the framework of the existing curriculum, the use of local data within the context of an authentic situation was effective, and the GIS module encouraged student responsibility. Some challenges faced by implementing that GIS module were frustration with the technology, other group members and insufficient time. The external validity of those findings is a concern. While this study found that the use of a GIS increased students’ motivation and interest, the population for that study consisted of only outstanding students, who, before the treatment were already interested and motivated by computer technology. Those two factors might have contributed to students finding the GIS module motivating. In addition, no information was provided on the validity and reliability of the geographic skills rubric.

Kerski (2003) investigated the effects of inquiry-based lesson modules that use GIS technology on teaching and on the acquisition of standards-based geographic content and skills. His study was conducted with 184 students in grades nine, 11, and 12 in three public high schools in a metropolitan area enrolling between 1,200 to 3,000 students. The schools were selected based on criteria aimed at ensuring that the schools, courses, teachers, and students would be as equivalent as possible. The study was implemented for a whole academic year in one school and for one semester in the other two schools. Whole sections or class periods of students were kept in the same group rather than splitting a class in half, and groups were assigned randomly to treatment as part of regular course and room assignments.

Kerski created two versions of geography lessons, a GIS-based version for the experimental group, and a version using traditional print materials (textbooks, paper maps, atlases, and data tables) for the control group. He administered a pretest, two standardized tests and a posttest. The two standardized tests were based on national, state, and district geography standards; one test was created by National Council for Geographic Education, and the other test was created by the County Assessment Board. The effectiveness of a GIS on student performance using standardized and spatial analysis tests showed mixed results in each school. To test the difference between pretest and posttest scores, he conducted paired *t*-tests that revealed no significant difference between the experimental group [$t(45) = 4.5556$, $p = .0001$] and the control group ($t(47) = 4.4980$, $p = .0001$] in the first school, significant differences for both experimental group [$t(68) = 3.9475$, $p = .0001$] and control group [$t(45) = 7.1034$, $p = .0001$] in the second school, and a decline in scores for both experimental group [$t(14) = 2.3227$, $p =$

.0358] and control group [$t(7) = -1.1784$, $p = .2771$] in the third school. In four out of nine tests, Kerski found that students who used GIS performed significantly better on their assignments than those who used traditional methods.

The researcher found some barriers to the adoption of GIS such as limited hardware and software, limited time required to develop GIS-based lesson modules, and inadequate student access to computers. Other barriers included inadequate training, and pressure to teach a given amount of content during each term. The researcher concluded that a GIS seems to foster higher-order analytical thinking and also appeared to improve learning of content and not just skills. This study did not, however, make clear the factors that might have contributed to the disparate findings across the three high schools. It was also unclear whether the spatial analysis tests developed by the researcher were valid and reliable.

Crabb (2001) sought to describe the issues, contexts, processes, and outcomes involved as he integrated a GIS into the teaching and learning of geography in a ninth grade classroom. He conducted a seven-week study with a purposive sample of 21 students enrolled in two honors world geography classes. He employed a mixed method research design, with the qualitative methodology being the dominant design. The researcher integrated GIS activities into the geography curriculum, and taught the two classes. Data were collected using interviews, observations, field notes, student journals, student-created documents, and photographs. In addition, the researcher administered a GIS/geography test, a performance test, a computer skills survey, and an attitude survey at predetermined times to evaluate how well the students were acquiring GIS skills and geography knowledge as the study progressed. Crabb identified and refined categories in the data to form interpretations. The researcher employed several strategies to ensure the validity and reliability of the findings: triangulating the data by using multiple data sources and analysis, peer examination, member checks, long-term observation, participatory research, an audit trail, and recognition of his biases and assumptions at the onset of the study.

Among his qualitative findings were, a GIS complements existing geography curriculum, a teacher-created GIS curriculum is necessary for situation-specific activities, and block scheduling is advantageous for a GIS-based instruction. Other findings included a GIS infusion is time-consuming, school technology readiness and computer reliability need to be assessed, and resistance may be encountered in the integration process. Further, a GIS is best suited to constructivist teaching and learning, administrative and technical support is vital for successful integration, and the teacher and students perceived the GIS treatment as beneficial. The mean score of the performance test administered thrice (during week one, week five, and week seven) to measure student acquisition of twelve fundamental GIS skills increased ($M = 41.1$, $SD = 9.5$; $M = 56$, $SD = 5.5$; $M = 56.9$, $SD = 4.3$). Likewise, the mean score for the GIS/geography test administered thrice to measure student learning increased ($M = 52.8$, $SD = 8.7$; $M = 82.1$, $SD = 5.2$; $M = 84.5$, $SD = 5.3$). Crabb concluded that students' learning of geography was enhanced by the use of the GIS. While this study appears to support integrating a GIS to complement geography curriculum, the study sample consisted of only honors students so the findings cannot be generalized to other populations. There was no information provided on the validity and reliability of the performance test and the GIS/geography test. It is also possible that the students became better test takers since they took the same tests three times.

Shin (2006) conducted a case study in which she examined whether a GIS could be used as an effective tool to enhance how fourth graders learn geography. Her sample consisted of 18 fourth-grade students. She chose a school in a lower-to-middle class neighborhood in order for the sample to represent a more typical group of students. Shin developed a GIS module consisting of four lessons and administered the module in the classroom. All the four lessons corresponded with the national and state social studies curriculum standards. Students were asked to sketch mental maps before and after each lesson. Four areas (inclusion of roads, buildings, population distribution, and modes of transportation) were compared between pre- and post-instruction mental maps. To ensure reliability and internal validity of the findings the researcher used multiple methods of data collection and employed both qualitative and quantitative data analysis. Data were collected using observations, field notes, interviews and discussions with the teacher and students, and students' work and mental maps. Shin analyzed the data to find any emerging patterns. She also used quantitative methodology to analyze the mental maps. The pre- and post-instruction mental maps were scored using an established set of rubrics. The researcher compared the means of the sketched maps using paired *t*-tests. After the second lesson, the students' sketch maps indicated a statistically significant improvement in inclusion of modes of transportation [$t(14) = 4.432$, $p<.001$]. After the third lesson, the students showed significant improvement in inclusion of different modes of transportation [$t(14) = 3.798$, $p<.001$] and inclusion of different regions in the U.S. [$t(14) = 3.379$, $p<.001$]. Overall, the results were significant for students' ability to draw maps from aerial view [$t(14) = 5.329$, $p>.0001$], use of boundary skills [$t(14) = 4.938$, $p>.0001$], and accuracy [$t(14) = 4.938$, $p>.0001$].

The findings suggested that the students gradually grew in gaining geographic content knowledge as the lessons progressed. Thus, the students were able to progress in remembering and transferring the geographic content knowledge that they gained and used it when a new lesson was taught using a GIS. Shin concluded that the GIS enhanced students' ability to learn geography. One concern about this study is the reliability of its findings. Though the study used multiple data sources, the researcher did not mention any other methods that were employed to ensure those findings could be replicated. Also, there was no information provided on the validity and reliability of the rubrics that were used to score the mental maps.

The studies presented in this section are examples of how a GIS has been implemented in K-12 geography classrooms. The next section presents studies of how a GIS has been implemented in science classrooms.

The Promise of GIS to Enhance Science Inquiry

A GIS has been called the answer to providing authentic, inquiry-based learning environments within the K-12 classroom (Bednarz & Audet, 1999). Kerski (2003) contended that the use of a GIS has the potential to incorporate issues-based and inquiry-based learning, and to increase the relevancy and utility of the disciplines in which they are used. An issues-based approach sets up situations in which a) people feel able to discuss together, b) a worthwhile controversial issue is presented, and c) there is access to knowledge of various kinds relating to the issue (Their & Nagle, 1994). GIS technology empowers students to solve real-life problems as students identify problems, hypothesize, collect data, develop procedures, and produce workable results that they communicate to others (Ramirez & Althouse, 1995).

Baker and White (2003) investigated whether or not the use of a collaborative GIS to support a learning module in science positively affects acquisition and use of science process skills and attitude toward science and technology. The researchers developed two versions of a nine-day unit adhering to national and state standards for eighth grade earth science: a GIS-supported unit and a traditional (paper) mapping-supported unit. The student population consisted of 94% White, 2.7% African American, 0.6% Hispanic, and 2.7% all others. The sample consisted of two eighth-grade science teachers and all eighth-grade science classrooms for a total of 192 students. Whole classes of students were randomly assigned to a treatment group (n = 93) that utilized a PBL-GIS model or a control group (n = 99) that used traditional (paper) mapping techniques to support and foster data analysis and science process skills. Both groups took a pretest and a posttest to assess their attitudes toward science and technology concepts. A posttest only performance assessment was administered to gauge individual student achievement of science process skills. The performance assessment rubric was based on the Kansas State Science Performance Assessment rubric to which the researchers added some items to expand the data analysis concepts.

Paired t-tests analysis and an analysis of variance were conducted between experimental and control groups for attitudinal data and for gains in achievement respectively. Students who used the paper mapping techniques increased their attitudes toward science [$t(72) = 2.00$, $p<.05$]. Students who used the GIS-supported materials were found to show positive and significant improvements in science self-efficacy [$t(77)$

= 2.64, $p < .01$], and positive attitudes toward technology [$t(82) = 3.71$, $p < .001$], as well as performing significantly better [$F(1, 166) = 3.91$, $p < .05$] than traditional mapping students. A Cronbach's alpha reliability coefficient for researcher scoring/evaluation was 0.73 on all items and 0.79 on data analysis items. Baker and White concluded that the use of a GIS supports scientific inquiry and problem solving and can foster complex cognitive activities by students using sophisticated computer applications and data in an authentic learning environments. There is a concern, however, about the population validity of this study. Although the sample was typical of the population from which it was drawn, it is unclear whether the sample was representative of other populations to which the findings of this study might be generalized.

Hagevik (2003) conducted a mixed methods study to examine middle school students' understandings of the environment after using two GIS inquiry-based problem-solving science units. The sample for the study consisted of seventh and eighth graders (n =164) in two public middle schools and three teachers. One school had 96 students and the other school had 68 students. Each of the two schools was a North Carolina School of Excellence in which students had met high growth standards in academic gains during the 2001-2002 school year, a year prior to the study. All class periods were 50 minutes in length and were held every day for six weeks. The study employed a nonequivalent comparison group design and sought to investigate whether there were any differences in understanding environmental content between the experimental group (n = 131) and the control group (n = 33). Both experimental and control groups collected similar data about their school campuses, used a GIS to analyze patterns, formulate problems, and report results.

The experimental group did an open inquiry in which students chose their own problem questions and designed their own investigations. The control group did a guided inquiry in which the teacher chose the topic, the question, and provided the necessary materials required to complete the investigation. The instrumentation consisted of three quizzes developed by the researcher that measured students' understanding of the environment and a GIS. Qualitative data were collected from students' presentations of their projects, field notes, classroom observations, and interviews on the nature and extent of their understanding of environmental content and the GIS. The findings revealed that the experimental group performed significantly better on the quiz [$F(5, 158) = 9.33$, $p < .001$] than the control group. Qualitative findings revealed that all students reported that learning the GIS was important and that direct student experiences were important in learning and recall of information.

Hagevik concluded that a GIS may aid students in constructing concepts and in promoting understanding of environmental content, problem solving, experimental design and data analysis, and communicating findings to others. That study tends to support the conjecture that a GIS may play an important role in supporting authentic science inquiry (Baker & White, 2003). As mentioned earlier, students in both middle schools had met high growth standards in academic gains the year prior to this study. Thus, those findings might not be generalizable because the sample was not representative of other populations. Since there was no random assignment of the students to the treatments and no random assignment of the treatments, it is possible that the findings were influenced by the nonequivalence of the groups. It is also unclear whether the two GIS inquiry-based problem-solving science units were deemed equivalent given that they engaged students in different activities. There was no information provided on the validity and reliability of the three quizzes.

Barriers to Implementing GIS in Instruction

Few studies address the challenges of implementing a GIS. Parker (1999) noted that teacher inservice and preservice training on implementing GIS in the classroom are scarce, and there is poor equipment and insufficient access to equipment. Kerski (2003) agreed and noted that barriers to implementing a GIS in education are very similar to the challenges faced in implementing many educational technologies, such as a lack of teacher training, hardware and software issues (see also Crechiolo, 1997 and Shin, 2006). Sanders et al. (2002) noted that barriers to implementation of a GIS include insufficient hardware in schools, insufficient access in the classroom to existing hardware, lack of GIS software for use on available computers, and lack of usable data about the desired focus topic. Further, there were insufficient GIS skills on the part of teachers, lack of professional development opportunities and time to learn a GIS, and lack of specific relevant curriculum that includes a GIS. Some other barriers the authors noted included insufficient time to engage in open explorations with only vaguely defined goals or highly variable results, and the lack of pedagogical style conducive to a GIS especially as an exploratory tool.

Keiper (1998) also found some barriers to implementing a GIS were frustration with the technology, frustration with other group members, and insufficient time. Baker and Case (2000) agreed noting that many teachers find that time is a limiting factor on using a GIS because of the need for personal time to learn and practice using the GIS and the amount of time needed to teach the software to students. The authors suggested that teachers integrating a GIS into their classrooms need to make changes in their teaching styles, the most common of which is a shift to problem-based learning coupled with authentic assessment. Problem-based learning involves presenting a rich problem that affords free inquiry by students, and learning is student-centered (Hmelo & Evensen, 2000).

Science Instruction in Middle School

"Science is for all students," a principle that embodies both excellence and equity, is an underlying principle of the *National Science Education Standards* (NRC, 1996). Lynch (2000) defined equity as justice and fairness. She contended that achievement test scores are one of the indicators of equity in science education. The findings of the Trends in International Mathematics and Science Study (TIMSS) conducted in 1999 revealed that eighth-grade US students ranked 18th out of 38 nations, exceeding the international average score by 27 points (National Center for Education Statistics [NCES], 2000). In 2003 TIMSS results showed that eighth-grade U.S. students ranked 9th out of 45 nations in science achievement, exceeding the international average score by 54 points (Gonzales et al., 2004). While those findings show an improvement in performance, the U.S. has still not met the goal of being first in the world in mathematics and science achievement as envisioned by *Goals 2000: Educate America Act* (U.S. Congress, 1994). Regarding racial/ethnic groups in the U.S., both African American and Hispanic eighth-grade students demonstrated improvement in their average science achievement between 1995 and 2003, and between 1999 and 2003. However, achievement gaps between White and both African American and Hispanic students persisted across the three years.

On the national scene, the National Assessment of Educational Progress (NAEP) developed by the National Center for Education Statistics is a measurement tool used across the nation to assess student achievement in many subject areas including science. The NAEP science assessment is given to students in grades four, eight, and 12, and results are reported at each of those grade levels. The NAEP results are also analyzed for trends across time. For over three decades, NAEP assessments have been conducted periodically in various subjects to measure the academic achievement of elementary, middle, and secondary students over time. According to the results of the *Nation's Report Card: Science 2005* (Grigg, Lauko, & Brockway, 2006), middle school students have shown no improvement in their science achievement; overall science scores for eighth graders have remained unchanged since 1996. The average score for eighth-grade students in 2005 showed no significant difference from results in 1996 (O'Sullivan, Reese, & Mazzeo, 1997) and 2000 (O'Sullivan, Lauko, Grigg, Qian, & Zhang, 2003). Regarding racial/ethnic groups, African American students were the only group that made achievement gains since 1996. While African American students showed improvement, significant achievement gaps still persisted between White and minority students since 1996. Closing the achievement gaps among racial/ethnic groups while improving the science achievement of all students is a central commitment of the reform efforts in science education.

The Promise of GIS to Promote Environmental Education in Middle School

The Environmental Protection Agency (1996) defined environmental education as a learning process that increases people's knowledge and awareness about the environment and associated challenges, develops the necessary skills and expertise to address these challenges, and fosters attitudes, motivations, and commitments to make informed decisions and take responsible action. Environmental educators envision caring, responsible people who construct for themselves the values that underpin wise judgments and competent actions relating to the environment:

The *Belgrade Charter* (UNESCO, 1975) states that,

> The goal of environmental education is to develop a world population that is aware of, and concerned about, the environment and its associated problems, and which has the knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions of current problems and prevention of new ones. (p. 3)

According to the *National American Association for Environmental Education* (NAAEE, 2004), the general principles that guide environmental education instruction are,

- The learner is an active participant. Instruction should be guided by the learner's interests and treated as a process of building knowledge and skills.
- Instruction provides opportunities for learners to enhance their capacity for independent thinking and effective responsible action.
- Instruction should strongly emphasize developing communication skills for learners to be able to both demonstrate and apply their knowledge.
- Because environmental issues can prompt deep feelings and strong opinions, educators must take a balanced approach to instruction. Educators incorporate differing perspectives and points of view even-handedly and respectfully, and present information fairly and accurately.

- Environmental literacy depends on a personal commitment to apply skills and knowledge to help ensure environmental quality and quality of life. For most learners, personal commitment begins with an awareness of what immediately surrounds them.

Gough (1993) asserted that environmental education needs to challenge students with more complex and complicated learning experiences through real-world investigations. Audet (1993) stated further that combining real-world investigations and interactive visualizations (characteristic of a GIS) helps students grasp the interrelationships of natural and human elements in their environment and develop key concepts and inquiry skills. A GIS according to Tinker (1992) represents a technology that could support student investigation through the use of a set of software tools with particular applicability to a wide range of pressing environmental questions. Thus, inquiry into a real-world environmental science question with the help of a GIS may provide opportunities for middle school students to learn key science and environmental concepts.

CHAPTER 3: METHODOLOGY

The purpose of this study was to determine how a Web-based module might enhance science inquiry supported by GIS with eighth-grade students. This study investigated not only the prototype so developed, but also the implementation of such a module in the actual classroom. Changes in student knowledge of science content as a result of the implementation of the module were also assessed. Quantitative data was used to complement classroom observations, data from reflective meetings with the teacher, and data from the researcher journal. This chapter presents the study's research questions, research design, population and sample, instrumentation/data collection, treatment, statistical definition of fidelity of implementation, data analyses, and limitations of the study.

Research Questions

This study examined five interrelated research questions. Those questions were,

1. How faithfully was the teacher able to implement the design and what factors account for loss of fidelity?
2. What are the strengths and weaknesses of the design?
3. What improvements should be made to the design?
4. How does a GIS-supported learning unit affect students' attitudes toward science and technology?
5. Does a GIS-supported learning unit affect student science achievement?

Research Design

This study is an example of design-based research. Design-based research is the study of learning in context through the systematic design and study of instructional strategies and tools (Design-Based Research Collective [DBRC], 2003). According to Collins, Joseph, and Bielaczyc (2004), design-based research was developed as a way to carry out formative research to test and refine educational designs based on theoretical principles derived from prior research. Researchers test the designs in authentic settings and gather evidence about the impact of the materials. Bell, Hoadley, and Linn (2004) contended that design-based research studies improve designs for instruction and advance understanding of learning materials. Design-based research can help create and extend knowledge about developing, enacting, and sustaining innovative learning environments (DBRC, 2003). The focus of design-based research may be on developing a theory that characterizes the design in practice (Barab & Squire, 2004). The researcher develops a profile of the design in operation (O'Donnell, 2004). Design-based research, according to Wang and Hannafin (2005), posits synergy between practice and research in everyday settings.

Design-based research studies are guided by partnerships (Bell et al., 2004). Partnerships are interdisciplinary teams that include teachers, technologists, education researchers, and disciplinary experts who bring diverse but relevant expertise to the effort and practitioners and researchers collaborate to produce meaningful change in contexts of practice (DBRC, 2003). The partnerships develop shared criteria for the activities they are conducting and develop approaches for further modifying the materials and instruction. Those approaches involve putting a first version of a design into the world to see how it works. Then the design is constantly revised based on experience, until all the bugs are worked out. Our design partnership (team) consisted of nine people, an associate professor of science education and GIS expert (project director), two professors of Earth and environmental science, a graduate student with an environmental education and teaching background, three graduate students with GIS expertise, an eighth-grade science teacher, and a graduate student with an instructional design and teaching background (me).

A primary goal of design-based research is to improve the initial design by testing and revising conjectures as informed by ongoing analysis of both the students' reasoning and the learning environment (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The evaluation of the design is an ongoing iterative process that changes as the design changes. The iterative nature of design-based research, according to O'Donnell (2004), can contribute to the production of credible evidence. Bell et al. (2004) asserted that design-based research studies respond to the systematic, complex nature of education and align well with the goal of promoting inquiry in science courses.

According to the Merriam-Webster's learner's dictionary (2011), "a guideline is a rule or instruction that shows or tells how something should be done." Collins et al. (2004) offered 26 practices, elements, and variables under six headings that they termed "guidelines" for carrying out design-based research. Although the headings, practices, elements, and variables were helpful and informative, as worded, the vast majority of them did not meet Merriam-Webster's definition of a guideline. I, therefore, derived six appropriately worded guidelines that address what I suggest Collins et al. sought to convey. Each derived guideline is preceded by the name of the key component of design-based research that it addresses.

1. IMPLEMENTING A DESIGN: Identify the critical elements of the design and how they fit together, and describe how each element is addressed in the implementation.
2. MODIFYING A DESIGN: Modify the design if its elements are not working and describe the reasons for making the modifications.
3. EMPLOYING MULTIPLE WAYS OF ANALYZING THE DESIGN: Analyze the design on multiple levels such as cognitive, resources, interpersonal, group or classroom, and school or institution.
4. MEASURING DEPENDENT VARIABLES: Assess several dependent variables, including climate, learning, and system variables.
5. MEASURING INDEPENDENT VARIABLES: Assess several independent variables, such as the setting, nature of the learners, technical support, financial support, professional development, and implementation path.
6. REPORTING ON DESIGN RESEARCH: Report several aspects of the design, including goals and elements of the design, settings where implemented, description of each phase, outcomes found, lessons learned, and multimedia documentation.

Collins and his colleagues stated that they did not expect every study to address all the elements of each guideline but they hoped the design-based research community would move in the direction of adopting many of the ideas they suggested.

Each of the first five derived guidelines above deals with the formulation and testing of the design (methodology). As such, each logically should be discussed in this chapter and is, therefore, addressed in the appropriate section below. The sixth derived guideline above, however, is a mixture of methodological issues (like setting and study phases) and non-methodological issues (like aspects of the design and results of the research). While the methodological issues are addressed in the appropriate sections below, subsequent chapters in this dissertation discuss these non-methodological issues.

Population and Sample

This study was conducted in an eighth-grade classroom at a culturally and linguistically diverse middle school located in eastern Pennsylvania. The school was one of four middle schools in the school district. In 2006, the school was selected and added to the National Aeronautics and Space Administration (NASA) Explorer Schools (NES) project. The NES project (http://www.nasa.gov/offices/education/programs/national/nes2/home/index.html) is an initiative that promotes and supports the incorporation of NASA content and programs into science, technology, and mathematics curricula in grades four through twelve. Through the NES project, NASA establishes a three-year partnership with up to 50 school teams each year. Schools teams consist of teachers and education administrators of underserved students from diverse communities across the U.S. The project offers sustained professional development, student learning opportunities, technology tools for inquiry learning, and involvement of parents in their student's learning (Loston, Steffen, & McGee, 2005).

The middle school had an ethnically diverse population of approximately 623 students in grades six through eight. That student population comprised 65% Hispanic, 18% White, 15% African American, 1% Indian, and 1% Asian students. In terms of distribution by gender, 283 were female and 340 were male. Four hundred and sixty-six students (75%) received free lunch and 61 students (10%) received reduced-price lunch. Thus, the school had a poverty level of 85% based on the percentage of students receiving free or reduced-price lunches. One hundred students (16%) were special education students. Every teacher in the school had a laptop and a class set of student laptops. The sub-population of this study consisted of one eighth-grade science teacher and 108 eighth-grade science students from five of her classes (54% Hispanic, 30% White, and 16% African American). The assistant principal assigned the classes of students to one of three tracks: *advanced proficient*, *proficient*, and *below proficient*. The assistant principal assigned classes to these three proficiency tracks using his assessment of central tendency among the scores of students in the class on the mathematics and reading sections of the Pennsylvania System of School Assessment (PSSA) test. The PSSA is a standards-based criterion-referenced assessment used to measure a student's attainment of academic standards. The academic standards identify what a student should know and be able to do at different grade levels. Class sizes ranged from 13 to 32 students whose average age was 13 years old.

I used an intact group of students. My cluster volunteer sample consisted of all students that returned signed informed consent forms agreeing to participate in this study. Table 1 presents the class tracks, meeting times, and demographics of students in the five classes. The students had experience using ArcExplorer–Java Edition for Education (AEJEE) GIS software (http://edcommunity.esri.com/software/aejee) in their science and technology classrooms. The eighth-grade teacher had prior professional development experience using AEJEE GIS.

Table 1

Class Tracks, Times, and Demographics

Class	1	2	3	4	5
Track categories	"Below proficient"	"Below proficient"	"Proficient"	"Advanced proficient"	"Proficient"
Regular meeting time	8:40 – 9:30	9:30 – 10:20	10:20 – 11:10	11:10 – 12:00	2:15 – 3:00
Activity meeting time	8:30 – 9:15	9:15 – 10:00	10:00 – 10:45	10:45 – 11:30	1:30 – 2:15
Total number of students	15	13	26	32	22
Hispanic	10	9	13	11	15
White	2	1	9	19	2
African American	3	3	4	2	5
Number of females	4	6	15	20	10
Number of males	11	7	11	12	12

Note. The school operated on a six-day cycle. Class periods were 50 minutes on regular days (days 2, 3, 5, and 6) and 45 minutes on activity days (days 1 and 4).

Instrumentation/Data Collection

One characteristic of design-based research is that the design team deepens its understanding of the phenomenon under investigation while the experiment is in progress (Cobb et al., 2003). It is, therefore, important that the team generates a comprehensive record of the ongoing design process. The team should generate data on both learning and the means by which that learning was generated and supported. Thus, I assessed several dependent variables such as the students' content knowledge, students' attitudes toward science and technology, and the teacher fidelity of implementation of the design. The independent variables I assessed included the class proficiency rating and the time of day the classes met. I collected both qualitative and quantitative data. This is in keeping with Cobb et al.'s (2003) advice that multiple sources of data help ensure that retrospective analyses conducted when the experiment has been completed are likely to produce rigorous, empirically grounded claims and assertions.

Qualitative data were collected through (1) daily classroom observations using the appropriate protocol for the specific sub-model employed that day, for the larger model, and for assessing student performances; (2) daily reflective meetings with the teacher and, occasionally, with the project director, as well as implementation-related comments the teacher made as an aside in individual classes during the period; and (3) the daily researcher journal. According to Patton (2002), the purpose of observational data is to describe the setting that was observed, the activities that took place in that setting, the people who participated in those activities, and the meanings of what was observed from the perspective of those observed. Observational data represent a firsthand encounter with the phenomenon of interest; and observation relies on detailed, accurate, and extensive field notes (Bogdan & Biklen, 1992). Field notes from observations, according to Maxwell (1996), consist of two kinds of materials. The first is descriptive in which the concern is to capture a word-picture of the setting, people, actions, and conversations as observed. The other is reflective in which the concern is to capture more of the observer's frame of mind, ideas, and concerns (see also Bogdan & Biklen, 1992; Merriam, 1998). Thus, I recorded daily activities, teacher-student interactions, teacher's comments during class time, and my analytical thought processes and insights that occurred during data collection.

The daily classroom observation protocols listed the steps in each specific model/sub-model (see Appendix C). These protocols assessed two attributes, *duration* (if the teacher devoted the right amount of time to a step) and *completeness* (if the teacher implemented all events) of each step in the models/sub-models. Steps were made up of one or more *events* the teacher was supposed to do. The ratings on the protocol for duration ranged from 0 (*not done*) to 3 (*enough time devoted*), while the ratings for completeness ranged from 0 (*not implemented*) to 4 (*everything implemented*). I created a duration-and-completeness rubric with which I used to generate total scores for fidelity of implementation. Every step in the model was eligible to receive a maximum of 12 possible points (*teacher devoted enough time to the step* [3] and *teacher implemented all events* [4]). The duration-and-completeness multiplications produced nine possible ratings: 0, 1, 2, 3, 4, 6, 8, 9, and 12. These ratings convert to percentages of maximum possible points as follows: 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%. Table 2 presents the duration-and-completeness rubric with percentages of possible total scores indicated.

Table 2

Duration-and-Completeness Rubric with Percentages of Possible Total Scores for each Cell

Duration

Completeness	Enough time devoted (3)	%	Slightly less time devoted (2)	%	Much less time devoted (1)	%	Not done (0)	%	**Total**
Everything implemented (4)	Teacher devoted the right amount of time to the step and implemented all events that were suggested in the step to accomplish the goals.	100.0	Teacher devoted slightly less time to the step and implemented all events that were suggested in the step to accomplish the goals.	66.7	Teacher devoted much less time to the step and implemented all events that were suggested in the step to accomplish the goals.	33.3		0	
Many events implemented (3)	Teacher devoted the right amount of time to the step and implemented more than two thirds of the suggested events in the step but not all.	75.0	Teacher devoted slightly less time to the step and implemented more than two thirds of the suggested events in the step but not all.	50.0	Teacher devoted much less time to the step and implemented more than two thirds of the suggested events in the step but not all.	25.0		0	
Quite a few events implemented (2)	Teacher devoted the right amount of time to the step and implemented about two thirds of the suggested events in the step.	50.0	Teacher devoted slightly less time to the step and implemented about two thirds of the suggested events in the step.	33.3	Teacher devoted much less time to the step and implemented about two thirds of the suggested events in the step.	16.7		0	
A few events implemented (1)	Teacher devoted the right amount of time to the step and implemented about a third of the suggested events in the step.	25.0	Teacher devoted slightly less time to the step and implemented about a third of the suggested events in the step.	16.7	Teacher devoted much less time to the step and implemented about a third of the suggested events in the step.	8.3		0	
Not implemented (0)		0		0		0	Teacher did not do.	0	
Total									

I observed and assessed students in various performances daily to help evaluate the quality of the instructional materials. I assessed 10 specific performances (see Appendix C) such as what percentage of students worked independently, were on task, completed the task, and had thoughtful questions. The student performance protocol rated various student performances on a scale ranging from 0 (*performance not done by students/teams in the class*) to 5 (*performance done by more than 75% of students/teams in the class*). For example, for a performance such as *independence*, 0 represented that none of the students/teams worked alone without intervention from the teacher and 5 represented that more than 75% of students/teams worked alone without intervention from the teacher. I also met with the teacher daily to discuss her perspectives on the day's lesson, materials, and student performance. I asked the teacher to rate 10 aspects (see Appendix D) of the day's lesson on a scale ranging from 1 (*extremely badly*) to 5 (*extremely well*). At the end of each day, I assigned an overall rating for the design, student performance, science instruction, and the model on a scale ranging from 1 (*extremely badly*) to 5 (*extremely well*) in my research journal (see Appendix E).

The project director and I conducted simultaneous classroom observations in order to get a rough index of reliability of the observation protocols. We did the observations on days 6, 7, 8, and 9 for a total of 195 minutes. To measure the reliability of the observation protocols, I compared the project director's ratings and my ratings for both duration and completeness of steps in the models/sub-models, as well as the ratings for student performances. I used Cohen's kappa to obtain interrater reliability. According to Landis and Koch (1977), a kappa coefficient ranging from .61 to .80 is *substantial* agreement and .81 to 1 is *almost perfect* agreement. Cohen's kappa was .96 for the computer-supported activities protocol, .88 for the larger model protocol, .79 for the student performance protocol, and .73 for the combined content presentation and laboratory activities protocol. Thus, the coefficients for the computer-supported activities and larger model protocols fell in the *almost perfect* agreement range, while the coefficients for the student performance and the combined content presentation and laboratory activities protocols fell in the *substantial* agreement range. All four coefficients were statistically significant ($p <. 001$). I also calculated the interrater reliability for duration-and-completeness ratings for each sub-model. Cohen's kappa was .90 for duration and 1.0 for completeness for the computer-supported activities sub-model. These two coefficients were both significant ($p <. 001$). The combined content presentation and laboratory activities sub-models had interrater reliability of .78 for duration ($p = .001$) and .68 for completeness ($p <. 001$).

Quantitative data were also collected through the same three data sources/instruments that were used to collect qualitative data, as well as through two tests, one administered as an attitudes toward science and technology pretest/posttest and a second administered as a content knowledge pretest/posttest. The *Energy Unit Science and Technology Survey* (see Appendix A) was a subset of the *Science and Technology Survey* that was developed and validated by the content matter experts of the University of Montana's Geotechnology in the Classroom Project (GTEC) based on a variety of sources dealing with standards in geosciences (Crews, 2008). I sought permission to use select items from the Science and Technology Survey. To test the reliability of the instrument that measured attitudes toward science and technology, I calculated the internal consistency for both the pretest and posttest. The Cronbach's alpha was .89 for the pretest and .91 for the posttest.

The content knowledge pre-posttest was designed by the design team. The subject matter experts on the design team led by the project director verified the content validity of the content knowledge assessment. The internal consistency of the instrument was .76 for the pretest and .81 for the posttest. According to Nunnally and Bernstein (1994), a reliability coefficient of .70 and higher is respectable for research instruments used for comparing group data, as opposed to individual assessment (see also DeVellis, 1991). Although test-retest reliability is not generally considered to be a rigorous method of measuring reliability, I calculated it. The test-retest reliability of the attitudes toward science and technology instrument was .65 ($p <. 001$) and .59 ($p <. 001$) for the content assessment instrument. When the students took the posttests they were preparing to take the state-mandated standardized tests. Given the need to perform well each year on the state standardized tests in order to satisfy *No Child Left Behind* requirements, the school focuses very heavily each year on preparing students to perform as well as possible on these crucial tests, thus, affecting other normal classroom and school activities. This was the case during the administration of this study's posttests.

Treatment

The design team collaboratively designed a Web-based science inquiry unit on energy. We used the *Understanding by Design* (UbD) instructional development process model (Wiggins & McTighe, 2005) to identify desired results (goals or standards), determine acceptable evidence (performance), and plan learning experiences and instruction (see Appendix B). I then analyzed various design models and derived an instructional model (see chapter four) that would best bring about desired outcomes in student knowledge and skills when students engaged in the unit. The subject matter experts on the design team determined the content validity of the learning unit and two interface design and instructional design experts reviewed the interface and instructional designs of the unit.

Typically, courses are divided into units, which are subdivided into lessons, and lessons are made up of activities (Oliva, 1997; Posner & Rudnitsky, 2001). The structure of the energy unit was as follows, the unit was divided into days; each day had tasks/activities; tasks/activities utilized a specific model/sub-model; each model/sub-model had steps; and steps were made up of one or more events the teacher was supposed to do. The critical elements of the design were the models/sub-models that made up the instructional model. Table 3 presents the models/sub-models, the number of steps in each model/sub-model, the sequence of the study, and the frequency with which the models and sub-models were intended to be used. As shown, seventeen days of the unit were devoted to the computer-supported activities sub-model and a quarter of the unit utilized the content presentation sub-model. The blended sub-models consisted of two or more sub-models and the total steps ranged from 13 to 20. A fifth of the unit was allotted the use of these blended sub-models. In addition to the individual sub-models, a subset of the larger model which had five steps was used every day. Note that the unit introduction, unit review, and unit conclusion were also subsets of the larger model. The teacher used the appropriate model/sub-model for each day to teach.

Table 3

Number of Steps and Days Allotted for each Model/Sub-model

Model/Sub-model	Number of Steps	Days Scheduled	Total Number of Days
Computer-supported activities	8	3, 6-8, 10, 11, 14-17, 19, 25-30	17 (42.5%)
Content presentation	9	4, 9, 13, 18, 20, 22-24, 32, 33	10 (25.0%)
Blended sub-models (four)	12-16	2, 5, 12, 34-38	8 (20.0%)
Laboratory activities	13	21, 31	2 (5.0%)
Unit introduction	5	1	1 (2.5%)
Unit review	4	39	1 (2.5%)
Unit conclusion	4	40	1 (2.5%)

Students took a pretest prior to taking the inquiry unit supported by a GIS. The driving question for the unit was, *How do we plan for future energy use*? Students learned the various forms and sources of energy resources, alternative energy sources, and managing and conserving energy resources, among others. The main activities that students engaged in during the instructional unit included content readings; exploring and analyzing the distribution, production, and consumption of different kinds of energy resources around the world; conducting inquiry-based laboratories; developing an energy policy for a fictitious island; and presenting their energy policies at a simulation energy summit. Students used My World GIS software (http://www.myworldgis.org/) to explore and analyze world energy resources. My World GIS was developed by the Geographic Data in Education (GEODE) Initiative at Northwestern University. It was designed specifically for use in educational settings.

We chose to use My World GIS software because it combines the power of a full-featured GIS environment with the support and structure required by novice users in an educational environment. While AEJEE is free and is designed for use particularly in educational environments, it does not have all the features of a GIS environment. Also, ArcView is a full-featured GIS software (http://www.esri.com/software/arcview/index.html) that is too robust for middle-grade students. Since the students were using My World GIS for the first time, instruction was highly scaffolded. I developed handouts that provided simplified step-by-step instructions for using GIS map tools, provided instructions with appropriate screen shots to which students referred to at any time, and embedded screen shots of the desired results in the data-analysis activities.

I went to the school daily to observe the implementation of the unit. My role was that of participant-observer. In that role, the researcher observes and interacts closely enough with individuals to establish a meaningful identity within their group; however, the researcher does not engage in activities that are at the core of the group's identity (Gall, Gall, & Borg, 2007). In the course of the implementation, I held daily reflective meetings with the teacher and, occasionally, the project director to share and discuss her perspectives on each day's lesson. We discussed the elements of the design that worked well and those that did not work well, and modifications that needed to be made to the design in order to promote effective learning strategies. According to Cobb et al. (2003), regular debriefing sessions are the forum in which past events are interpreted and prospective events are planned for. I documented the teacher-identified strengths and weaknesses of the design, as well as suggested improvements to the design. The students took a posttest at the conclusion of the unit. The unit, which was designed to be done in eight weeks, took 13 weeks to be completed.

The design team also developed educative curriculum materials for the teacher. According to Davis and Krajcik (2005), educative curriculum materials are materials that are intended to promote teacher learning. The authors asserted that educative curriculum materials should help to increase teachers' knowledge in specific instances of instructional decision making and also help them develop more general knowledge that they can apply flexibly in new situations.

According to Raths et al. (1967), critical thinking is important because it causes students to be active learners (see chapter two of this document). The unit promoted critical thinking by having students use the knowledge they acquired and their own reasoning to formulate explanations and find solutions to the performance tasks outlined in the *Understanding by Design* framework. By using the GIS, students were able to interpret, analyze, evaluate, and make inferences from data based on sound judgment, which, according to Facione (1990), entails critical thinking. Constructivist teaching and learning were incorporated in the instructional module in a number of ways as discussed in chapter two. The instructional unit posed problems of emerging relevance that were complex enough to elicit multiple problem-solving approaches (Brooks & Brooks, 1993). Knowledge construction, social negotiation, and multiple viewpoints, essential components of a constructivist learning environment (Jonassen, 1994) were evident in the unit's authentic performance tasks. The tasks involved students determining ideal locations for placing different power plants, investigating how raw materials are refined to process liquid fuels, recommending ways to conserve energy, developing energy policies for the provinces of a fictitious island, and presenting the energy policies at a simulated energy summit. The essential and topical questions as well as the performance tasks in the instructional unit (see Appendix B) addressed the five objectives of Environmental Education (see chapter one), for example,

- Awareness: What damage have we done to energy resources?
- Knowledge: How may energy consumption impact the availability of resources?
- Attitudes: How can I manage and conserve energy resources?
- Skills: How does a GIS enable us to explore the worldwide consumption patterns of energy resources?
- Participation: What practices can you do at your school to use less energy?

Statistical Definition of Fidelity of Implementation

Design-based research relies on thick descriptive datasets and systematic analysis of data with carefully defined measures (DBRC, 2003). Fullan and Pomfret (1977) defined *implementation* as “the actual use of an innovation” (p. 336). The innovation in this study was a new instructional model for (1) using a GIS to support (2) science inquiry. In her review of the literature, O’Donnell (2008) noted that there was no universally accepted way to collect and report fidelity of implementation data. Several authors presented their fidelity of implementation data as percentages; that is, what proportion of the innovation or program was implemented (see for example, Dusenbury, Brannigan, Falco, & Hansen, 2003; Hall & Loucks, 1977; Mills & Ragan, 2000; Penuel & Means, 2004; Songer & Gotwals, 2005).

The proportion of elements of the innovation that were actually implemented may not, however, be the only way to gauge fidelity of implementation. Later in their article, Fullan and Pomfret (1977) extended their definition by stating that *fidelity of implementation* is “the extent to which actual use of the innovation corresponds to intended or planned use" (p. 340). This definition matches how other writers define *integrity* and *adherence* (see, for example, Brandon, Taum, Young, Pottenger, & Speitel, 2008; Dane & Schneider, 1998; McGrew, Bond, Dietzen, & Salyers, 1994; Sánchez et al., 2007; Ysseldyke et al., 2003). Brandon and his colleagues contended that "collecting data on adherence requires that evaluators measure how fully or frequently discrete steps, units, or components are implemented" (p. 236).

But even if we use percentages to represent the proportion of steps implemented or the extent to which the teacher followed the design's prescribed sequence, we are still left with the question of what constitutes *high, medium,* and *low* fidelity of implementation. I was unable in the fidelity of implementation literature to find a general standard for what percentages represent such fidelity ratings. I searched online for instances where the terms *high, medium,* or *low* fidelity were used, in order to get a sense of how these three categories might be determined. The best illustration I found was in audio recording where the terms *low fidelity* and *high fidelity* are used to refer to digital audio files with lower and higher sampling rates, respectively (Wikipedia, 2010a). In digital audio, 44,100 Hz is the widely used sampling rate for audio CDs; 22,050 Hz is half the sampling rate of audio CDs and is used for medium quality audio; and 11,025 Hz is a quarter the sampling rate of audio CDs and is used for lower quality audio (Regina Public Schools & Saskatchewan Learning, 2002; Thaddeus Computing, 2010; Wikipedia, 2010b).

If one assumes that the commonly used top sampling rate, 44,100 Hz, represents *high* fidelity (100%), then 22,050 Hz would represent *medium* fidelity (50%) and 11,025 Hz would represent *low* fidelity (25 %). Using these positions on the audio sampling spectrum (and their associated percentages), I derived a continuous scale to help me classify the fidelity of implementation data. That scale consists of three bands, each of which represents one-third of the fidelity spectrum. Thus, *low* fidelity implementation would be represented by implementation percentages between 0 and 37.5% (inclusive) – equating to 0 to 16.5 KHz on the audio sampling spectrum; *medium* fidelity implementation would be represented by percentages above 37.5% but lower than 75% – equating to sampling rates above 16.5 KHz but below 33 KHz; and *high* fidelity implementations would be represented by percentages of 75% or higher –equating to the remainder of the sampling spectrum up to 44 KHz.

Note that this statistical definition sets the threshold for *high fidelity* implementation at 75%, rather than 100% or some value much closer to 100%. Mowbray, Holter, Teague and Bybee (2003) contended that there is always a valid reason to adapt a program to the setting; for example, populations in different locations have different strengths and needs. Cho (1998) agreed and noted that teachers cannot help but fit an innovation to their contexts, thus, adapting the innovation to the setting (see also Penuel & Means, 2004). Mowbray and her colleagues cautioned, however, that adaptation should not contradict the underlying intent of the program (see also O'Donnell, 2008). Hall and Loucks (1978) asserted that developers may allow user adaptation of innovation components up to a *point of drastic mutation* beyond which the adaptations made to the innovation will not be acceptable. If a program is adapted to meet the demands of the instructional setting, one would, therefore, not expect 100% fidelity of implementation and the system employed here recognizes this fact.

Data Analyses

To answer research question one, I used Microsoft Excel 2008 for Macintosh (Microsoft, 2007) to analyze each model and sub-model for the proportion of specified steps actually implemented by the teacher (*actual use*) and the extent to which the teacher followed the design's prescribed instructional sequence in implementing individual steps in the models/sub-models (*adherence*). I then conducted a content analysis of the data collected from my classroom observations, reflective meetings with the teacher, comments the teacher made in the course of the class periods, and my research journal to determine the factors that accounted for loss of fidelity.

To answer the second and third research questions, I conducted a content analysis of the data from my classroom observations and reflective meetings with the teacher. Patton (2002) defined content analysis as the process of identifying, coding, and categorizing the primary patterns in the data. I analyzed field notes from my observations, reflective meetings with the teacher, and journal entries for themes and recurring patterns and wrote down words and phrases (coding categories) to represent those themes and patterns.

To answer research question four, I used *Predictive Analytics Software* [PASW, formerly SPSS] version 18.0.2 for Windows (IBM, 2010) to run a paired *t*-test of the students' scores on the *Energy Unit Science and Technology Survey* instrument. This measure helped me evaluate the influence of the learning unit on the students' attitudes toward science. To answer research question five, I used PASW's *t*-test for correlated means to compare students' content knowledge pretest and posttest means. This measure helped me evaluate student learning of content.

Limitations of the Study

This study involved only one teacher and an intact sample of students in five of her classes. The teacher was a member of the design team and was very dedicated to the project. There was no control group that would have helped us verify that the student outcomes were really caused by the treatment. Thus, the findings may not be generalizable because the participants and setting in this study may not be representative of other populations and settings.

Though the interrater reliabilities of the different classroom observation protocols were high, they were based on a few classroom observations that were done in the first few days of the study. It is possible that my biases and assumptions subsequently affected my judgment in assigning ratings. This may also be unlikely because findings from the different data sources seemed to triangulate.

CHAPTER 4: INSTRUCTIONAL THEORIES AND DESIGN MODELS

As discussed in the previous chapter, this study is design-based research. Design-based research studies are guided by partnerships. Our design partnership (team) consisted of nine people, an associate professor of science education and GIS (Geographic Information System) expert, two professors of earth and environmental science, a graduate student with an environmental education and teaching background, an eighth-grade science teacher, three graduate students with GIS expertise, and a graduate student with an instructional design and teaching background (me). The design team met to discuss the scope and sequence of the unit. The two professors were the subject matter experts, the associate professor was a subject matter expert and also helped with designing the unit, the graduate student was a subject matter expert and also helped with developing the unit, and the GIS experts were responsible for developing the GIS files. My design task was to derive an instructional model that would best bring about desired outcomes in student knowledge and skills when students engaged in a unit developed using my derived instructional model.

Instructional designers use the general principles of teaching and learning and systematically apply them to design effective, efficient, and relevant instruction. They identify and analyze the goals and objectives of the instruction as well as the audience. They work with subject matter experts to identify what content needs to be presented. They make decisions such as what methods of instruction should be used for the given content and target audience. They then organize, structure, and sequence the content, learning activities, and assessments in an optimal way in order to achieve the goals and objectives of the instruction.

It is easy to become confused by the difference between an instructional theory and an instructional model. An instructional **theory** states a series of beliefs or principles about teaching and learning. Theories can either be prescriptive or descriptive. Descriptive theories make general statements about how learning occurs, while prescriptive theories specify what a teacher or students should do. An example of a broad belief is “learners learn most effectively by doing” while an example of a broad principle is “learners work hardest when they take ownership for the learning.” Both of these are rather general statements. They do not provide specific details of what a teacher needs to do in the learning environment in order to assure that learners “do” whatever it is that leads to greater learning or how teachers promote student “ownership” of the material under study. Further, an instructional theory may postulate numerous beliefs or prescriptions without making clear in what sequence they should be implemented or what teachers or designers need to do in order to implement them appropriately. In contrast, an instructional **model** takes one or more instructional theories and applies a theory’s beliefs and principles to real-world instructional settings to create an instructional sequence designed to achieve what the theory argues is most important. Instructional models turn broad instructional prescriptions into realistic applications; they present explicit guidelines in form of sequenced steps. In this way, such models provide guidelines on how to organize and present the instruction, how and when to practice, and when and how to assess. For example, while either an instructional theory or an instructional model might state that “students should explain their solutions using valid arguments,” an instructional model would sequence this activity among other activities to accomplish the broader goal, in this case perhaps to enhance learners’ critical thinking skills. In creating an instructional model, a designer may discover that there are, in addition to the instructional principles implemented in specific activities of the model, broader principles that apply across all activities to which the model is applied. Such principles are known as meta-principles. In many cases, meta-principles reflect the implementation of some of the broader beliefs of instructional theories.

In the sections that follow, I first address the conditions and limitations under which I designed. Second, I address three instructional design theories and present their prescriptions. Third, I address four instructional development process models and present their steps. Fourth, I address three instructional models and identify and discuss components that I selected to include in my instructional model. Fifth, I address the strategies of the derived instructional model and how I implemented those strategies. Lastly, I address the meta-design principles that I used to design the unit.

Design Conditions and Limitations

Instructional designers do not design in a vacuum. They are constrained by the settings in which they work and by the instructional conditions under which the materials they design will be used. This project was no different. There were six conditions and limitations that shaped how I designed my materials and what instructional approaches I was able to employ.

1. The students were of diverse ethnic backgrounds with 19 % of them being non-native English speakers. Eighty-three students (41%) received lower scores on the 2008 Pennsylvania System of School Assessment (PSSA) reading test. Thus, almost half of the students would be classified as low-level readers.

2. One hundred and ninety-eight students (78%) received lower scores on the 2008 Pennsylvania System of School Assessment (PSSA) science test. Therefore, more than three quarters of the students would be classified as low-level science learners.

3. The school had adopted the *Understanding by Design* instructional development process model for its new science curriculum. I was required to design instruction using this model.

4. Science education experts and earth and environmental science experts who were part of the larger design team developed the content. As with all design projects, my role was to organize, sequence, and design science instruction, not the content. The instruction was to be completed in eight weeks and developed materials had to be reviewed and approved by the design team.

5. The instructional unit was to be supported by My World GIS. The students and the teacher did not have experience using this particular GIS software. They were going to use My World GIS for the first time. This is important because, as Keiper (1998) found, one of the barriers to implementing a GIS in the classroom is student frustration with the technology. Further, Baker and Case (2000) noted that many teachers find that time is a limiting factor on using a GIS because of the need for personal time to learn and practice using the GIS and the amount of time needed to teach the software to students. It appeared that using a GIS in the classroom may have some unusual cognitive demands on the learners and time constraints on the teachers.

6. Other barriers Keiper (1998) noted to implementing a GIS in the classroom were lack of a specific relevant curriculum that includes a GIS and lack of a pedagogical style conducive to a GIS (see also Sanders et al., 2002). Hence the reason for me designing and developing the instruction.

Instructional Design Theories

This section addresses three instructional design theories and their instructional prescriptions that guided me in the design process. The theories include behaviorism, constructivism, and inquiry teaching. I chose the behaviorist theory because the population of students with which the study was to be conducted is one that research suggests is likely to benefit from direct instruction and extensive practice, two behaviorist approaches (Gerstern, Keating, & Becker, 1988). In addition, behaviorists tend to emphasize correct responses and I was concerned that the students in my study would be measured against state standardized tests that employ behaviorist assessment techniques almost exclusively. I chose the constructivist theory because I wanted students to construct their own meaning of concepts and collaborate on performing tasks as they learn from one another. I chose the theory of inquiry teaching because I wanted students to engage with hands-on activities and use evidence to justify their explanations, just like scientists do. Further, inquiry is the central tenet of science education reform.

Behaviorism

This theory is concerned with external, observable, and measurable behaviors. Behaviorists claim that there is a response to every stimulus and the response is immediate (Watson, 1930). The individual must be conditioned first to stimuli and the environment does that conditioning (Watson, 1928). According to Pavlov (1928), the basic process of learning is the formation of an association between a stimulus and a response (S-R). Associations, once established and acquired between definite stimuli and responses, are persistently and automatically reproduced. Different extra stimuli, however, inhibit and discoordinate a well established routine of activity. Thorndike and Gates (1930) posited that the connection between a stimulus and a response can be strengthened by rewards or weakened by punishment; that is, if something is to be learned, a reward must be presented for the desired behavior and if something is to be eliminated, punishment must follow. Rewards shape the behavior and continue to be important long after an organism has acquired behavior (Skinner, 1954; 1974).

Behaviorists contend that learning occurs because of associations among stimuli and responses. A response that one wants the individual to learn must be made contingent on the occurrence of certain stimulus conditions, which in turn bring about another response. Most behavior involves multiple S-R units that are "chained" together in a particular sequence (Gagné, 1985). The learner must be prepared for the next response in a sequence and a difficult task should be approached by gradual steps. According to this theory, learning has occurred when learners evidence the appropriate response to particular stimulus.

Bugelski (1971) and Snelbecker (1974) synthesized the instructional practices deriving from behaviorism as follows,

1. The teacher must be in charge of the whole learning environment.
2. The teacher should take into account the temperamental differences among learners.

3. Since the learner can be conditioned to respond favorably or unfavorably to his/her teacher, content material, and surrounding, the teacher should take steps to elicit the appropriate response from the learner.
4. Learners should be rewarded immediately for correct responses.
5. Learners must be ready for learning to take place.
6. The teacher should ensure learners have the prerequisite knowledge and skills.
7. The teacher should identify and eliminate competing responses.
8. The teacher should provide enough practice until all content is well learned.
9. A learner who is avoiding the learning situation should not be taught.
10. The teacher should reinforce every desired behavior.
11. Punishment should not be used to foster learning.
12. The teacher should break down instruction into small components and teach those small components.
13. The learner should never leave the learning environment with an incorrect response. The last response should be correct.

Constructivism

According to Savery and Duffy (1996), constructivism is a philosophical view on how we come to understand or know. Jonassen (1994; 1999) asserted that knowledge is individually constructed by the learner and socially co-constructed by learners based on their interpretation of experiences in the world. Instruction in a constructivist environment is more a matter of nurturing the ongoing process whereby learners ordinarily and naturally come to understand the world in which they live (Knuth & Cunningham, 1993). What learners understand is a function of the content, the context, the activity of the learner, and the goals of the learner (Savery & Duffy, 1996). Knowledge is constructed from experience and there may be little or no shared reality among them, since learning is a personal interpretation of the world (Bednar, Cunningham, Duffy, & Perry, 1992). Cognitive conflict or puzzlement is the stimulus for learning and determines the organization and nature of what is learned. In a learning environment, there is some goal for learning. That goal is a major factor in determining what the learner attends to, what prior experience the learner brings to bear in constructing an understanding, and what understanding is eventually constructed.

Bednar et al. (1992) suggested that learning is an active process in which meaning is developed on the basis of experience and learning should be situated in a rich context that is reflective of real-world contexts. Constructivists also argue that knowledge evolves through social negotiation and through the evaluation of the viability of individual understandings. The social environment is critical to the development of our individual understanding because learners can test their own understanding and examine the understanding of others to enrich, interweave, and expand their understanding (Honebein, 1996; Knuth & Cunningham, 1993). According to Vygotsky (1978), learning awakens some internal developmental processes which are developed through guidance by or interaction with others. He used the term "zone of proximal development" to describe "the distance between the actual developmental level of a child as determined by independent problem-solving and the level of potential development as determined through problem-solving under adult guidance or in collaboration with more capable peers" (p. 86). Another constructivist contention is that meaning is negotiated from multiple perspectives for students to understand alternative views (Duffy & Jonassen, 1992; Honebein, 1996).

The instructional practices deriving from constructivism, as synthesized from several authors (Bednar et al., 1992; Duffy & Jonassen, 1992; Honebein, 1996; Knuth & Cunningham, 1993; Savery & Duffy, 1996), include,

1. Anchor all learning activities to a larger task or problem. The learner should clearly perceive and accept the relevance of the specific learning activities in relation to the larger complex task.
2. Provide experience with the knowledge-construction process by having students take primary responsibility of determining the topics, the methods of how to learn and the strategies for solving problems. The role of the teacher is to facilitate this process.
3. Provide experience in and appreciation for multiple perspectives since problems in the real world rarely have one correct solution. Students must engage in activities that enable them to test ideas against alternative views and alternative contexts to enrich their understanding.
4. Design authentic tasks; that is, tasks that have relevance in the real world.
5. Embed learning in realistic and relevant contexts for students to be able to transfer what they learn in school to everyday life.
6. Support the learner in developing ownership for the overall problem or task. Students should play a strong role in identifying their issues, direction, goals, and objectives with the teacher's guidance.

7. Embed learning in social experience to encourage interactions and collaboration between both teachers and students, and students and students.
8. Design the task and the learning environment to reflect the complexity of the environment students should be able to function in at the end of learning.
9. Design the learning environment to support and challenge the learner's thinking.
10. Encourage the use of multiple modes of representation such as oral and written communication, video, computer, photographs, and sound to provide richer experiences.
11. Give the learner ownership of the process used to develop a solution.
12. Evaluate the knowledge construction process along with the product.
13. Encourage self-awareness of the knowledge-construction process. Students should be able to explain how they solved a problem in a certain way and why. Teachers should model reflective thinking throughout the learning process and support the learners in reflecting on strategies for learning as well as what learned.

Inquiry Teaching

Collins and Stevens (1983) suggested that the main components of inquiry teaching are (a) the goals of teachers; (b) a set of strategies for achieving those goals; and (c) a mechanism for deciding which goal to pursue when. In inquiry teaching, the goals of the teacher are to teach students to apply particular rules or theories and how to derive rules or theories. Learners are required to discover generalities based on observation of varied cases, presumably to force greater depth of processing of the new knowledge (see also Collins, 1987). Inquiry teachers use a set of strategies to accomplish these goals, many of which are intended to develop higher-order thought processes. Collins and Stevens (1983) suggested the following strategies for inquiry teaching,

1. Select positive and negative exemplars to highlight the relevant factors.
2. Vary cases systematically to emphasize particular factors.
3. Select counterexamples to make students pay attention to different factors.
4. Generate hypothetical cases to challenge students' reasoning.
5. Learners should form hypotheses to predict how variables vary.
6. Learners should test hypotheses by controlling variables or testing out special cases that are important for them to learn.
7. Learners should consider alternative predictions when making conclusions.
8. Entrap students by suggesting incorrect hypotheses to get the students to reveal their underlying misconceptions.
9. Trace consequences to a contradiction to correct students' misconceptions.
10. Learners should question authority by conducting their own experiments and reaching their own conclusions, and no just relying on the teacher or a textbook for the answers.

Instructional Models

This section addresses two categories of instructional models that I used in designing instruction. The two categories include instructional development process models and instructional design models. Instructional development process models describe the phases/stages of designing and developing instruction, while, instructional design models provide steps to guide designers organize, structure, and sequence instruction. Designers use instructional design models to make decisions about how content ideas are sequenced, the use of overviews and examples, how to practice, and how to assess. The paragraphs that follow discuss these two categories of instructional models and the various models under each category that I used.

Instructional Development Process Models

An instructional development process model describes the phases of the entire process of planning, preparing, and creating effective instruction. It provides the designer a systematic way of designing instruction. This section describes four instructional development process models. The second and third models are a variation of the first model, while the fourth model focuses on enhancing student motivation. As I present each process model below, I talk about why I selected that model.

ADDIE Models. The ADDIE model is a generic and simplified instructional development process model. ADDIE is an acronym for **A**nalyze, **D**esign, **D**evelop, **I**mplement, and **E**valuate (Learning Theories Knowledgebase, 2008; Strickland, 2006). Each phase of this model feeds into the next phase in the sequence as illustrated in Figure 1.

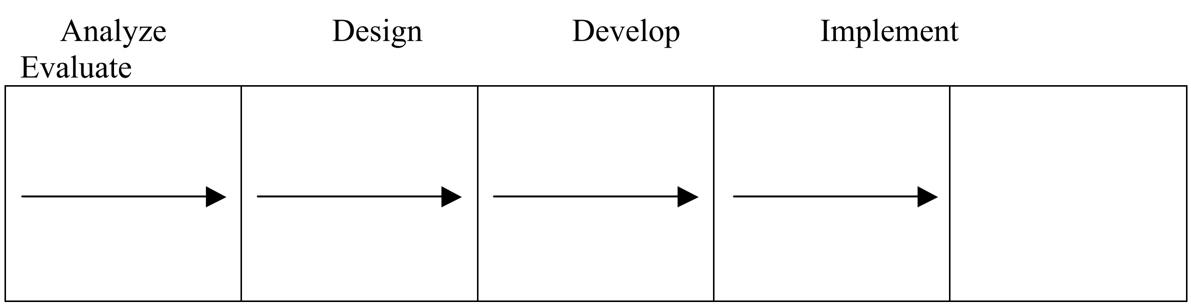


Figure 1. The ADDIE model.

In the *analyze* phase, designers clarify the instructional problem, the goals and objectives, and the learner characteristics. The designers also identify the learning environment, including any constraints. The *design* phase deals with systematically designing the measurement plan, instructional plan, instructional strategies, and choosing media. Detailed storyboards are often created in this phase. In the *develop* phase, designers create and assemble content and instructional materials according to the decisions made during the design phase. The prototype materials are then tested with target audience in the *implement* phase. Also, the product is put in full production. Lastly, the *evaluate* phase consists of two parts. Formative evaluation is done in each phase of this process. Summative evaluation consists of criterion-referenced tests and is also done to provide opportunities for feedback from the users. Designers make revisions based on this feedback as needed.

Many variations of the ADDIE model exist and I describe two variations below. In each case, I make clear why I chose to discuss that variation.

Dick and Carey Model. Probably the best known variation of the ADDIE model is the Dick and Carey systems approach to designing instruction (Dick, Carey, & Carey, 2009). This model has evolved over the years to include a wider range of analyses (Dick & Carey, 1978; 1985; 1990; 1996; Dick, Carey, & Carey, 2001; 2005). It breaks ADDIE's basic five phases into nine stages. Further, it makes clear that the process is iterative; that is, a designer goes back to any of the stages of design to make revisions. A phase may contain one or more stages. Stages break down the phases into more specific details and provide more guidance on how to design. Although the model specifies sequenced stages, it recognizes explicitly that many design processes are complementary and may occur near simultaneously. The nine stages of the Dick and Carey model and where they fit in the five phases of the ADDIE model are presented in Figure 2. The designer first identifies the goals that will represent a desirable performance. The designer then conducts a needs assessment to identify a discrepancy between a desired performance and the current performance. The designer conducts an instructional analysis to determine the skills involved in reaching a goal. The three different sub-analyses include task analysis which gives a list of steps and skills used at each step in a procedure; information-processing analysis which gives the mental operations used by a person who has learned a complex skill; and learning-task analysis which is appropriate for objectives of instruction that involve intellectual skills. A designer may need to conduct any or all three sub-analyses. Stage 2 may occur before, after, or simultaneously with Stage 3. In the *identify entry behaviors and learner characteristics* stage, the designer determines which of the required skills the learners bring to the learning task. The designer may also need to consider learner abilities and personality traits. Abilities may include, for example, verbal comprehension and reading level. The designer then writes sufficiently specific and detailed performance objectives. Performance objectives are statements of observable, measurable behaviors. They specify what learners will be able to do as a result of completing the instruction. Next, the designer develops criterion-referenced test items. Criterion-referenced tests measure the performance of the students against predetermined standards. The tests help to diagnose whether an individual possesses the necessary prerequisites for learning new skills, to check the results of student learning during the progress of a lesson, and to document student progress for parents and administrators.

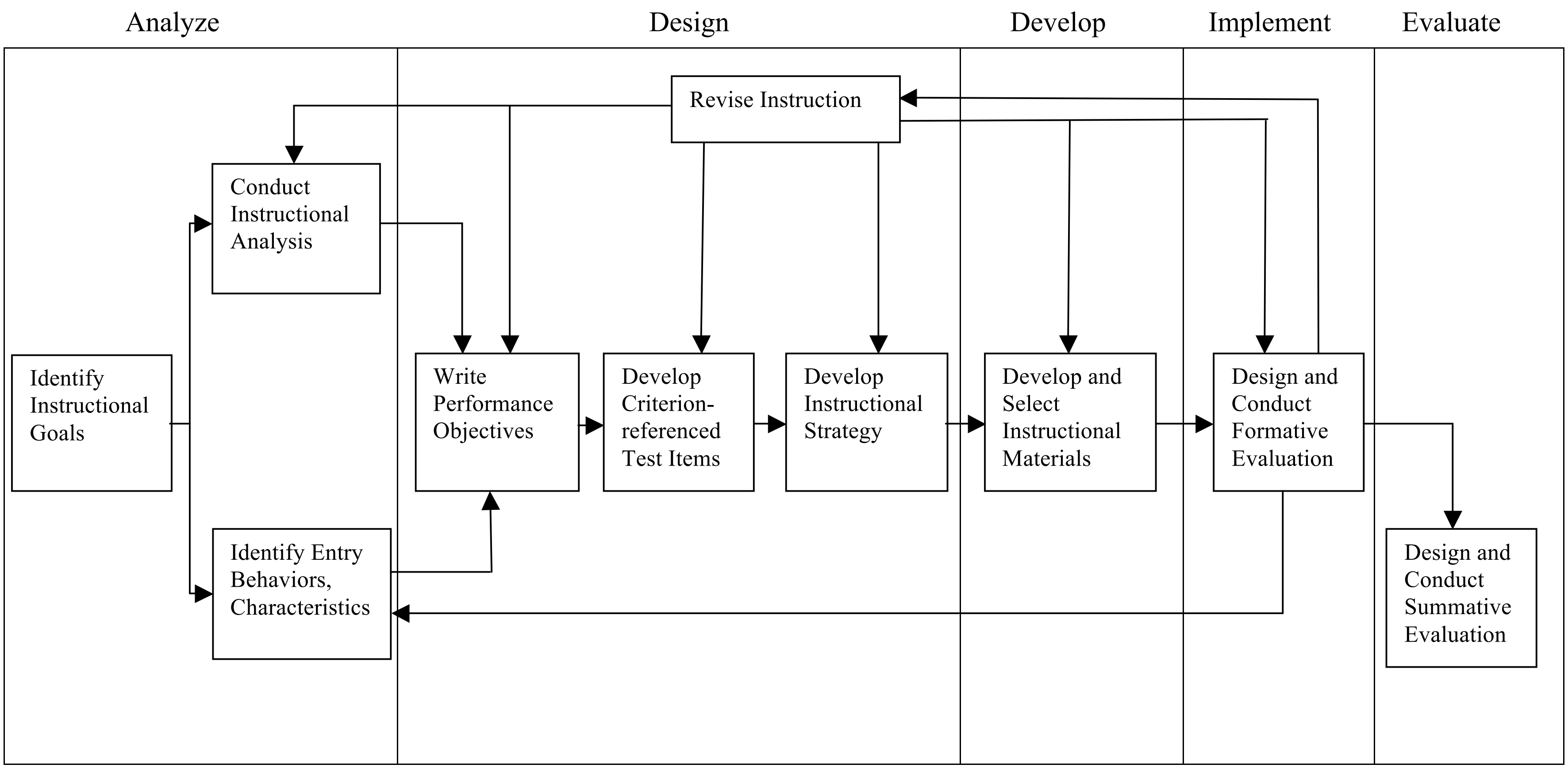


Figure 2. The Dick and Carey model.

Developing instructional strategy involves formulating a plan for how instructional activities will relate to the accomplishment of the objectives. The instructional activities entail prerequisites, presentation of content, practice, feedback, and assessment. The designer uses the analyses from the entry behaviors and learner characteristics, and the tasks included in the performance objectives to develop instructional strategies. In this stage, the designer also chooses the delivery system since different media have different capabilities for delivering instruction. The designer then uses the instructional strategies to develop printed or other media intended to convey instruction. Instructional materials include student modules, student handouts and worksheets, teacher's guides, videos, audio, and Web pages. The designer also selects existing relevant instructional materials.

Formative evaluation provides data for revising and improving instruction so as to make it as effective as possible for the largest number of students. This data may be collected by testing the prototype materials with one representative learner, with a small group of six to eight students, or with a whole class in a field test. The arrows looping back in the figure imply that data obtained at this stage may call for the revision of instruction at any of the previous stages of design. After instruction is revised, evaluation of the overall effectiveness of the instruction is done. Summative evaluation may take place at the time of the first field test or at a later time when large numbers of students have used the revised instruction. I selected this model because it provides more guidance on how to design instruction at every phase of the ADDIE model.

The Understanding by Design Model. As noted under design conditions and limitations earlier in this chapter, this project had to adhere to Wiggins and McTighe's

(2005) Understanding by Design model because that model had been adopted by the school for the design of its new science curriculum. This model focuses on selecting and teaching the “enduring” understandings of a given topic since there is usually more content than can realistically be taught. *Enduring understandings* refer to the big and important ideas that the teacher wants the students to retain. Wiggins and McTighe (1998) contended that “by having students encounter big ideas in ways that provoke and connect to students’ interests, we increase the likelihood of student engagement and sustained inquiry” (p. 11). The model emphasizes a “backward design” process that begins with designing assessment first then instructional activities last, as shown in Figure 3.

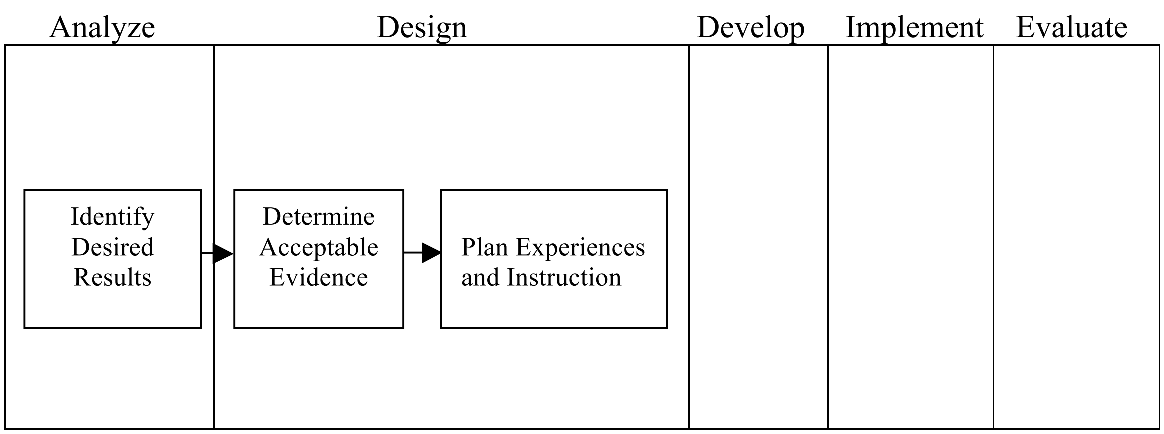


Figure 3. The Understanding by Design model.

This approach aligns clearly with the way ADDIE models operate. The first stage is concerned with what students should know, understand, and be able to do. It is also concerned with what content is worthy of understanding and what enduring understandings are desired. In this stage, designers should consider the instructional goals, and applicable national, state, and district content standards, and review curriculum expectations. Thus, the designer identifies instructional goals in this stage just like in the Dick and Carey model.

The second stage is concerned with what will be accepted as evidence of student understanding and proficiency; how designers will determine if students have attained the desired understandings and met the standards. Designers should consider various assessment methods such as oral questions, observations, quizzes, tests, open-ended prompts, projects and performance tasks. These assessments should vary from simple to complex, from short-term to long-term, from decontextualized to authentic contexts, and from highly structured to unstructured. The assessment of understanding should be done in terms of a collection of evidence over time. This stage aligns with Dick and Carey's *write performance objectives* and *develop criterion-referenced test items*.

In the third stage, the designer selects the most appropriate instructional activities. Designers identify the knowledge, skills, and activities that students will need to perform effectively and achieve desired results. Designers also identify what will need to be taught and how it should best be taught, in light of performance goals. Also, designers identify the materials and resources that are best suited to accomplish the goals. This aligns with Dick and Carey's *develop instructional strategy*.

Unlike the Dick and Carey model that provides guidance at every phase of the design process, the Understanding by Design model has only three stages; one in the *analyze* phase and two in the *design* phase. It does not provide any guidance on how to develop, implement, and evaluate instruction. Some crucial stages in the design process that are not included in the Understanding by Design model are identifying entry behaviors and characteristics of the learners and conducting formative and summative evaluation. The Understanding by Design model differs, however, from the Dick and Carey model because of its emphasis on teaching big ideas that are worthy of understanding.

Keller's ARCS Motivation Model. John Keller, working with colleagues and his students, formulated the ARCS Motivational Model (Keller, 1983; Keller & Kopp, 1987; Keller & Suzuki, 1988). The model postulates that there are four major categories of motivational factors that the instructional designer must understand and use in order to design interesting, meaningful, and challenging instruction. The four categories are **A**ttention, **R**elevance, **C**onfidence, and **S**atisfaction.

Attention refers to whether the learner's curiosity is aroused and whether this arousal is sustained appropriately over time. Strategies for attention include using novel, surprising, incongruous, conflictual, and paradoxical events (perceptual arousal); stimulating information-seeking behavior by posing or having the learner generate questions, or a problem to solve (inquiry arousal); and maintaining student interest by varying the elements of instruction (variability).

Relevance refers to whether the learner perceives the instruction to satisfy personal needs or to help achieve personal goals. Strategies for relevance include using concrete language, examples, and concepts that are related to the learner's experience and values (familiarity); providing statements or examples that present the objectives and utility of the instruction, and either present goals for accomplishment or have the learner define them (goal orientation); and using teaching techniques that match the motive profiles of the students (motive matching).

Confidence refers to the learner's perceived likelihood of success, and the extent to which he or she perceives success as being under his or her control. Strategies for confidence include helping students estimate the probability of success by presenting performance requirements and evaluative criteria (expectancy for success); providing challenge levels that allow meaningful success experience under both learning and performance conditions (challenge setting); and providing feedback that supports student ability and effort as the determinants of success (attribution molding).

Satisfaction refers to the learner's intrinsic motivation and his or her reactions to extrinsic rewards. Strategies for satisfaction include providing opportunities to use newly acquired knowledge or skill in a real or simulated setting (natural consequences); providing feedback or reinforcements that will sustain the desired behavior (positive consequences); and maintaining consistent standards and consequences for task accomplishment (equity).

Keller and Kopp (1987) suggested four stages that instructional designers should follow when using the ARCS model, as Figure 4 illustrates.

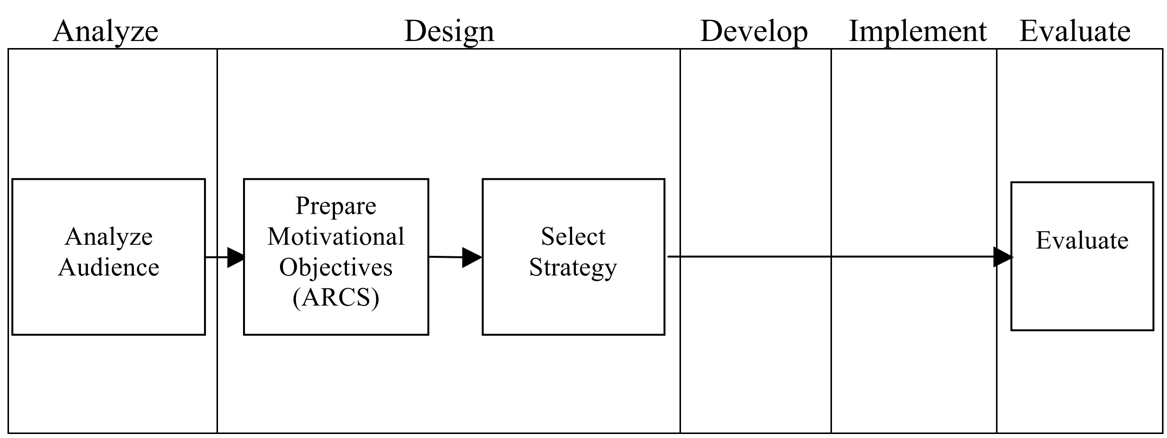


Figure 4. Keller's ARCS motivation model.

Instructional designers should do an audience analysis to determine what type of motivational problems are likely to exist. Second, designers should prepare motivational objectives that specify the student behaviors that the instructor wishes to observe relative to the four motivational factors, Attention, Relevance, Confidence, and Satisfaction. The third stage requires the designer to select or create activities that accomplish the motivational objectives. However, the authors cautioned that motivational strategies should (a) not take up too much time; (b) not detract from the learning objectives; (c) fall within the time and money constraints of the development and implementation phases of the instruction; (d) be acceptable to the audience; and (e) be compatible with the delivery system, including the instructor's personal style. Lastly, evaluation should be tied specifically to motivational objectives.

I chose this model because, given that the learners were low-level science learners, sustaining their motivation was crucial for their success in this unit. In addition, as discussed earlier, one of the barriers to implementing a GIS in the classroom is student frustration with the technology. Students would need to be motivated to stay on task and not get frustrated with the GIS.

Instructional Design Models

Designers use instructional design models to help guide their individual decisions about what to present, when to present it, how to present it, how to practice and reinforce it, and how to confirm that learning has occurred. This section describes three instructional design models I used to help me derive the instructional model for this study. The three models parallel the three instructional theories presented earlier. As I present each model below, I talk about why I selected that model and what it offered that seemed appropriate to this project.

Gagné's Nine Significant Events Model (Behaviorist Instructional Model). This design model represents a sequence that many teachers use in direct instruction. Direct instruction is a method of teaching in which the teacher explains a new concept or skill to students, has them test their understanding by practicing under his/her direction, and encourages students to continue to practice under his/her guidance (Joyce, Weil, & Showers, 1992). Behaviorist theories suggest instruction should cause an observable and measurable change in the learner's behavior. This model addresses that by presenting instruction in small units and providing lots of practice until the learner shows mastery of the content before moving onto the next unit of instruction.

Gagné (1974) formulated the Nine Significant Events Model that has evolved over the years (Gagné, 1977; 1985; Gagné, Briggs, & Wager, 1992). He identified nine events of instruction that may occur in a learning situation.

1. Gain attention – this focuses the learner's attention on the learning task at hand. The most frequently used strategy for gaining attention is to appeal to the learner's interests. Some strategies for gaining attention include asking a question, presenting a demonstration, and showing a video.
2. Inform the learner of the objectives – this helps learners know what to expect and what kind of performance is expected of them. The objectives must be put into words that the learner can easily understand.
3. Stimulate recall of prerequisite learning – this helps learners get prepared for the new learning and reminds them of important prerequisite knowledge or skills

learned earlier. The teacher may ask a recall question to help learners remember previously learned content.

4. Present the stimulus material – the teacher presents material to be learned once learners are prepared. A variety of delivery techniques including text, images, audio, and video, may be used.
5. Provide learning guidance – this helps learners understand the material. Guidance may be in the form of examples, illustrations, analogies, or the teacher answering learner questions.
6. Elicit performance – after having had learning guidance, learners practice the new skill or behavior to ensure that they know how to do it. This helps to determine whether learners have understood the material.
7. Provide feedback – as learners practice, the teacher provides feedback to reinforce correct responses and clarify misunderstandings.
8. Assess performance – after completing the instruction, learners are assessed to determine if the desired learning has occurred.
9. Enhance retention and transfer – this is done through lots of practice, reminding students of previously learned material, and by using realistic examples.

Gagné (1974) noted that these events usually occur in just about the order they are listed; however, not all of the events are always used. Further, critical learning occurs between events five and six. Other practices of this model synthesized by Cates (2002) include (a) instruction should consist of blocks of instruction that are made up of cycles, each of which includes at least seven of the nine events of instruction; (b) a teacher goes through a recursive cycle of events to ensure that the learner has mastered the material being studied; (c) some events such as gaining attention, presenting stimuli, providing guidance, eliciting performance, and providing feedback occur more frequently within one block of instruction because during events 4, 5, 6, and 7, new material is presented after which performance is required to confirm comprehension, then feedback is given; and (d) other events such as assessing performance or enhancing retention and transfer may occur only once or may not occur at all in the instruction.

I chose to use Gagne's model as a framework around which to structure direct instructional segments because the Nine Significant Events Model parallels the way many teachers deliver direct instruction and the current project includes a strong direct instruction component in the form of the teacher presenting the content, giving examples, and providing guidance as learners practice. In choosing Gagne's model, I accepted the key ideas of sequencing, iterative cycles, and including at least a minimum of seven events. I decided, however, to modify the names of some events.

Constructivist Models. This project seemed well suited to use a constructivist model because of the open-ended nature of the learning tasks and activities. Several authors have proposed different constructivist models. I chose two promising models that appeared well matched to the content and target audience. In each case below, I discuss first why I think the model holds promise and then how the model operates. Unlike the previous section where I discussed how I used the model to derive my instructional model, in this section I present both models and then talk about how I used both models to incorporate constructivist approaches into my model. I then present what steps I chose from each model and why I chose those steps.

Jonassen's Model for designing constructivist learning environments. Jonassen (1999) proposed a model for designing constructivist learning environments. This model matches up with constructivist theory in that it fosters presenting authentic problems for learners to solve in order for them to construct their own conceptual knowledge. This model is based on problem-based learning and it is a good example because it focuses on ill-structured problems; that is, problems that have multiple solutions, possess multiple criteria for evaluating solutions, and require learners to make judgments about the problem and defend them (Jonassen, 1997). In this model, the teacher presents an ill-structured problem and provides tools to help the learners solve the problem. The teacher provides examples, coaches, and scaffolds the learners.

Jonassen's model includes six major steps and three instructional activities to support learning. One instructional activity seemed to fit in with Step 2 of his model, so I added it to that step. I inferred and created two additional steps from the other two instructional activities and added them to Jonassen's model. Inferred steps are in italics. The steps of Jonassen's model are presented below.

1. Select an appropriate task for learners to do. The problem should be authentic, interesting, relevant, and engaging.
2. Provide related cases or worked examples and model how to perform the task to help students recall what they have learned and transfer their learning. Related cases provide learners with multiple perspectives and multiple representations of the concepts being learned.
3. Provide relevant and easily accessible information resources for the learner. This may include text documents, graphics, sound, video, and animations.

4. *Coach the learners as they do the task to improve their performance. This can be done through encouraging the learners, thus increasing their confidence level; providing hints for performing the task; providing feedback; and provoking learners to reflect on their performance.*
5. Provide cognitive tools that support learners' performance of task. Such tools may include visualization tools for learners to visualize the task; knowledge representation tools such as concept maps; and performance support tools such as templates to help learners perform the task.
6. *Scaffold learners' performance by adjusting task difficulty or redesigning the task to accommodate learners who are experiencing difficulties in performing the task.*
7. Provide conversation and collaboration tools to encourage learners to work collaboratively with each other. Learning most naturally takes place when learners collaborate to solve problems.
8. Provide social/contextual support for the learners as they explore, articulate what they have learned, and reflect on their learning performance. Guide learners as they search for evidence to support their solutions of the task or to complete the project.

Black and McClintock's ICON Model. Black and McClintock (1996) proposed a constructivist model called the Interpretation Construction (ICON) model. The authors wrote that designing for knowledge construction can be seen as designing Study Support Environments (SSEs) instead of learning environments. The key consideration in designing a SSE is fostering the construction of interpretations based on observations and background contextual information. This model aligns with constructivist theory because students work collaboratively with one another to construct interpretations as they engage with authentic tasks. The teacher's role is to support the students. In this model, the teacher presents an authentic task for students to do. Students work in groups and use different contextual materials to help them do the task. Students then construct their own understanding of the task and share it with one another.

The steps of the ICON model for SSE design are presented below.

1. Students make observations of authentic artifacts anchored in authentic situations.
2. Students construct interpretations of their observations and construct arguments to support their interpretations.
3. Students access background and contextual materials of various kinds to help them construct interpretations and arguments.
4. The teacher models how to make observations and interpretations and how to search for contextual materials. Once students gain mastery of these processes, the teacher fades his/her involvement and continues to coach and support the students.
5. Students work collaboratively to make observations and interpretations, and to search for contextual materials.
6. Students share their interpretations within and between groups. This exposes them to multiple interpretations of the observations.
7. Students continue to make observations of different artifacts and apply the same interpretations.

Derived Constructivist Model. I judged that neither constructivist model above, by itself, offered a rich enough sequence of instructional events to reflect the breadth of constructivist theory. Therefore, I selected all the steps of the two constructivist models and interweaved them to create a combined sequenced model. I modified the wording in some steps and combined steps that were associated. That combined model is as follows,

1. Present an appropriate authentic and interesting task.
2. Provide related cases or worked examples and model how to perform the task.
3. Have students work collaboratively on the task.
4. Ask students to construct interpretations of the task and construct arguments to support their interpretations.
5. Provide relevant and easily accessible information resources to help learners perform the task. This may include text documents, graphics, sound, video, and animations.
6. Coach the learners as they do the task to improve their performance.
7. Scaffold learners' performance by adjusting task difficulty or redesigning the task to accommodate learners who are experiencing difficulties in performing the task.
8. Provide cognitive tools to help learners perform the task. Such tools may include a GIS, spreadsheets, concept maps, and presentation templates.
9. Provide conversation and collaboration tools to encourage learners to work collaboratively with each other.
10. Have students share their interpretations within and between groups to expose them to multiple perspectives of the same task.
11. Provide adequate instructional materials and support for the teacher and students. For example, adequate equipment/materials, training for the teachers, and support for the different types of learners.

In choosing which steps to include, I considered my design task, the learners, and the content. Steps 1, 4, 5, 8, and 11 were accomplished in my task of organizing, sequencing, and designing science instruction supported by a GIS. Almost half of the learners were low-level readers and more than three quarters were low-level science learners; hence, they needed lots of instructional support from both the teacher and the instructional materials. This was supported by steps 2, 6, 7, 8, and 11. Given that the learners had no experience with using a GIS and Keiper (1998) argued that this could lead to student frustration, steps 2, 6, 7, and 11 seemed appropriate. Recognizing that having learners work together towards solutions of sustaining the world's energy resources was a goal of the project, social approaches seemed promising. They were reflected in steps 3, 9, and 10. As is apparent, some design conditions and limitations were supported in multiple steps.

Inquiry Teaching Models. An inquiry model seemed fitting for this project because the inquiry model emphasizes that students should be actively engaged with hands-on activities and learn science by doing, just like real scientists. Several authors have formulated different inquiry models. I chose three promising models; the first model is a common model that has been used over the years to design instruction; the second model is an expansion of the first model; and the third model specifically applies to science. In each case below, I discuss first why I think the model holds promise and then how the model works. I discuss the first two models in a single section below. In the last section below, I talk about what steps I chose from each model and why I chose those steps.

Bybee's 5E Model / Eisenkraft's 7E Model. Bybee's (Bybee et al., 2006) formulated the 5E model. This model aligns with inquiry theory because it focuses on students engaging with hands-on explorations. The steps of this model are engage, explore, explain, elaborate, and evaluate. In the *engage* step, students engage in the learning task through the use of short activities that promote curiosity and access prior knowledge. In the *explore* step, students are provided with a common base of activities within which concepts, processes, and skills are formulated. In the *explain* step, students demonstrate their conceptual understanding, process skills, or behaviors. Also, the teacher introduces a concept, process, or skill. In the *elaborate* step, students conduct additional activities to extend their conceptual understanding and skills. In the *evaluate* step, students use the skills they have acquired and evaluate their understanding and abilities. Also, in this phase teachers evaluate student progress and provide feedback.

Eisenkraft (2003) added two Es to make the 5E model into a 7E model. Eisenkraft divided the *engage* component into *elicit* and *engage*, and expanded the *elaborate* and *evaluate* steps into *elaborate, evaluate,* and *extend*. In the *elicit* step, teachers find out what students know by asking questions prior to the lesson. In the *extend* step, teachers ask students to apply knowledge to different contexts in order to enhance the transfer of their learning.

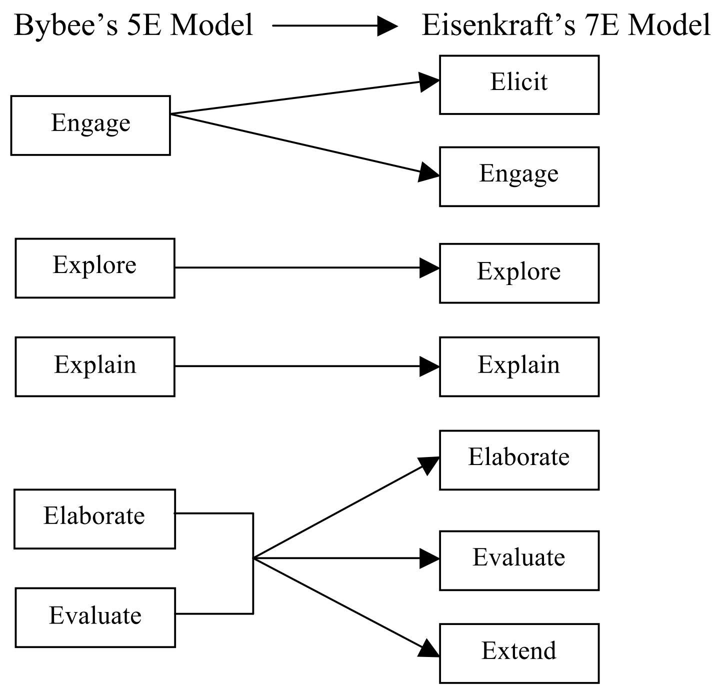


Figure 5. Bybee's 5E / Eisenkraft's 7E models.

National Research Council's Model. The National Research Council in *Inquiry and the National Science Education Standards* (National Research Council [NRC], 2000) synthesized inquiry teaching and learning and suggested effective inquiries contains as many as five essential features. These features, if reworded slightly, can be converted to five steps. This model aligns with inquiry theory because it focuses on students engaging with investigations and using evidence to form and justify their explanations, just like scientists do. The teacher's role is to facilitate the inquiries. The steps of this model include,

1. Engage learners using scientifically oriented questions – scientifically oriented questions center on objects, organisms, and events in the natural world. They lend themselves to empirical investigation, and lead to gathering and using data to develop explanations for scientific phenomena.

2. Guide learners to give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Have learners formulate explanations from evidence to address scientifically oriented questions.
4. Ask learners to evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
5. Have learners communicate and justify their proposed explanations.

Inquiry-based teaching can vary in the amount of structure, guidance, and coaching the teacher or materials provides for students. The more responsibility learners have for posing and responding to questions, designing investigations, and extracting and communicating their learning, the more “open” the inquiry. More open inquiries afford the best opportunities for cognitive development and scientific reasoning. The more responsibility the teacher takes in inquiry, the more guided the inquiry. Guided inquiry can best focus learning on the development of particular science concepts. The intended learning outcomes influence the teacher’s decision of how much guidance to provide in an inquiry. I presented this model last because it specifically deals with science; the other models can be used in other subjects.

Derived Inquiry Model. I used the 7E model as the overall inquiry model because its first and last steps lend themselves well to the way a good lesson should typically start and end. The steps of the other inquiry models seemed to fit well between the 7E’s first and last steps. I drew steps from the remaining two inquiry models discussed above and inserted them in the 7E model to create a sequenced model. I selected all the steps of the 5E and the NRC models. I modified the wording in some steps and combined steps that were associated. Further, I incorporated some of Collins and Stevens' (1983) strategies of inquiry teaching in appropriate places. My sequenced instructional model is presented below.

1. Elicit learners' prior understandings of lesson concepts.
2. Engage learners with a scientifically oriented question.
3. Ask learners to form hypothesis/make predictions.
4. Have learners explore the task.
5. Ask learners to use evidence to address questions.
6. Have learners make observations.
7. Have learners formulate explanations from evidence.
8. Ask learners to consider alternative predictions/explanations.
9. Ask learners additional questions to elaborate task.
10. Evaluate learners' predictions/explanations in light of alternative predictions/explanations.
11. Have learners draw their own conclusions (*modified from "question authority"*).
12. Have learners communicate and justify their proposed explanations.
13. Address misconceptions (*modified from "trace consequences to a contradiction").*
14. Ask learners to perform extension tasks.

I used my design task, the learners, and the content to guide me in selecting which steps to include in the inquiry model. My task was to design science instruction and since the national science education standards (NRC, 1996) emphasized using hands-on inquiry approaches to teach science content, steps 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, and 13 supported what inquiry entails. I designed learning activities that were hands-on and in which students had to use evidence to form their explanations and draw conclusions. Given that more than three quarters of the learners were low-level science learners, I conjectured that questions and lots of practice would help learners recall what they had learned. This was supported by steps 1, 9, and 14.

Some of Collins and Stevens' strategies are not included in the derived model because they were implemented in the materials and not by the teacher. Those steps include, select positive and negative exemplars (*modified to select positive and negative examples*), vary cases systematically, and select counterexamples. The other steps I chose from the Collins and Stevens' inquiry model include, form hypotheses, test hypotheses, consider alternative predictions, tracing consequences to contradiction (*modified to "addressing misconceptions"*), and questioning authority (*modified to "drawing own conclusions"*). Since the content was determined by the subject matter experts, I did not select generate hypothetical cases and entrap students because that would have required using other content outside of what was provided to me.

The Derived Instructional Model

As a result of my analyses of the various design models listed above, I derived an instructional model and three sub-models for this project. The larger instructional model has four major steps and the sub-models are presented under the second step which represents presentation of all types of instructional content. The three sub-models are unified under the larger model and they present instructional models for the presentation of content, for computer-supported activities, and for laboratory activities.

This section discusses the procedures in the derived instructional model and how I implemented those procedures in my design, as well as provides some examples of the implementation. The steps of the instructional model are listed below and explained in the paragraphs that follow.

1. Confirm learners have necessary background.

    1.1 Administer content knowledge pretest.

    1.2 Administer attitude towards science and technology pretest.

    1.3 Elicit and discuss prior understandings of unit concepts aloud.

    1.4 Elicit additions to the concept map independently.

    1.5 Identify misconceptions from student responses.

2. Present instruction using the appropriate sub-model.

    2.1 Instructional sub-model for content presentation

    2.1.1 Elicit prior understandings of lesson concepts.

    2.1.2 Gain and sustain learners' attention.

    2.1.3 Tell learners the objectives.

    2.1.4 Stimulate recall of prerequisite learning.

    2.1.5 Explain content.

    2.1.6 Illustrate content.

    2.1.7 Elicit answers to specific questions on students' worksheets.

    2.1.8 Solicit some responses from students' worksheets and provide feedback aloud.

2.1.9 Review content.

2.2 Instructional sub-model for computer-supported activities

2.2.1 Elicit prior understandings of lesson concepts.

2.2.2 Present authentic task.

2.2.3 Model task.

2.2.4 Provide worked example.

2.2.5 Ask learners to perform task.

2.2.6 Scaffold task.

2.2.7 Ask learners additional questions to elaborate task.

2.2.8 Review activity concepts.

2.3 Instructional sub-model for laboratory activities

2.3.1 Elicit prior understandings of lesson concepts.

2.3.2 Present authentic task.

2.3.3 Form student groups.

2.3.4 Model task.

2.3.5 Ask students to make predictions.

2.3.6 Ask group members to collaborate on task.

2.3.7 Have students make observations.

2.3.8 Have students use evidence to form explanations.

2.3.9 Have students evaluate explanations and draw conclusions.

2.3.10 Have students share and justify results.

2.3.11 Address misconceptions.

2.3.12 Ask learners to perform extension tasks.

2.3.13 Review activity concepts.

3. Confirm instruction is meeting goals and objectives.

    3.1 Ask questions aloud and respond to student answers.

    3.2 Solicit and respond to student questions.

    3.3 Check students' worksheet responses aloud.

    3.4 Provide feedback aloud.

    3.5 Ask students to reflect on topic.

    3.6 Adjust instruction to meet learners' needs.

4. Confirm learners have acquired desired knowledge, skills, and attitudes.

    4.1 Assess culminating activity.

    4.2 Assess concept map.

    4.3 Administer and analyze content knowledge posttest.

    4.4 Administer and analyze attitude towards science and technology posttest.

Step 1 reflects Dick and Carey's *identifying and analyzing entry behaviors and learner characteristics*, Eisenkraft's first E, *elicit*, and Jonassen's constructivist step of *providing knowledge representation tools.*

In Steps 1.1 and 1.2, learners take a content knowledge and attitude and behavior pretests to determine what knowledge, skills, and behaviors they bring to the learning task.

In Step 1.3, the teacher asks learners aloud what they know about energy through questions. For example, *"What is Energy?" "Where does it come from?"* The teacher then discusses learners' responses aloud.

In Step 1.4, the teacher asks learners to brainstorm independently everything they know about energy on a concept map. Students revise their concept maps and add new ideas periodically in the course of the unit and at the end of the unit. The intent is for learners to construct their own meaning of the relationships between the concepts as they learn them.

In Step 1.5, the teacher identifies and addresses misconceptions that learners may have about the unit concepts. Given the time constraints in one class period, the teacher may not be able to examine the learners' responses to the pretests. Thus, the teacher can examine those responses during the preparation period, or during his/her free time to check for students' misconceptions so as to know which areas to pay close attention to when teaching this unit.

Step 2 includes three sub-models; the first for presenting content, the second for doing computer-supported activities, and the third for doing laboratory activities. Computer-supported activities include using GIS, Google Earth, and spreadsheets to perform tasks. The content and activities are presented using Wiggins and McTighe's (2005) framework of focusing on big ideas. The instructional sub-model for the content presentation is presented first because students need to acquire and understand the knowledge before they can practice. The instructional sub-model for the computer-supported activities is presented before the instructional sub-model for the laboratory activities because the unit is primarily based on using GIS to support science teaching and learning. The laboratory activities complement the GIS activities. The teacher uses the appropriate sub-model to teach. The three instructional sub-models are explained below.

Instructional sub-model for presenting content

Step 2.1.1 reflects Dick and Carey's *identifying and analyzing entry behaviors and learner characteristics*, and Eisenkraft's first E, *elicit*. The teacher determines what knowledge and skills learners bring to the learning task by asking them questions about the specific lesson concepts. For example, when introducing students to solar energy, the teacher asks *"What is solar energy?"*

Step 2.1.2 is a combination of Bybee et al.'s first E, *engage*, Gagné's *gain attention*, and Keller's *attention*. In the unit, such *attention* is captured by showing brief videos, animations, giving demonstrations, telling a story, and showing objects. For example, when introducing students to geothermal energy, the teacher begins the lesson by showing students a brief video of geothermal areas in Iceland. To sustain attention throughout the lessons, the model uses Keller's strategies such as posing questions, engaging learners with tasks, and balancing content presentation with interactive sessions.

Step 2.1.3 combines Gagné's *inform the learner of objectives* and Keller's *relevance*. This is accomplished through presenting objectives in a way that conveys the usefulness of the instruction. For example, *"Inform students that they will investigate ways of conserving energy."* This objective informs students that the usefulness of the instruction is to learn ways of conserving energy.

Step 2.1.4, is Gagné's *stimulate recall of prerequisite learning* in which the teacher reminds learners important prerequisite knowledge or skills learned previously, and also helps learners get prepared for the new content.

The teacher then explains the new content in Step 2.1.5 through direct instruction, demonstrations, and videos. In other sections of the unit, learners access new content on the unit's student resources Web page. This step combines Gagné's *present stimuli* and Bybee et al.'s third E, *explain.* The instruction is presented in small cycles and images are used on materials where possible instead of having many words.

Step 2.1.6 combines Gagné's *provide guidance*, Keller's *relevance*, and Collins and Stevens' strategies. The teacher provides examples, illustrations, and answers questions to help learners understand the new content. The teacher uses *positive and negative examples*, *counterexamples,* and also relates examples to the learner's experience and values. For example, the teacher guides the learners on how to complete their personal energy audit in which students fill out their daily and weekly energy consumption.

Step 2.1.7 is a variation of Gagné's *elicit performance*. Students are asked to respond to specific questions on their worksheets during the presentation of content.

Step 2.1.8 is Gagné's *provide feedback*. The teacher gives feedback aloud. This step also echoes Keller's *satisfaction*. The teacher asks students to share their responses with the class. The teacher discusses some of the responses aloud. The teacher also reinforces correct responses, clarifies misunderstandings, and summarizes the content. The teacher provides feedback that will sustain the desired behavior.

In Step 2.1.9, the teacher reviews the lesson concepts to reinforce student learning and to clarify any concepts students did not understand. This is Gagné's *enhance retention and transfer*.

Instructional sub-model for computer-supported activities

Step 2.2.1 reflects Eisenkraft's first E, *elicit* and Dick and Carey's *identifying and analyzing entry behaviors and learner characteristics*. The teacher determines what knowledge and skills learners bring to the learning task by asking them questions about the lesson concepts.

In Step 2.2.2, the teacher presents an authentic task that learners will do. This reflects Jonassen's *select (modified to "present") an appropriate task for learners to do*. Also, the instructional materials present the tasks in different ways. For example, in some tasks, learners analyze regional or worldwide cases first then move to local cases. In other tasks, learners analyze local cases first then move to regional or worldwide cases. This echoes Collins and Stevens' *vary cases systematically*.

In Step 2.2.3, the teacher demonstrates to the learners how to do the task. For example, how to use the My World GIS get information tool to obtain data about solar power plants. This echoes both Jonassen's and Black and McClintock's steps in which the teacher *models* the task.

Step 2.2.4 is Jonassen's *provide worked example*. The teacher and/or the materials provide a worked example to help guide the learner in performing a task. For example, the materials provide a worked example of how students should complete the solar power plants data chart. Further, as discussed under the derived inquiry model section, the materials *provide positive and negative examples,* and *counterexamples* so as to highlight important things that will help learners complete the task. These are Collins and Stevens' strategies. For example, the materials provide screenshots of positive and negative examples of the results students would get when they perform a task correctly or incorrectly.

Learners perform the task in Step 2.2.5. This step combines Bybee et al.'s second E, *explore,* NRC's *learners engage with a scientifically oriented question,* and Keller's *satisfaction*. In this step learners construct their own understandings by being actively engaged with the learning task. For *satisfaction*, learners use their newly acquired knowledge and skills to manipulate data in a simulated setting. For example, the culminating task has learners applying the knowledge and skills they have learned in the course of the unit to recommend the best combination of energy sources for a fictional island.

In Step 2.2.6, the teacher and materials provide guidance to the learners as they engage with GIS tasks. This echoes Jonassen's steps in which the teacher *coaches* the learners and *provides cognitive tools to support the learners' performance*. Learners only use the GIS when they need it to accomplish a learning task. The teacher gives an orientation of the GIS and models how to use it to visualize, manipulate, and analyze data. Learners engage with authentic tasks while learning to use the GIS. The handouts for using GIS are also heavily scaffolded. The handouts use screen shots, hints, and a consistent sequence. The intent is for learners to be able to use those handouts and complete tasks on their own with ease outside the classroom setting. Since the learners were using the GIS software for the first time, GIS activities were integrated with non-GIS activities that learners are accustomed to so as not to overwhelm learners with the novel technology.

Step 2.2.7 reflects Bybee et al.'s fourth E, *elaborate.* The teacher and materials pose higher-order questions to foster learners' understanding. Learners answer questions, draw conclusions, and reflect on how concepts relate to each other.

In Step 2.2.8, the teacher reviews the concepts learned in the activity to reinforce student learning and to clarify any concepts students did not understand. This is Gagné's *enhance retention and transfer*.

Instructional sub-model for laboratory activities

Step 2.3.1 is Eisenkraft's first E, *elicit* and Dick and Carey's *identifying and analyzing entry behaviors and learner characteristics*. The teacher determines what knowledge and skills learners bring to the learning task by asking them questions about the lesson concepts.

The teacher presents the task to the learners in Step 2.3.2. This is Jonassen's *select (modified to "present") an appropriate task for learners to do*.

In Step 2.3.3, the teacher assigns learners to groups to perform laboratory experiments.

The teacher demonstrates the task in Step 2.3.4. This echoes both Jonassen's and Black and McClintock's steps in which the teacher *models* the task.

In Step 2.3.5, students make predictions before they engage in laboratory experiments. This is Collins and Stevens' *make predictions*.

Learners perform laboratory experiments in Step 2.3.6. This step combines Bybee et al.'s second E, *explore*, NRC's *learners engage with a scientifically oriented question.* This step also echoes Janssen and Black and McClintock's steps in which students work *collaboratively* on tasks.

Students make observations of their laboratory experiments in Step 2.3.7. This is Black and McClintock's step in which *students make observations of authentic artifacts*.

In Step 2.3.8, learners give priority to evidence, consider alternative predictions, and formulate explanations from evidence. Learners examine each other's understanding to expand their own understanding of concepts. This combines Bybee et al.'s third E, *explain*, NRC's *guide learners to give priority to evidence* and Collins and Stevens' *consider alternative predictions.*

Learners evaluate explanations and draw conclusions in Step 2.3.9. In this step, learners evaluate their explanations in light of alternative explanations, and reason towards solutions. This is Bybee et al.'s fifth E, *evaluate*, Collins and Stevens' *question authority (modified to "draw own conclusions")* and the NRC's *ask learners to evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding*.

Step 2.3.10 echoes the NRC's steps and Black and McClintock's steps. Learners share their results with one another; they communicate and justify their proposed explanations. This should give them a sense of ownership of the content and increase their motivation. This step also includes Keller's *confidence*. For example, in developing an energy policy for a fictional island, the teacher provides students with performance requirements and evaluative criteria to help them accomplish this task successfully.

In Step 2.3.11, the teacher corrects any misconceptions from learners' explanations. This is Collins and Stevens' *trace consequences to a contradiction (modified to "address misconceptions")*.

Step 2.3.12 is Eisenkraft's seventh E, *extend*. Students use the skills they have acquired to perform additional tasks. The intent here is for learners to enhance the transfer of their learning.

In Step 2.3.13, the teacher reviews the concepts learned in the activity to reinforce student learning and to clarify any concepts students did not understand. This is Gagné's *enhance retention and transfer*.

Moving back out to the larger model, Step 3 is a variation of Dick and Carey's *formative evaluation.* This step also reflects Jonassen's constructivist model in which the teacher *adjusts task difficulty or redesigns the task to accommodate learners who are experiencing difficulties in performing the task.* In Step 3.1, the teacher asks questions and responds to student answers. In Steps 3.2, 3.3, and 3.4, the teacher solicits and responds to student questions, and provides feedback to students' worksheet responses. The intent is to assess whether the instruction is effective, to identify any weaknesses, and identify where instruction needs to be revised and improved. Since this evaluation occurs while the instruction is in progress, the teacher is able to adjust instruction to meet the needs of the learner. Step 3.5 is a constructivist instructional practice in which students reflect on how they performed tasks and what they learned. Reflection is done periodically in the course of the unit by students responding to questions in their journals or adding new ideas to their concept maps. In Step 3.6, the teacher focuses on improving classroom instruction and, consequently, student performance.

Finally, Step 4 is a variation of Dick and Carey's *summative evaluation.* In Steps 4.1 and 4.2, the teacher assesses the culminating activity and concept maps. In Steps 4.3 and 4.4, learners finish the unit by taking content knowledge and attitude and behaviors posttests. The teacher analyzes these assessments to evaluate the overall effectiveness of the unit.

Meta-Design Principles

I derived five meta-principles that apply to the design of the unit as a whole. These meta-principles specify when to apply a rule and how to apply it. My meta-principles are presented in the paragraphs that follow, along with discussion of ways in which I applied them to the design of materials and activities in the unit.

1. Use multiple ways of learning to address learner differences.

Gardner (1993; 1999) initially proposed seven intelligences and contended that everyone is born with potential in all intelligences; however, cultural and personal contacts determine which intelligences are developed. *Linguistic intelligence* entails being sensitive to spoken and written language, being able to learn languages, and having the capacity to use language to accomplish certain goals. *Logical-mathematical intelligence* involves having the capacity to analyze problems logically, carry out mathematical operations, and investigate issues scientifically. *Spatial intelligence* is the ability to form a mental model of a spatial world and to be able to maneuver and operate using the model.

Musical intelligence entails skill in the performance, composition, and appreciation of musical patterns. *Bodily-kinesthetic intelligence* is the ability to solve problems or to fashion products using one's whole body, or parts of the body. *Interpersonal intelligence* is the ability to understand the intentions, motivations, and desires of other people, and accordingly work effectively with others. *Intrapersonal intelligence* is the capacity to understand oneself, to form an accurate mental model of oneself and use the model to operate effectively in life. *Naturalist intelligence* is the ability to recognize and classify the numerous species in the environment.

I applied this meta-principle in the present project by conveying the core concepts of the unit using as many intelligences as possible to reach the various students. Examples include having students investigate optimal areas for building different energy-generating facilities (*logical-mathematical intelligence*); having students read about different energy sources (*linguistic intelligence*); having students manipulate GIS data and recognize patterns (*spatial intelligence*); and having students collaborate on group activities (*interpersonal intelligence*). I used different entry points such as telling a story (*linguistic intelligence*); asking questions (*logical-mathematical intelligence*), displaying real objects in class (*bodily-kinesthetic intelligence*), and doing hands-on activities (*bodily-kinesthetic intelligence*) to help engage learners with the topic.

Gardner also suggested using analogies and examples that are most likely to capture important aspects of the topic and reach a significant number of students. I applied the use of analogies and examples in various parts of the instruction, for instance, comparing the flow of electrons through a wire to the flow of water through a pipe to help students understand electricity. Another analogy is comparing a dam reservoir to a constantly charging battery.

2. Use procedural facilitators to guide learners' responses.

According to Scardamalia and Bereiter (1986), *procedural facilitators* are questions, prompts, or simple outlines of important learning structures that teachers use as scaffolds. Scaffolds provide the support students need to tackle higher-level thinking strategies (Rosenshine & Meister, 1992).

I applied this meta-principle by providing prompts in the form of key words on the student worksheets to help students see types of responses they might give. For example, in describing the land cover and topography of wind farms, I provided key words such as *flat land area, hilly, dirt, bushes, vegetation, and trees.* I also provided hints to guide students how to manipulate the GIS data to obtain the answer, which map tools to use, and what data they need to respond to the questions. For example, to get the top five countries that produced the highest amount of coal, I gave students a hint to *"click the coal production column twice to sort it in descending order."* To get the names of highly populated countries based on the colors on the GIS map, I gave students a hint to *"use the get information tool."*

3. *Use icons consistently to enhance and reinforce student learning and use illustrations to reduce learner dependence on text.*

Paivio (1969; 1971) argued that images act as mediators in learning and memory tasks, and can be amazingly effective as memory aids. To comply with what Paivio suggested and to implement this meta-principle, I used icons throughout the materials, both materials for teachers and materials for students and I illustrated all materials extensively. But my use of icons and images was not simply to make the materials more attractive.

For example, I used thematic icons employed by the software to reinforce concepts. Thus, when designing the solar energy activity, I used an icon of the sun and when designing the hydroelectric power and tidal energy activities, I used an icon of water. When designing a geothermal energy activity, I used an icon of a volcano. Further, I used task-oriented icons lifted from the software to clarify the nature of the task and/or where task is to be accomplished. For example, I used an image of a toolbox to alert learners that the task involves checking whether they have all the apparatus they need to carry out an experiment and an image of a face with a pair of goggles to alert learners that the task involves the procedure for carrying out an experiment. I used an image of a computer to alert learners that the task is computer-based, for example, downloading a file or manipulating GIS data. I used an image of a note pad and a pencil to alert learners that the task is paper-based, for example, filling out their worksheets.

I implemented this meta-principle by using illustrations to connect the text with the task and to illustrate the task. For example, I put screen shots of the GIS maps or layers learners will be manipulating adjacent to or below the text (instructions). I also put screen shots of the results learners will get when they manipulate the GIS maps correctly. I used arrows (with numbers, if needed) on the screen shots to alert learners to the location of the task and/or procedure for doing the task. Thus, I labeled illustrations in such a way as to help learners identify salient properties and sequences where needed.

4. *Facilitate the process of modifying instructional materials to meet the needs of different learners.*

As Kinnaman noted (1993) teachers play a major role in effective implementations. They have the ability to identify how to modify materials to address the needs of the range of learners in their classrooms. To facilitate this, I created this meta-principle.

I implemented this fourth meta-principle by developing two sets of handouts; one for the teacher and the other for the students. The basic simplified handouts for students provide step-by-step instructions with screen shots for doing tasks, while the more detailed handouts for the teacher include the step-by-step instructions available on the student handout as well as implementation suggestions and detailed explanations of the task results and procedures. The teacher may wish to enrich the student handouts by copying the detailed explanations and procedures from the teacher handouts and adding it to the student handouts. The teacher may also wish to modify the task for a number of reasons, for example, adjust the task difficulty for the lower-level learners; remove steps from the task if the students take longer than anticipated to complete it; add steps to the task for the higher-level learners; or modify the analysis questions. To facilitate teacher modification of materials to implementing this meta-principle, I provided handouts in both Portable Document Format (PDF) and Microsoft Word format. The teacher can use the Microsoft Word file to enrich the student handouts and/or to modify the task and materials as needed.

5. Use Contrast, Repetition, Alignment, and Proximity (CRAP) design.

Williams and Tollett (2000) suggested four basic design principles for developing both print materials and Web pages. These are contrast, repetition, alignment, and proximity (see also Williams, 1994).

Contrast refers to what draws people's eyes in. To apply this to the current project, I used Arial bold 10 point to emphasize key words in the handouts. On the Web site, I used a background color that contrasts well with the text and images. I used Arial bold 14 point to emphasize key words on the student content Web pages. I used arrows on the illustrations to point out specific things

Repetition refers to using certain elements consistently. On the main Energy unit Web site, I used the same shades of green and white colors, typeface, left navigation bar, and Environmental Literacy and Inquiry (ELI) logo at the top. On the student content Web pages, I used the same shades of green and white colors, typeface, title bar, Environmental Literacy and Inquiry (ELI) logo at the top, and light bulb navigation buttons at the bottom of the pages. For the handouts, I used Times New Roman bold 14 point for headings, Times New Roman bold 12 point for subheadings, and Arial bold 10 point to emphasize key words. I used Arial 10 point for the rest of the body text.

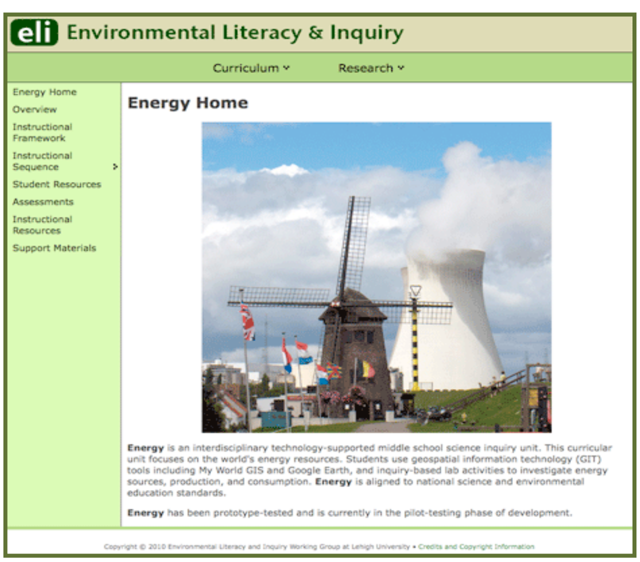
Alignment refers to lining up items on the page with each other. I aligned items on the left side on both printed materials and on the Web pages. The illustrations on the handouts were aligned with the text. Some images were centered, however, on the student content Web pages to create symmetry.

Proximity refers to grouping items that belong together close to each other. On both the handouts and the Web site, I placed headings and subheadings closer to their related text or graphic than to the text or graphics above them. I placed illustrations adjacent to or below the text. On the learner handouts, I placed the procedural steps for doing tasks in separate tables. The intent for this was to create lots of white space to enhance readability and help reduce cognitive load on the learners.

CHAPTER 5: DESIGN OF THE MATERIALS

I used the instructional model discussed in chapter four to design and develop the Energy Unit. The Energy Unit Website is available online at http://ei.lehigh.edu/eli/energy/index.html. The site itself was designed to obey interface design principles. For instance, it made use of the four basic design principles of contrast, repetition, alignment, and proximity. This was for easy navigation, readability, and consistency. As the images in Figure 6 show, there were two links in the navigation ribbon across the top. The *Curriculum* link listed the three units under development by the design team; these three include Energy (the unit I worked on), Climate Change, and Land Use Change. The *Research* link listed publications and presentations. The eight navigation buttons in the left column were common to all three units and allowed teachers to gain access to the materials for each unit. I discuss each of these eight links for the Energy unit below.

The Eight Sections of the Energy Unit Web Site



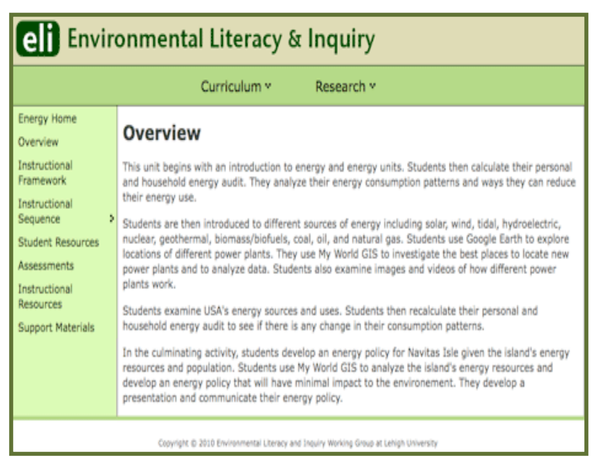


Figure 6. Energy unit home and overview pages.

The first two pages of the Website (Figure 6) provided introductory information about the unit. For example, the *Energy Home* page (image on the left) presented a brief explanation of what the unit offers, while the *Overview* page (image on the right) gave a brief summary of the sequence of the unit's content and activities.

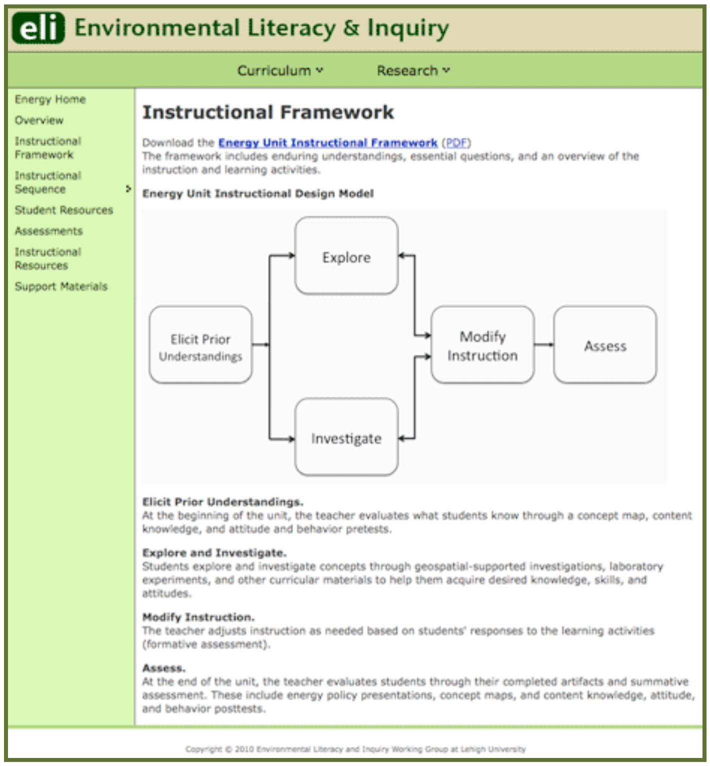


Figure 7. Instructional Framework page.

The *Instructional Framework* page (Figure 7) contained a link entitled Energy Unit Instructional Framework that allowed the teacher to download a PDF of the unit's enduring understandings, essential questions, and an overview of the instruction and learning activities based on the Understanding by Design (UbD) model. This page also displayed a simplified framework of my instructional model with brief explanations of what each step means. The explanation of how the model worked was simplified so that visitors to the site would understand it more readily. Recall that the UbD model was simply one part of the overall design model I used for this study. Since it was a common model for all units, however, the design team was consistent in including it under *Instructional Framework* for all three units.

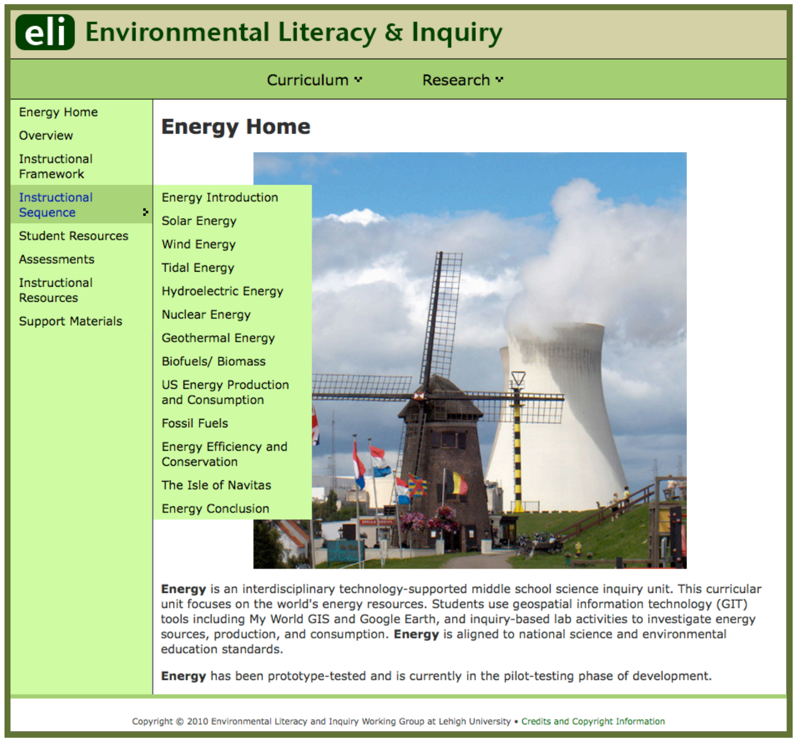
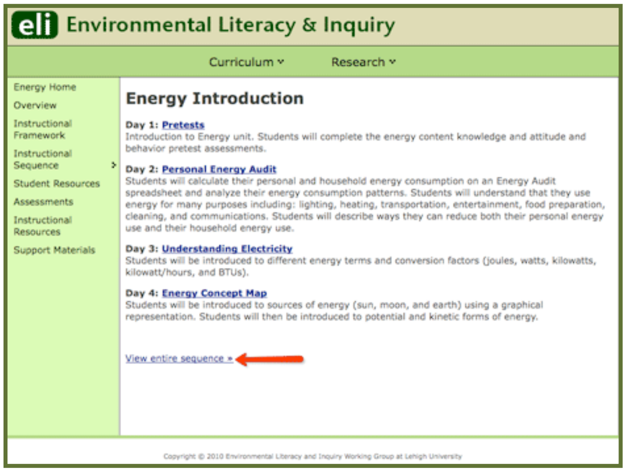


Figure 8. Instructional sequence drop-down menu.

The *Instructional Sequence* link had a drop-down menu of the different topics in the unit (Figure 8). Clicking on a topic led to a page that listed the days and sub-topics falling under that topic. Each day had a link that took teachers to a page where they found an instructional sequence, links to files needed for that day (GIS, Google Earth, video, spreadsheet), and materials in both Word and PDF form. In addition, at the bottom of these pages there were links to Teacher Resources/Content Support. These were materials designed to help teachers understand the energy concepts and vocabulary under study that day. The science education literature suggests that this sort of scaffolding for teachers increase the likelihood of better learning outcomes for students in science.



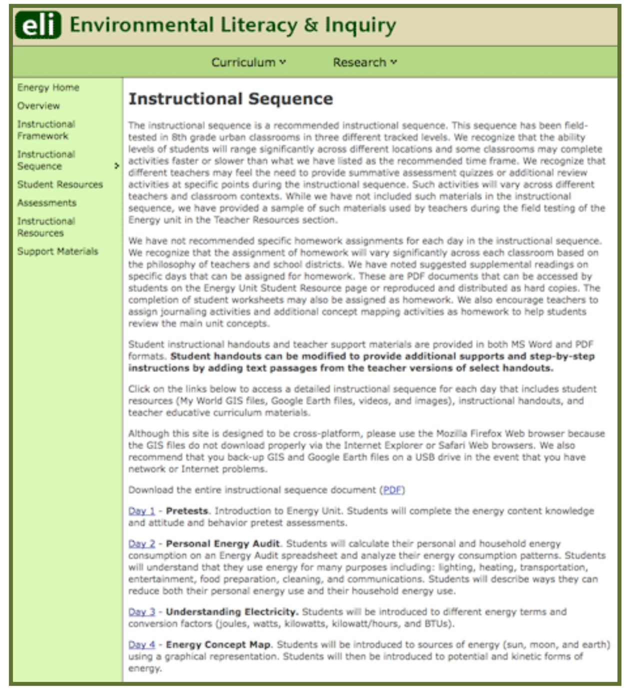


Figure 9. Energy introduction and entire instructional sequence pages.

For example, the image on the left in Figure 9 displays the *Energy Introduction* page and a list of the days and sub-topics falling under the Energy Introduction topic. At the bottom of every topic page was a *View entire sequence* link (see arrow in left image) that took the teacher to the entire *Instructional Sequence* page (image on the right), should the teacher prefer to view the whole sequence on one page. The Instructional Sequence page began with a few implementation comments for the teacher and then presented a summary of the instruction for all 40 intended days of the unit.

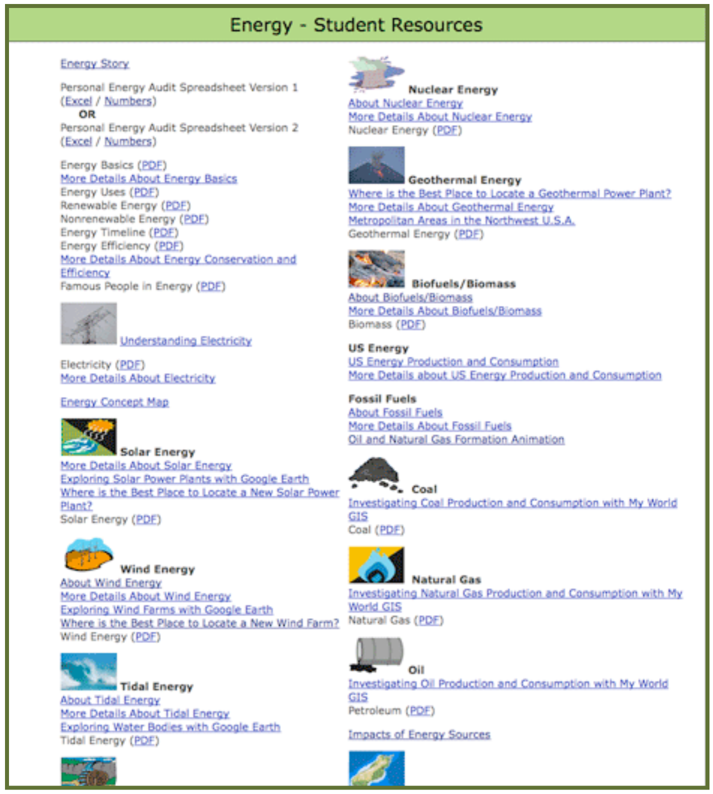


Figure 10. Student resources page.

Figure 10 displays the *Student Resources* page where the learners went to find all the files and content links they use. The files included GIS files, Google Earth files, an energy story, two versions of the energy-audit spreadsheet, a concept map as an Inspiration file, supplemental homework readings, and a template for student energy policy presentations. To avoid learners having access to assessment information, this page did not have a link to the main Energy unit page. Instead, learners access the *Student Resources* Web page by going directly to this URL, http://www.ei.lehigh.edu/learners/energy/index.html. Since learners used this page almost every day, I used images that depict each energy source to facilitate navigation, and also to enhance and reinforce student learning. Further, activity files were arranged in the order in which they were accessed, from the left column going down then to the right column going down.

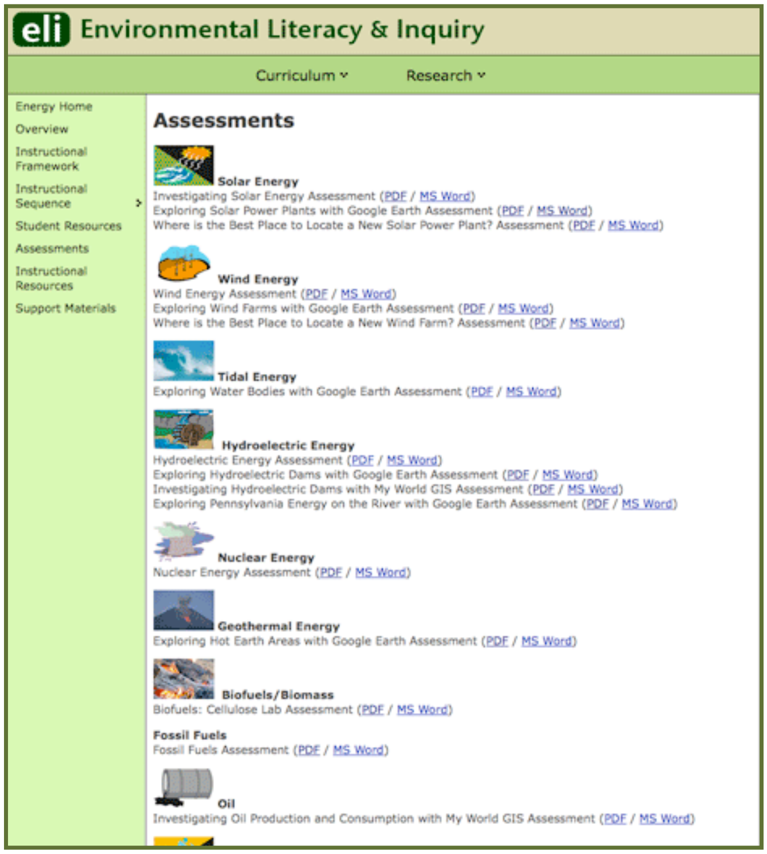


Figure 11. Assessments page.

The *Assessments* page (Figure 11) was a repository of all the assessment files. Once again, I used images to make clear which topic an assessment goes with and the assessments were provided in both PDF and Word versions. The energy-audit spreadsheet and the concept map Inspiration file were also provided on this page.

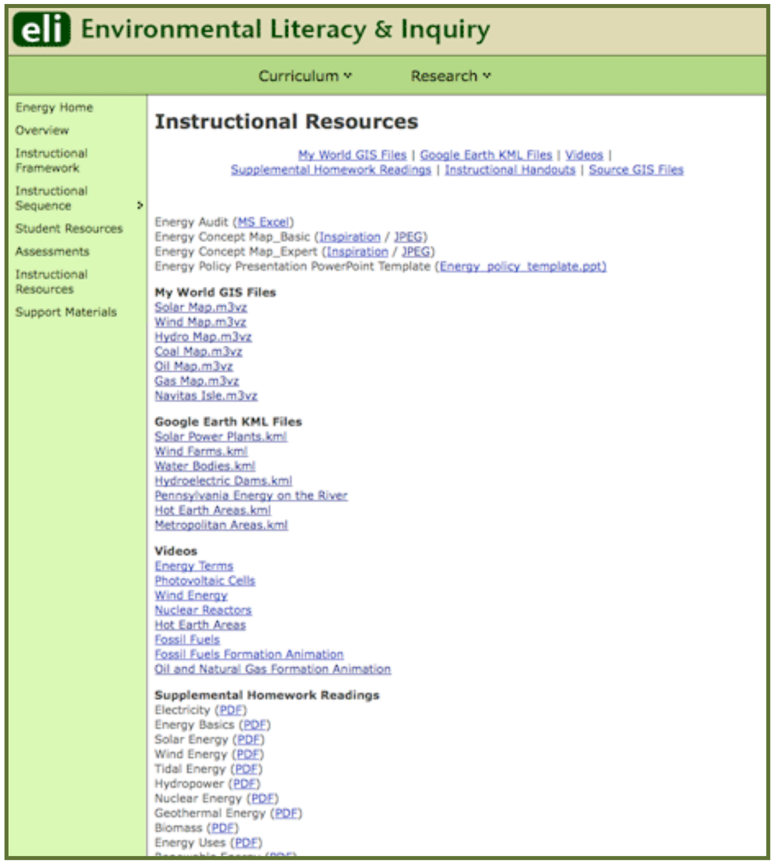


Figure 12. Instructional resources page.

As displayed in Figure 12, the *Instructional Resources* page contained all the unit's files, including Spreadsheets, Inspiration files, My World GIS files, Google Earth files, videos, supplemental homework readings, instructional handouts and source GIS files. By providing links to all files needed to complete the unit, the *Assessments* and *Instructional Resources* pages made it easier for the teacher to find a file quickly, instead of having to search through the instructional sequence pages day by day.

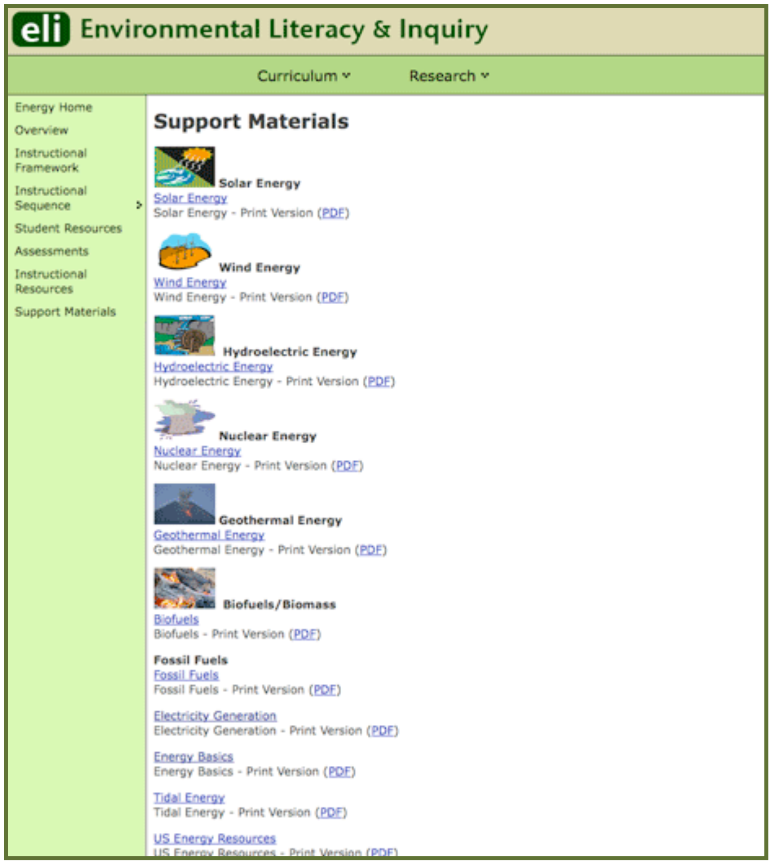


Figure 13. Support materials page.

Finally, the *Support Materials* page (Figure 13) contained educative curriculum materials to promote teacher learning presented on Web pages and also available in PDF form. As discussed in chapter two, educative curriculum materials help teachers increase their knowledge and also make instructional decisions.

Exemplars Illustrating My Design

This section presents 10 exemplars to provide a good sense of what the various types of materials in my study looked like. The exemplars include the design of handouts, the Web site, at least two of each of my three instructional sub-models (see chapter 4), and the culminating activity, which had a blend of the three sub-models. Each exemplar is listed below with the day the activity was scheduled to be implemented, the actual day(s) it was implemented, and an explanation of how it was shaped by my design principles (as explained in chapter 4) and how it facilitated learning or teaching.

Exemplar One

To implement meta-principle 5, handouts were designed using contrast, repetition, alignment, and proximity (CRAP) principles. For example, Figure 14 displays page 2 of the student handout for the *Investigating Coal Production and Consumption with My World GIS* activity available on scheduled Day 25 (actual implementation days 33 and 34) at http://ei.lehigh.edu/eli/energy/sequence/day25.html. I used Arial bold 10 point for contrast to emphasize key words. I used Times New Roman bold 14 point for headings, Times New Roman 12 point for subheadings, and Arial 10 point for the body text. I aligned the illustrations on the left with the text or placed the illustrations adjacent to the text.

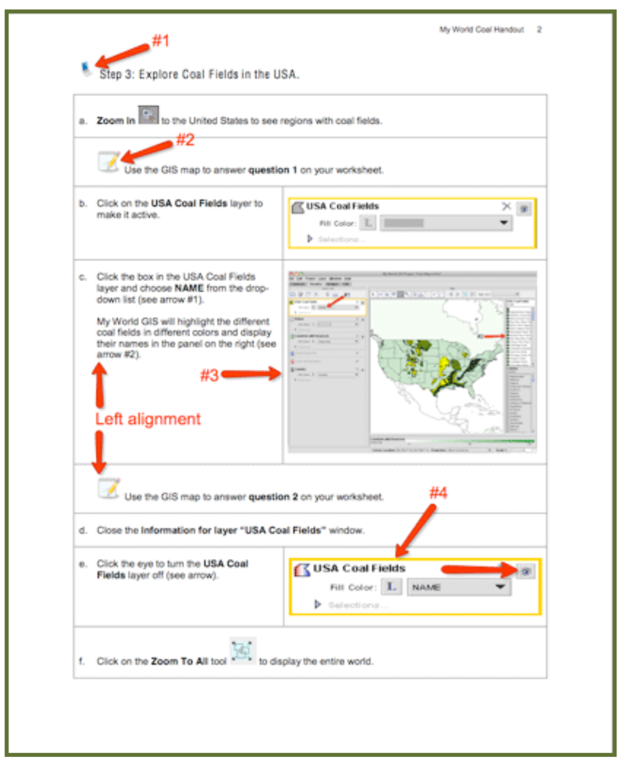


Figure 14. Illustration of the use of meta-principles 3 and 5 on a student handout.

I applied meta-principle 3 by using task-oriented icons lifted from the software to clarify the nature of the task and/or where task was to be accomplished (see arrows #1 and #2 in Figure 14). The image of a computer alerted learners that the task was computer-based while the image of a note pad and a pencil alerted learners to fill out their worksheets. I also used illustrations to connect the text with the task and to illustrate the task (see arrows #3 and #4 in Figure 14). The handouts had lots of white space to help reduce cognitive load on the learners. In implementing meta-principle 4, I developed two sets of handouts, a detailed one for the teacher and a simplified one for the students. I provided the handouts in both PDF and Word format. The teacher could have chosen to modify the activity and the materials based on how learners performed the task. This included adjusting the task difficulty. The teacher could also have chosen to enrich the student handout by adding detailed explanations of the activity copied from the teacher's handout. Figure 15 presents an example of detailed explanations on the teacher guide.

The **positive numbers** at the top of that column mean that those countries **consumed more coal** in
2008 than in 1980. Their coal consumption increased.

The **zeros** mean that those countries **did not consume** any coal in 2008 and 1980. Countries that consumed the same amount of coal in 2008 and 1980 also have zeros because there was no difference in their coal consumption.

The **negative values** mean that those countries **consumed less coal** in 2008 than in 1980. Their coal consumption decreased.

The 2008 coal consumption data for some countries at the bottom of the column was not yet available.

Figure 15. Illustration of detailed explanations on the teacher guide.

The teacher guides did not have all the illustrations that the learners' handouts had because I conjectured that the important thing the teacher guides needed was the additional detailed explanations so they could scaffold the students as they performed tasks. The teachers could refer, however, to the learners' handout if they need to see the illustrations.

Exemplar Two

Figure 16 illustrates some CRAP principles on a student content Web page available at http://www.ei.lehigh.edu/learners/energy/nuclear2.html. This activity was scheduled to be done on Day 18 (actual implementation day 23).

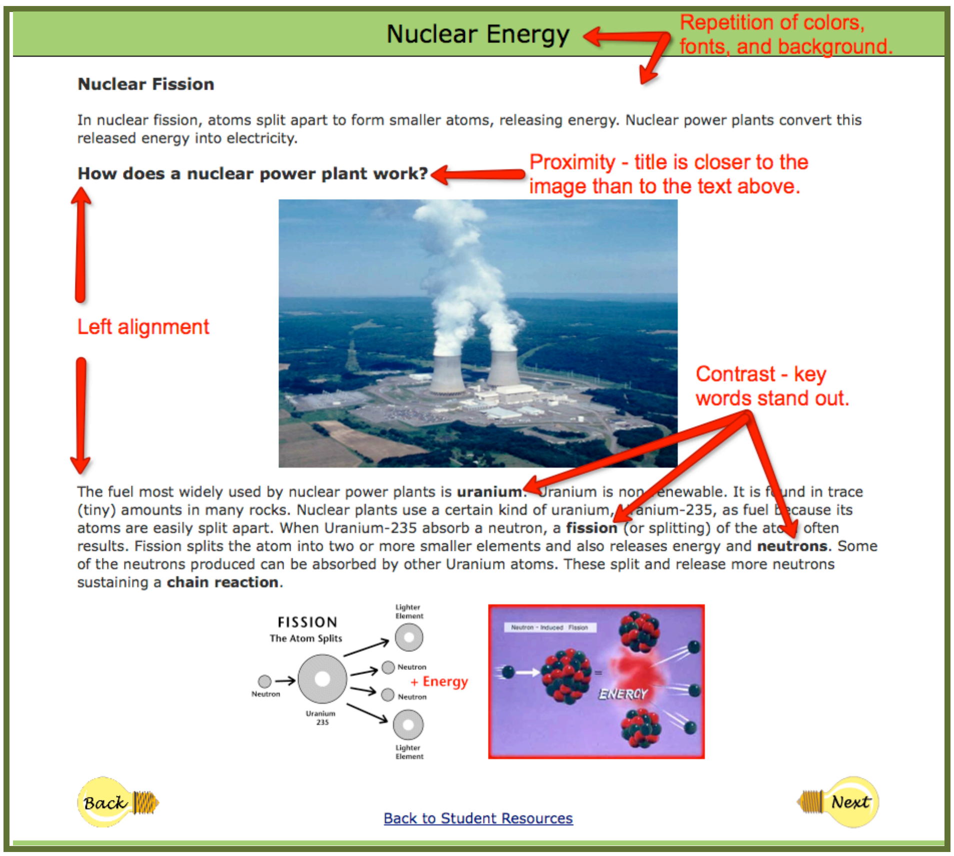


Figure 16. Illustration of the use of CRAP principles on a student Web page.

I applied contrast by using Arial bold 14 point to emphasize key words and used a background color that contrasts well with the text and images. I applied repetition by using the same shades of green and white colors, typeface, and light bulb navigation buttons. I used Arial 14 point for the rest of the body text. I used left alignment for the items on the Web pages. I applied proximity by placing headings and subheadings closer to their related text or graphic than to the text or graphics above them. The Web pages also had lots of white space to help reduce cognitive load on the learners. The intent for this was to enhance the readability.

Exemplar Three

On scheduled Day 2 (actual implementation days 2 and 3), **s**tudents learned energy terms and units and started calculating their personal energy audits (see http://ei.lehigh.edu/eli/energy/sequence/day2.html). To accomplish these activities, I designed steps intended to present content and utilize the computer. For instance, the teacher in Step 1 *elicits prior understandings of lesson concepts* by asking learners how electricity is measured and how the electricity company knows how much to charge for one's energy use each month. To *gain the learners' attention,* the teacher shows the energy terms video clip in Step 2 then *tells learners the objectives* of the lesson in Step 3. The teacher asks students to go to the Student Resources Web page and then she reads an energy story to them and *explains* different energy units in Step 4. To *stimulate recall of prerequisite learning*, the teacher asks learners what they learned from the video clip in Step 5. The students download the spreadsheet in Step 6 and the teacher gives out the handout to students in Step 7. The teacher *illustrates* to students instructions on their handout in Step 8.

Students in Step 9 go to their resource page to read content while the teacher *explains* and *illustrates* the content by clarifying energy terms and units. The link to the understanding electricity content pages is http://www.ei.lehigh.edu/learners/energy/electricity1.html. In Step 10, students change the values in their spreadsheets and the teacher directs them to note how that affects the total cost on their spreadsheets. In Step 11, the teacher asks the students to complete filling in their spreadsheets and save their files in Step 12. The students continue doing the activity (http://ei.lehigh.edu/eli/energy/sequence/day3.html) on scheduled Day 3 (actual implementation days 3 and 4). The teacher *elicits prior understandings of the lesson concepts* in Step 1, *tells learners the objectives* of the lessons in Step 2, and asks students to complete their spreadsheets in Step 3. In Step 4 the teacher *elicits answers to specific questions on students' worksheets.* The teacher discusses some responses and answers student questions in Step 5 and then reviews the concepts covered in Step 6. Step 7 illustrates the instructional model's *confirm instruction is meeting goals and objectives* in which the teacher adjusts instruction to meet the learners' needs. In Step 8, learners save their files to be used later on in the unit.

Providing multiple ways of learning (meta-principle 1) was implemented through asking questions (*logical-mathematical intelligence*), narrating a story (*linguistic intelligence*), and reading about different sources of energy (*linguistic intelligence*). I also used an analogy that might likely be understood by a large number of students. The flow of electrons through a wire was compared to the flow of water through a pipe to help students understand electricity.

Figure 17. Illustration of the use of thematic icons on the student resources Web page.

I used thematic icons on the student resources Web page (Figure 17 and available at http://www.ei.lehigh.edu/learners/energy/index.html). The intent for this was to reinforce learning (meta-principle 3). I also used illustrations on the handouts to connect the text with the task and to illustrate the task in order to reduce learner dependence on text (Figure 18).

Step 2: Enter data in the energy audit spreadsheet.

*How much does it **cost** ($$) to watch TV **2** hours a day every day of the year?*

a. Enter **2** in the **Hours used DAILY** column (see arrow #1 below).

b. Enter **1** in the **# of appliances being used** column (see arrow #2 below).

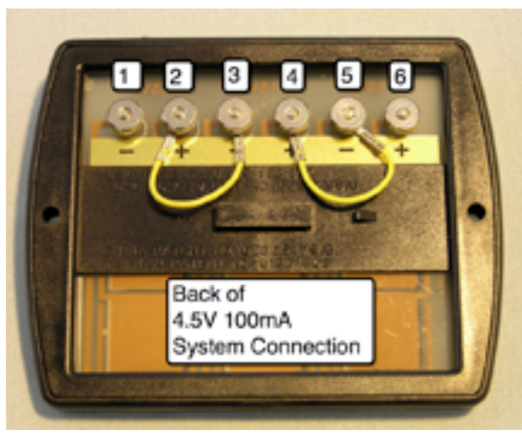
c. Look at the amount it costs each year to watch TV for 2 hours a day on your spreadsheet (see arrow #3 below).

PERSONAL ENERGY AUDIT 1	Hours Used	Repeated Use	Typical Wattage	kW*h/year	BTU/Year	Out of pocket cost/day or week	Out of pocket cost/year
NOTES:	How many hours do you do following things? If appliance is on all the time list 24 hours/day.	List number of appliances.	These values were found using a variety of Web pages and appliance manuals.	for daily use =(kW*h) X 365 For weekly use =(kW*h) X 52 (or number of weeks used)	for daily use =BTU X 365 For weekly use =BTU X 52 (*or number of weeks used if seasonal*)	Cost =(kW*h) x average rate (average rate is $0.11 per kW*h)	Cost/year= Cost per day X 365 or Cost per week X 52 (*or number of weeks used if seasonal)*
Everyday Activities	Hours used DAILY	# of appliances being used	Typical Wattage	kW*h/year	BTU/Year	Out of pocket cost per day (cents)	Out of pocket cost per year (dollars)
Entertainment							
Watch TV	2	1	150	109.50	373,592.63	0.03	12.05
Charge your iPod/MP3 player			12	0.00	0.00	0.00	0.00
Charge hand-held video games (i.e. PSP or Nintendo DS)			50	0.00	0.00	0.00	0.00
Play video games (i.e. Xbox 360, Wii)	#1	#2	165	0.00	0.00	0.00	#3 0.00
Watch a DVD or VHS tape on the TV			195	0.00	0.00	0.00	0.00

Figure 18. Illustration of the use meta-principle 3 on a student handout.

Exemplar Four

Students learned about solar energy (see http://ei.lehigh.edu/eli/energy/sequence/day5.html) on scheduled Day 5 (actual implementation day 6). I designed this day's activities to combine the content presentation and laboratory activities sub-models (see pages 118-119 of chapter 4). In that blended sub-model, Step 1 illustrates *elicit prior understanding of lesson concepts*. The teacher asks the learners what solar energy is. In Step 2, the teacher plays the photovoltaic cells video clip to *gain learners' attention*. The teacher then *tells the learners the objectives* of the lesson in Step 3. In Step 4, the teacher *stimulates recall of prerequisite learning* by reminding the learners that the sun is one of the main sources of energy. The teacher *explains content* in Step 5. In Step 6, the teacher presents the handout and worksheet to students and forms *student groups* in Step 7. The teacher reviews components of solar kits in Step 8 and *asks students to make predictions* in Step 9. Students *perform the task* in Step 10 and *make their observations* in Step 11. In this step, students also *form explanations using evidence* and answer questions on their worksheets. The students *evaluate their explanations* against alternative explanations then *draw conclusions* in Step 12. The teacher asks students to *share their results* with the class in Step 13 and *justify* how they reached their conclusions. The teacher instructs learners in Step 14 to *extend this task* using any simple appliances in the classroom. In Step 15, the teacher *reviews the activity concepts* and *addresses misconceptions*.



1. Turn your solar cell panel over. Be sure it is wired as shown above. This is a **series** connection. This pattern increases **Voltage**.
    a. The **positive (+) pole 2** is connected to **negative (-) pole 3** with a connecting wire. **Positive (+) pole 4** is connected to **negative (+) pole 5.**

Figure 19. Illustration of the use of meta-principle 3 on a student handout.

The multiple ways of learning I implemented (meta-principle 1) included asking questions (*logical-mathematical intelligence*), doing hands-on activities (*bodily-kinesthetic intelligence*), and performing the task in groups (*interpersonal intelligence*).

Figure 19 is an illustration of how meta-principle 3 was implemented on a student handout to connect the text with the task so as to reduce learner dependence on text.

Exemplar Five

The activity scheduled on Day 9 (actual implementation day 11) is available at http://ei.lehigh.edu/eli/energy/sequence/day9.html and exemplified the sub-model for content presentation (see page 118 in chapter 4). That sub-model comprised nine steps in which the teacher in Step 1 *elicits prior understandings of lesson concepts* by asking learners what wind is. To *gain the learners' attention,* the teacher shows the Wind Energy video clip in Step 2 then *tells learners the objectives* of the lesson in Step 3. Next in Step 4, the teacher asks learners what they learned from the video clip to *stimulate recall of prerequisite learning*. After providing the worksheet to students, the teacher directs learners to the student resources page in Step 5. The link to the wind content pages is http://www.ei.lehigh.edu/learners/energy/wind1.html. Learners read about wind energy, the teacher *explains content* and clarifies the concepts and terminology in Step 6 while *illustrating the content* using examples. The teacher uses examples that are personally relevant to the students to *sustain their attention*. In this step, students also *answer questions on their worksheets*. In Step 7, the teacher *provides feedback* to students' worksheet responses and questions and *reviews the content*.

For meta-principle 1, this task mainly had *linguistic intelligence* in which students read the Web pages and a bit of *logical-mathematical intelligence* when students answer the journal question and respond to the questions on their worksheets.

Exemplar Six

On scheduled Day 14 (actual implementation days 18 and 19), students used Google Earth to explore hydroelectric power dams around the world (see http://ei.lehigh.edu/eli/energy/sequence/day14.html). This day exemplified the computer-supported activities sub-model (see pages 118-119 of chapter 4). In that sub-model, the teacher *elicits prior understandings of lesson concepts* in Step 1 and *presents the task* by telling learners what they will do in Step 2. The teacher presents the handout and worksheet students will need for the task in Steps 3 and has the students access their Google Earth file in Step 4. In Step 5, the teacher *models* how to navigate from one dam to the next to the students. The teacher then *provides a worked example* in Step 6 to guide the students on how to perform the task. *Learners perform the task* in Step 7 while the teacher *scaffolds the task.* The teacher *asks learners to respond to additional questions* on their worksheets in Step 8 then *reviews activity concepts* by discussing student responses aloud and answering students' questions in Step 9. Step 10 illustrates the instructional model's *confirm instruction is meeting goals and objectives* in which the teacher adjusts instruction to meet the learners' needs.

I implemented meta-principle 1 by asking questions (*logical-mathematical intelligence*) and having students visualize dams on a virtual globe to recognize similarities (*spatial intelligence*). To implement meta-principle 2, I provided prompts in the form of key words such as *rocks, buildings, grass,* and *trees* to help students see types of responses they might use in describing the area surrounding dams. I also provided hints on which map tools to use to respond to some questions. For example, to find the nearest population center located near a dam I provided this helpful hint, *"You will need* *to zoom out* *to view a population center near the dam. Look for the nearest population center marked with a small red circle* *.”* I implemented meta-principle 3 by using illustrations to connect the text with the task to reduce learner dependence on text (Figure 20).

a. In the **Layers** window (lower left panel), click the arrow to the left of **Borders and Labels** (see arrow #1).

b. Click the box to the left of **Populated Places** to **place a checkmark** in the box (see arrow #2).

c. Click the box to the left of **Terrain** to **place a checkmark** in the box (see arrow #3).

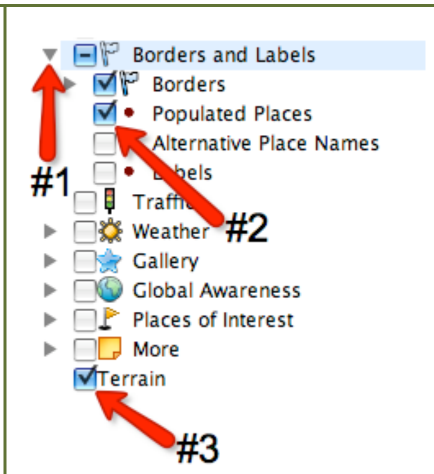


Figure 20. Illustration of meta-principle 3 on a student handout.

Exemplar Seven

Another exemplar for the content presentation sub-model is on scheduled Day 18 (actual implementation day 23). That activity is available at http://ei.lehigh.edu/eli/energy/sequence/day18.html. For this activity, the teacher in Step 1 *elicits prior understandings of lesson concepts* by asking learners what nuclear energy is. In Step 2, the teacher *gains the learners’ attention* by showing the nuclear reactors video clip. The teacher then *tells learners the objectives* of the lesson in Step 3 then asks learners what they learned from the video clip to *stimulate recall of prerequisite learning* in Step 4. The teacher provides the worksheet to students and directs them to the student resources page in Step 5. The link to the nuclear content pages is http://www.ei.lehigh.edu/learners/energy/nuclear1.html. In Step 6, learners read about nuclear energy, the teacher *explains content* and clarifies the concepts and terminology while *illustrating the content* with examples. The Web site uses animations to help *sustain students' attention*. Students *answer questions on their worksheets*. The teacher *presents content* and *elicits students' responses aloud* in Step 7. At the end of the lesson in Step 8, the teacher *provides feedback* to students' worksheet responses and questions and *reviews the content*.

This task mainly has *linguistic intelligence* when students read the Web pages and a bit of *logical-mathematical intelligence* when students answer the warm-up question and respond to the questions on their worksheets.

Exemplar Eight

I designed Day 21 (actual implementation days 27 and 28) to use the sub-model for laboratory activities (see page 119 of chapter 4). That activity is available at http://ei.lehigh.edu/eli/energy/sequence/day21.html. Laboratory activities involved hands-on experiments. In Step 1 of that day's activities, the teacher *elicits prior understandings of lesson concepts* by asking students how biomass is processed to become a fuel. The teacher then presents the task to the students in Step 2. The teacher *forms student groups* in Step 3 and *models* how to mark the test tubes in Step 4. In Step 5, the teacher asks students to *make predictions* and instruct students to *work in their groups* to *perform the task*. Students *make their observations* in Step 6 and *form explanations using evidence*. The students *evaluate their explanations* against alternative explanations then *draw conclusions* in Step 7. The teacher asks students to *share their results* with the class in Step 8 and *justify* how they reached their conclusions. In Step 9, the teacher *addresses misconceptions* and *reviews the concepts* learned. In designing this lab we assumed it would likely take the whole class period. We did not, therefore, include an extension task because of the time required to prepare the pulp solution.

I implemented meta-principle 1 by having the teacher ask learners questions as well as have them respond to worksheet questions (*logical-mathematical intelligence*), by having learners do hands-on activities (*bodily-kinesthetic intelligence*), and by asking learners to perform the task in groups (*interpersonal intelligence*).

Exemplar Nine

Students used My World GIS to investigate oil production and consumption (http://ei.lehigh.edu/eli/energy/sequence/day27.html) on scheduled Day 27 (actual implementation days 35 and 36). This day exemplified the sub-model for computer-supported activities (see pages 118-119 of chapter 4). In Step 1 of that sub-model, the *teacher elicits prior understandings of lesson concepts.* The teacher *presents the task* by telling learners what they will do in Step 2. The teacher presents the handout and worksheet students will need for the task in Steps 3 and has the students download the GIS file in Step 4. In Step 5, the teacher *models the task* to students and asks them *perform* the first part of the task in Step 6. The teacher *models* and *provides a worked example* of the second part of the task in Step 7 to guide the students on how to perform that task. *Learners perform the task* in Step 8 as the teacher *scaffolds the task.* Also, the teacher *asks learners to respond to additional questions* on their worksheets. The teacher *reviews activity concepts* by discussing student responses aloud and answering students' questions in Step 9. Step 10 illustrates the instructional model's *confirm instruction is meeting goals and objectives* in which the teacher adjusts instruction to meet the learners' needs.

I used multiple intelligences (meta-principle 1) by asking questions (*logical-mathematical intelligence*) and having students manipulate GIS data to recognize patterns (*spatial intelligence*). For meta-principle 2, I provided hints to guide students on how to manipulate the GIS data to obtain the answer. For example, to get how many countries in the world have oil reserves, I gave students a hint to *"click the oil reserves (billions barrels) column twice to sort it in descending order."* In Figure 21, I used illustrations to connect the text with the task to reduce learner dependence on text.

Click **By Math Operation** (see arrow #1).

Click the box to the right of **Add Field to the Table of** and select **Oil Production** from the list (see arrow #2).

Click the box to the right of **By Computing A** and select **Difference (subtraction)** from the list (see arrow #3).

Select **OP2008 (Thousand Barrels per Day)** in the box on the left (see arrow #4).

Select **OP1980 (Thousand Barrels per Day)** in the box on the right (see arrow #5).

Type **Oil Production Difference** in the **Result Name** text box (see arrow #6).

Click **OK** (see arrow #7).

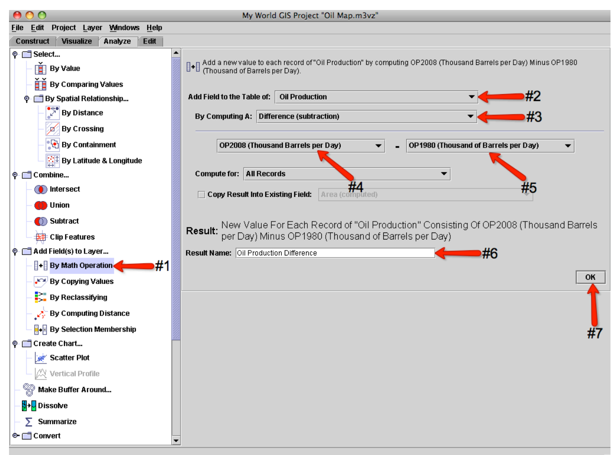


Figure 21. Illustration of meta-principle 3 on a student handout.

Exemplar Ten

The culminating activity was a five-day activity which was scheduled to begin on Day 34 (see http://ei.lehigh.edu/eli/energy/sequence/day34.html) and be completed on Day 38 (actual implementation days 46 to 63). This activity had a blend of all the three sub-models. Since the activity spanned five days, I only mention the specific steps in scheduled Days 35 and 36 that exemplify the continuation of the instructional model. For example, the teacher begins with *eliciting prior understandings of lesson concepts* in Step

1. The teacher *tells learners the objectives of the task* in Step 2 and what they will be required to do in the five days of the activity. In Step 3, the teacher *explains content* by explaining the term efficient energy policy. The teacher *presents the task* in Step 4 and *forms student groups* in Step 5. In Step 6 the teacher instructs students to write their assigned province on their worksheet then students download and open the GIS file in Step 7. The teacher *models the task* to the students by showing them the provinces and how to view the different data layers in Step 8. The teacher provides a *worked example* in Step 9. The students then *collaborate on performing the task* in Step 10. The teacher scaffolds the task in this step. Students complete analyzing energy resources for their province (see http://ei.lehigh.edu/eli/energy/sequence/day35.html) on scheduled Day 35 and *answer questions on their worksheets* in Step 4. The teacher *reviews student responses* in Step 2 of scheduled Day 36's activity (http://ei.lehigh.edu/eli/energy/sequence/day36.html) before asking students to go onto the next part of the activity.

This exemplar addressed asking questions (*logical-mathematical intelligence*), having students manipulate GIS data to recognize patterns (*spatial intelligence*), and having students collaborate on task (*interpersonal intelligence*). To guide learners' responses (meta-principle 2) I provided them a thought process for evaluating each energy source in their province. For example, I wrote, *"The factors needed to determine the ideal shore location of a tidal power plant include a large tidal range and a funnel shaped shoreline pointing inland. Tidal power requires a power plant at the coast and access to the grid for power distribution."* I used illustrations to connect the text with the task to reduce learner dependence on text (Figure 22).

Click the eye to turn the **Navitas Provinces.shp** layer off.	

Figure 22. Illustration of meta-principle 3 on a student handout.

Notice that the teacher used two or more sub-models in some activities and used a few steps from each sub-model and not all the steps of those particular sub-models. These 10 exemplars illustrate how the rest of the materials exemplified my instructional model and meta-principles.

CHAPTER 6: DATA ANALYSES AND FINDINGS

This study examined how a Web-based module might enhance science inquiry supported by GIS with eighth-grade students. The study investigated the design of the prototype so developed, the implementation of the module in the actual classroom, and student science content knowledge and attitudes outcomes as a result of the implementation of the module. The study's intent was not to determine fidelity of implementation for a finalized design and product. Instead, it was a formative evaluation pilot study. Recall from chapter three that the study involved one female science teacher and 108 eighth-grade science students from all five of her classes (54% Hispanic, 30% White, and 16% African American). The class sizes ranged from 13 to 32 students. (See Table 1 in chapter 3.)

My data sources/instruments included (1) daily classroom observations using the appropriate protocol for the specific sub-model employed that day, for the larger model, and for tracking student performances; (2) data from my daily reflective meetings with the teacher and, occasionally, the project director; (3) data from my daily research journal; (4) pre- and posttest data of the students' attitudes toward science and technology; and (5) data from pre- and posttest content knowledge assessments. I did a content analysis of the qualitative data and I used *Predictive Analytics Software* [PASW, formerly SPSS] version 18.0.2 for Windows (IBM, 2010) and *Microsoft Excel 2008* for Macintosh (Microsoft, 2007) to conduct quantitative analyses. The subsections on subsequent pages present the findings from the study and supporting data and analyses.

Findings

Observing how the teacher implemented the 10 models/sub-models; conducting teacher reflective meetings; writing reflections in my research journal; and assessing student performances, attitudes, and content knowledge produced a large amount of data. As an aid to the reader, therefore, I have divided the presentation of the findings from the presentation of the data and analyses that produced those findings. In this section I present the study findings for each research question and then in the next section I present the extensive data and analyses from which those findings were derived. Both sections are organized around the five research questions and each section uses the same general structure: Research question one has two parts which are addressed separately, followed by research questions two and three treated as a pair, followed by research question four and research question five.

Research Question 1a: How faithfully was the teacher able to implement the design?

Recall from chapter three that fidelity of implementation can be gauged in two ways; assessing the proportion of elements of the innovation that were actually implemented and measuring the extent to which elements of the innovation were implemented as intended/planned. Thus, I analyzed each model and sub-model for (1) the proportion of specified steps implemented by the teacher and (2) the extent to which the teacher followed the design's prescribed instructional sequence in implementing individual steps in the models/sub-models. I then classified the fidelity of implementation data in the *low, medium,* and *high* fidelity ranges delineated in chapter three. According to that set of ranges, *low* fidelity implementation is represented by implementation percentages between 0 and 37.5% (inclusive); *medium* fidelity implementation is represented by percentages above 37.5% but lower than 75%; and *high* fidelity implementations are represented by percentages of 75% or higher. Fidelity of implementation determined by identifying the proportion of steps that were actually implemented is referred to below as *actual use*, while fidelity of implementation determined by the extent to which steps were implemented as intended/planned is referred to as *adherence*.

Finding 1. As demonstrated by the analyses in the next section, actual use of the models/sub-models ranged from 52.3% to 89.3%. If we apply the percentage-based fidelity classifications from above to the current implementation in terms of proportion of steps implemented, we would classify as *high* fidelity the teacher implementation of the models/sub-models for:

- computer-supported activities;
- content presentation;
- unit introduction;
- unit conclusion; and
- blended sub-models for days two, twelve, and the culminating activity.

We would classify as *medium* fidelity the

- laboratory activities sub-model;
- blended sub-model for day five; and
- larger model as a standalone, as well as when incorporated with the sub-models for computer-supported activities and content presentation.

We would classify as *low* fidelity the implementation of the larger model when it was incorporated with the blended sub-models and laboratory activities sub-model. In fact, when incorporated with the laboratory activities sub-model, the steps in the larger model had the lowest mean fidelity of implementation of all sections of the design (22.0%).

Finding 2. Based on the completeness-and-duration ratings, adherence for the models/sub-models fell between 42.9% and 81.9%. We would rate teacher implementation of three sub-models (content presentation and days two and twelve) and the unit conclusion model as *high* fidelity. We would rate as *medium* fidelity the teacher's implementation of the models/sub-models for:

- computer-supported activities;
- day five;
- culminating activity;
- laboratory activities;
- unit introduction;
- larger model; and
- the larger model when combined with the computer-supported activities and content presentation sub-models.

Once again, we would rate the teacher implementation of the larger model when combined with the laboratory activities sub-model as *low* fidelity.

Finding 3. Adherence for the 21 steps that I included in my design to support inquiry teaching and learning was 60.6 %. We would rate this implementation as *medium* fidelity. These 21 steps involved doing inquiry through the use of GIS and hands-on laboratories. But combining GIS and hands-on labs obscures the fact that adherence for the hands-on science inquiry component was even lower. Thirteen of these 21 steps were part of the hands-on science inquiry activities and seven of these 13 steps were implemented with percentages ranging from 0% to 36.1%, classifying the teacher's implementation of those steps as *low* fidelity.

Finding 4. Overall, the teacher implemented 82.2% of the model and did not implement 17.8% of the model at all. Of that 82.2%, she implemented 68.1% of the model as intended/planned; that is, she devoted enough time to the steps and implemented all events in those steps. The remaining 14.1% of the model (the difference between 82.2% and 68.1%) was partially implemented: She either did not devote enough time to the steps or she did not implement all events in the steps as intended. Hence, for the entire instructional model, actual use had *high* fidelity (82.2%) and adherence had *medium* fidelity (68.1%).

At the end of each day, I assigned a global rating for the design, student performance, science instruction, and the model in my research journal. My daily ratings echo the actual use and adherence data: Overall, 82% of the design worked well and the teacher implemented 68% of the model well.

Research Question 1b: What factors account for loss of fidelity?

Finding 5. Based on the data from the daily reflective meetings with the teacher, comments and suggestions the teacher made in the course of the class periods, field notes from my observations and my research journal entries, there are five factors that appear to account for loss of fidelity. These factors are *scope of instruction, suitability of materials, independence, time,* and *eliciting student thoughts*. These five factors affected the various models/sub-models and activities in different ways. It seems scope of instruction, independence, and eliciting student thoughts mainly affected the middle steps in the models/sub-models. The steps that had *medium* and *low* fidelity of implementation that seems attributable to these three factors were typically the middle steps in the models/sub-models. In addition, the teacher, in most cases, skipped the last step(s) in the models/sub-models or did not implement all events in the last step(s) if she was pressed for time at the end of the period. Time and suitability of materials appeared to affect all three types of activities (content readings, computer-supported, and laboratory activities). Scope of instruction and independence mainly seemed to affect the computer-supported activities while eliciting student thoughts mainly seemed to affect the laboratory activities.

Finding 6. Four of the five factors are inter-dependent: Scope of instruction, suitability of materials, and independence all appear related to time. Tasks that the teacher reported had too much material to cover (big scope) also took more time than was allotted in the instructional sequence. If students took too long to complete a task, the teacher skipped the task and moved on to the next lesson because of time constraints. Students, especially in the classes categorized as *below proficient*, took longer to do tasks the teacher had reported were not relevant to the students. Also, because the teacher stated that she wanted students to do tasks independently without her intervention, students tended to take more time to complete tasks.

Finding 7. Fidelity of implementation of both types (*actual use* and *adherence*) differed by the proficiency categorization assigned to classes. These differences were not, however, statistically significant. Actual use of the models/sub-models was lower for the class categorized as *advanced proficient* and for one of the classes rated as *proficient*. These two classes met before lunch and at the end of the day respectively. Further analyses of the models/sub-models that had at least 10 observations which, according to Weiss (2006), is the suggested least number of scores required for research studies, however, indicated no significant differences in the actual use of the sub-models for computer-supported activities, $F(2, 79) = .109$, $p = .897$; content presentation, $F(2, 49) = .089$, $p = .915$; and the larger model, $F(2, 164) = .130$, $p = .879$.

Similarly, adherence was lower in the class rated as *advanced proficient* and for one of the classes classified as *proficient* with that of the latter class being much lower. Once again, however, there was no significant difference in my ratings for adherence for the computer-supported activities, $F(2, 79) = .708$, $p = .496$ and content presentation, $F(2, 49) = .218$, $p = .805$ sub-models, as well as for the larger model, $F(2, 164) = .110$, $p = .896$.

Research Question 2: What are the strengths and weaknesses of the design?

Finding 8. Based on the data from the daily reflective meetings with the teacher and occasionally with the project director, I categorized the strengths and weaknesses of the design into four factors: *learner engagement, design of materials, suitability of materials,* and *scope and sequence*. There does not appear to be a pattern to the strengths of the design across these four factors, however. The strengths of the design relate to specific aspects of the design the teacher rated as being effective and working well. The teacher reported that activities were highly engaging and that most materials were suitable to the learners. Further, she noted that the design of the materials (Web pages, instruction, activities, teacher and student handouts) was generally good. The teacher also reported that the scope of all content readings was good and the sequence, for the most part, was well done. For specific identified strengths of the design, see the section below on supporting data and analyses.

Finding 9. Likewise, the weaknesses of the design relate to specific aspects of the design the teacher rated as not being effective and not working well. For example, the teacher reported that some vocabulary in the content assessment and some readings was difficult, one computer-supported activity was not suitable, and the introduction of the culminating activity did not hold the students' interest. She also noted that the scope for most computer-supported activities and laboratory activities was too large and they had too much material to cover. Lastly, the teacher stated that some handout questions in the computer-supported activities did not demand critical thinking and one computer-supported activity did not have adequate scaffolding. While the teacher identified weaknesses in all three types of activities (content readings, computer-supported and laboratory) and materials under each factor, it appears that weaknesses in the computer-supported activities appeared across all four factors. The specific identified weaknesses of the design are discussed in the supporting data and analyses section.

Based on the teacher's ratings of the day's lesson, materials, and student performance and my daily ratings of student performances, students were on task most of the time but only a few students asked thoughtful questions. The mean ratings on student performances in classes one and two were much lower; these were the two classes rated as *below proficient*. Class two scored lower overall in five performances.

Research Question 3: What improvements should be made to the design?

Finding 10. Based on the identified weaknesses, the teacher and the project director suggested ways to improve the design in order to make it stronger. The improvements included redesigning some activities to make them more relevant to the students, providing more scaffolds for the teacher and students, changing the sequence of a few activities, and reducing the scope of activities to fit in one class period. Other improvements were to design different versions of instructional materials for some activities for students in different track categories, separate two-part questions into two separate questions, and have more questions that focus on critical thinking. For more specifics, see the next section of supporting data and analyses.

Research Question 4: How does a GIS-supported learning unit affect students' attitudes toward science and technology?

Finding 11. When all five sections are combined, students' mean score on the *Energy Unit Science and Technology Survey* instrument overall decreased significantly ($p < .01$) after the implementation of the unit. Though the mean scores for the classes classified as *proficient* and *below proficient* decreased, those decreases were not, however, statistically significant ($p = .250$ and $p = .127$, respectively). The decrease in mean score for the class rated as *advanced proficient* was still significant ($p < .05$). Additional analysis indicated a statistically significant main effect for time of testing, $F(1, 99) = 11.37$, $p = .001$ and no statistically significant main effect for proficiency track classification, $F(2, 99) = 2.41$, $p = .095$. Hence, students' scores were not significantly different by proficiency track classification. An item-by-item analysis of the items in the *Energy Unit Science and Technology Survey* instrument revealed statistically significant decreases in the mean scores for nine items, eight of which were items addressing attitudes toward science and one of which was an item addressing student attitudes toward technology.

Research Question 5: Does a GIS-supported learning unit affect student science achievement?

Finding 12. There was a significant difference between students' content knowledge pretest and posttest scores overall ($p < .001$) and for each of the three proficiency track classifications ($p < .001$). The students' grand mean score was higher on the posttest than on the pretest for all the three tracks. Further analysis showed statistically significant main effects for both time of testing, $F(1, 102) = 198.15$, $p < .001$ and proficiency track classification, $F(2, 102) = 9.62$, $p < .001$. The mean for the class classified as *advanced proficient* was significantly different from the means for the classes rated as *proficient* ($p < .01$) and *below proficient* ($p < .001$). The means for the classes rated as *proficient* and *below proficient* were not significantly different ($p = .260$).

Supporting Data and Analyses

This section summarizes the data I collected and reports the analyses upon which the findings for each research question are based. As noted above, this section is again organized around the five research questions. Question one has two parts whose data and analyses are presented in turn. In separately headed sections, I first present the quantitative data (finding 1), then the qualitative data represented by ratings I assigned on protocols (findings 2, 3, & 4), and third the qualitative data represented by notes I took during classroom observations or daily teacher interviews and by daily entries in my research journal (findings 5 & 6). Lastly, I present more quantitative data and qualitative data represented by ratings I assigned on protocols (finding 7). Research questions two and three are addressed simultaneously because the data that answer these questions are the same, supporting findings 8, 9, and 10 above. Finally, research questions four and five are addressed thereafter (findings 11 & 12). Qualitative data represented by ratings I assigned on protocols is referred to as *numerical qualitative data*.

Research Question 1a: How faithfully was the teacher able to implement the design?

The number of steps in the design's models and sub-models varied and this study allocated differing numbers of days to the use of these models and sub-models. For a reminder of the number of steps in each model/sub-model and the days allotted for each model/sub-model, please refer to Table 2 in chapter three.

Quantitative data. This section reports the percentage of days a step was actually implemented in each of the five classes across all days each model/sub-model was used. For each model/sub-model, I calculated the number of days a step was implemented as a percentage of the total number of days that utilized the model/sub-model for each class. I then calculated the mean of all five classes to get the mean percentage of total days in which a step was actually implemented. Finally, I computed the mean of the steps to obtain overall fidelity of implementation for that model/sub-model. For instance, using the data for the computer-supported activities sub-model in Table 4, the teacher *provided a worked example* (step 2.2.4) in class one 68.8% of the total days that sub-model was used and 70% of the total days across all five classes. Averaging the mean percentage of total days each of the eight steps was implemented produces the mean fidelity of implementation for steps in that sub-model (in this case, 84.4%). Data for each model/sub-model are presented below. In this section, fidelity of implementation for steps is referred to as *actual use*.

Computer-supported activities sub-model. This sub-model includes eight steps and was used across 17 days of the unit (42.5% of total instructional time). Table 4 presents fidelity of implementation for individual steps in the computer-supported activities sub-model. Only two out of eight steps were implemented every time. The teacher regularly elicited students' prior understandings of lesson concepts (step 2.2.1) and explained the task at hand (step 2.2.2) in all five classes. These were the first two steps in the sub-model. The next two steps had a lower fidelity of implementation; the teacher modeled the task (step 2.2.3) and provided a worked example (step 2.2.4) about 70% of the time. The fidelity of implementation for the next three middle steps fell gradually from 97.5% to 81.3%. The teacher reviewed activity concepts (step 2.2.8), the last step, about three fifths of the time. This last step had the lowest fidelity of implementation. As noted earlier, actual use of this sub-model across all five classes was 84.4%.

Table 4

Fidelity of Implementation for Individual Steps in the Computer-supported Activities Sub-model across Seventeen Days

Step		Class					
		1	2	3	4	5	*M*
2.2.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.3	Model task.	68.8%	75.0%	75.0%	68.8%	68.8%	71.3%
2.2.4	Provide worked example.	68.8%	75.0%	75.0%	62.5%	68.8%	70.0%
2.2.5	Ask learners to perform task.	100.0%	93.8%	93.8%	100.0%	100.0%	97.5%
2.2.6	Scaffold task.	93.8%	93.8%	93.8%	93.8%	93.8%	93.8%
2.2.7	Ask learners additional questions to elaborate task.	81.3%	81.3%	81.3%	81.3%	81.3%	81.3%
2.2.8	Review activity concepts.	62.5%	62.5%	62.5%	56.3%	62.5%	61.3%
Mean Fidelity of Implementation		84.4%	85.2%	85.2%	82.8%	84.4%	**84.4%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Content presentation sub-model. This sub-model consists of nine steps and was used across 10 days of the unit (25% of total instructional time). As Table 5 shows, actual use of the content presentation sub-model was 89.3%. While the teacher implemented four steps in all five classes and three steps at least 90% of the time, she provided feedback on the students' worksheet responses (step 2.1.8) and reviewed the content (step 2.1.9) only slightly more than half the time. These were the last two steps in the sub-model. Classes four and five that met during the last period before lunch and the last period of the day respectively demonstrated somewhat lower fidelity of implementation for these two steps than the other three classes.

Table 5

Fidelity of Implementation for Individual Steps in the Content Presentation Sub-model across Ten Days

		Class					
Step		1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.2	Gain and sustain learners' attention.	90.0%	90.0%	90.0%	100.0%	90.0%	92.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.4	Stimulate recall of prerequisite learning.	90.0%	90.0%	100.0%	100.0%	100.0%	96.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.6	Illustrate content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.7	Elicit answers to specific questions on students' worksheets.	90.0%	90.0%	90.0%	90.0%	90.0%	90.0%
2.1.8	Solicit some responses from students' worksheets and provide feedback aloud.	70.0%	70.0%	70.0%	50.0%	60.0%	64.0%
2.1.9	Review content.	70.0%	70.0%	70.0%	50.0%	50.0%	62.0%
Mean Fidelity of Implementation		90.0%	90.0%	91.1%	87.8%	87.8%	**89.3%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Blended sub-model for day two. The blended sub-model for day two (2.5% of total instructional time) had a total of 14 steps drawn from the content presentation and computer-supported activities sub-models. As displayed in Table 6, the teacher implemented 11 of these 14 steps in all five classes every time. Nine of those 11 steps were the first steps in the sub-model. The two remaining steps were less well implemented: The teacher asked students to answer questions on their worksheets (step 2.1.7) and provided feedback on their worksheet responses (step 2.1.8) only in one class. This was her first class of the day. The teacher did not implement the last step in the sub-model; she did review the activity (step 2.2.8) in any of the five classes. Thus, actual use of this blended sub-model was 81.4%.

Table 6

Fidelity of Implementation for Individual Steps in the Blended Sub-model for Day Two

		Class					
Step		1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.2	Gain and sustain learners' attention.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.4	Stimulate recall of prerequisite learning.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.3	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.4	Provide worked example.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.6	Illustrate content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.7	Elicit answers to specific questions on students' worksheets.	100.0%	0.0%	0.0%	0.0%	0.0%	20.0%
2.1.8	Solicit some responses from students' worksheets and provide feedback aloud.	100.0%	0.0%	0.0%	0.0%	0.0%	20.0%
2.2.5	Ask learners to perform	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	task.						
2.2.6	Scaffold task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mean Fidelity of Implementation		92.9%	78.6%	78.6%	78.6%	78.6%	**81.4%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Blended sub-model for day five. Table 7 displays the fidelity of implementation for the blended sub-model for day five (2.5% of total instructional time) that combined the content presentation and laboratory activities sub-models. This blended sub-model had 16 steps of which the teacher implemented 10 steps consistently in all five classes. Once again, the remaining steps were less well implemented: The teacher gained the learners' attention (step 2.1.2) in only one class (the first class of the day). The teacher did not ask learners to predict the results of the experiment (step 2.3.5) in any of the classes. While the teacher had students share and justify results (step 2.3.10) in her second and third classes of the day, she neither addressed students' misconceptions (step 2.3.11) nor did she ask students to perform extension tasks (step 2.3.12). The teacher reviewed the activity (step 2.3.13) in four classes. She did not review the activity in class one. Hence, actual use of this blended sub-model was 71.3%.

Table 7

Fidelity of Implementation for Individual Steps in the Blended Sub-model for Day Five

		Class					
Step		1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.2	Gain and sustain learners' attention.	100.0%	0.0%	0.0%	0.0%	0.0%	20.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.4	Stimulate recall of prerequisite learning.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.3	Form student groups.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

2.3.4	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.5	Ask students to make predictions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.6	Ask group members to collaborate on task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.7	Have students make observations.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.8	Have students use evidence to form explanations.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.9	Have students evaluate explanations and draw conclusions.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.10	Have students share and justify results.	0.0%	100.0%	100.0%	0.0%	0.0%	40.0%
2.3.11	Address misconceptions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.12	Ask learners to perform extension tasks.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.13	Review activity concepts.	0.0%	100.0%	100.0%	100.0%	100.0%	80.0%
Mean Fidelity of Implementation		68.8%	75.0%	75.0%	68.8%	68.8%	**71.3%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Blended sub-model for day twelve. On day twelve (2.5% of total instructional time), a blend of the content presentation and the computer-supported activities sub-models was used. The blended sub-model had a total of 13 steps. As shown in Table 8, actual use of the sub-model was 89.2% with that for the individual steps ranging from 20% to100%. The teacher implemented 11 steps in all five classes. The remaining two steps were implemented less frequently: She asked students questions to gain their attention (step 2.1.2) in the first two classes of the day and reviewed activity concepts (step 2.2.8) in only the class rated by the assistant principal as *advanced proficient*.

Table 8

Fidelity of Implementation for Individual Steps in the Blended Sub-model for Day Twelve

Step		Class 1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.2	Gain and sustain learners' attention.	100.0%	100.0%	0.0%	0.0%	0.0%	40.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.4	Stimulate recall of prerequisite learning.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.6	Illustrate content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.3	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.4	Provide worked example.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.5	Ask learners to perform task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.6	Scaffold task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.7	Ask learners additional questions to elaborate task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	100.0%	0.0%	20.0%
Mean Fidelity of Implementation		92.3%	92.3%	84.6%	92.3%	84.6%	**89.2%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Blended sub-model for the culminating activity. As presented in Table 9, actual use of the blended sub-model for the culminating activity was 80%. The culminating activity consisted of different subtasks and was allotted five days in the unit (12.5% of total instructional time). The sub-model for the culminating activity comprised 20 steps drawn from all three sub-models (content presentation, computer-supported activities, and laboratory activities). Those 20 steps, unlike any other sub-model, did not occur in a linear sequence. The nature of the subtasks and the blending process caused some steps to appear in different positions than their step numbers might suggest and eight of these steps represent repetition. Four steps (2.1.3, 2.1.5, 2.2.8, and 2.3.6) are repeated more than once.

Table 9

Fidelity of Implementation for Individual Steps in the Blended Sub-model for the Culminating Activity

		Class					
	Step	1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.2.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.3	Form student groups.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.3	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.4	Provide worked example.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.6	Ask group members to collaborate on task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.6	Scaffold task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.7	Ask learners additional questions to elaborate task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.6	Ask group members to collaborate on task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.6	Ask group members to collaborate on task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

2.3.10	Have students share and justify results.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mean Fidelity of Implementation		80.0%	80.0%	80.0%	80.0%	80.0%	**80.0%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

For the 20-step sequence of this activity that occurred over five days, the teacher implemented 16 steps in all five classes and did not implement four steps in any class. In terms of the four steps that occur more than once in the blended sub-model, the teacher did not explain the content (step 2.1.5) two out of the three times that called for implementing this step and she did not review the activity (step 2.2.8) either time she was required to do this step. These four steps fell in the middle and at the end of the sub-model.

Laboratory activities sub-model. Two days of the unit (5% of total instructional time) were devoted to the laboratory activities sub-model that includes 13 steps. Actual use of this sub-model was 52.3% as shown in Table 10. The teacher implemented only five of thirteen steps (38.5%) in all five classes. Actual use of the last six steps of the sub-model was lower, ranging 0% and 50%. The teacher did a warm-up exercise (step 2.3.1) once in only one class, once again her first class of the day. The teacher never asked students to make predictions (step 2.3.5) and share and justify their lab results (step 2.3.10), nor did she address students' misconceptions (step 2.3.11). While students consistently collaborated in doing the task (step 2.3.6) and making observations (step 2.3.7), only half the time were they asked to form explanations (step 2.3.8) and draw conclusions (step 2.3.9). Students in only two classes performed extension tasks (step 2.3.12). The two classes were one class classified as *proficient* and the class rated as *advanced proficient*; only the class categorized as *advanced proficient* did extension tasks on both days the sub-model was used. Last but not least, the teacher reviewed the lab concepts (step 2.3.13) in four classes only half the time; that was the last step of the sub-model. The class in which the teacher did not review the lab concepts met during the last period of the day.

Table 10

Fidelity of Implementation for Individual Steps in the Laboratory Activities Sub-model across Two Days

		Class					
Step		1	2	3	4	5	*M*
2.3.1	Elicit prior understandings of lesson concepts.	50.0%	0.0%	0.0%	0.0%	0.0%	10.0%
2.3.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.3	Form student groups.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.4	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.5	Ask students to make predictions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.6	Ask group members to collaborate on task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.7	Have students make observations.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.8	Have students use evidence to form explanations.	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
2.3.9	Have students evaluate explanations and draw conclusions.	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%
2.3.10	Have students share and justify results.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.11	Address misconceptions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.12	Ask learners to perform extension tasks.	0.0%	0.0%	50.0%	100.0%	0.0%	30.0%
2.3.13	Review activity concepts.	50.0%	50.0%	50.0%	50.0%	0.0%	40.0%
Mean Fidelity of Implementation		53.8%	50.0%	53.8%	57.7%	46.2%	**52.3%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Larger model: Unit introduction. Actual use of the larger model for the unit introduction was 84% (see Table 11). Students in all five classes took both pretests (steps 1.1 and 1.2). In addition to the pretests, the teacher asked students questions to check their background knowledge (step 1.3) in the first three classes. She then identified and addressed misconceptions from student responses (step 1.5). The teacher did not do these two steps in the last two classes of the day, however. On the fourth day of the unit, students brainstormed independently and added what they knew about energy to their concept maps (step 1.4).

Table 11

Fidelity of Implementation for Individual Steps in the Unit Introduction

Step		Class 1	2	3	4	5	*M*
1.1	Administer content knowledge pretest.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1.2	Administer attitude towards science and technology pretest.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1.3	Elicit and discuss prior understandings of unit concepts aloud.	100.0%	100.0%	100.0%	0.0%	0.0%	60.0%
1.4	Elicit additions to the concept map independently.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1.5	Identify misconceptions from student responses.	100.0%	100.0%	100.0%	0.0%	0.0%	60.0%
Mean Fidelity of Implementation		100.0%	100.0%	100.0%	60.0%	60.0%	**84.0%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Larger model: Daily check. This subset of the larger model comprised six steps, four of which were done every day of the unit except on the pretest and posttest days. Recall that the teacher was to ask students to periodically reflect on what they had learned by updating their concept maps or answering reflection questions. Reflection (step 3.5) was allotted eight days. Also, the teacher was to adjust instruction to meet learners' needs (step 3.6) when needed. As shown in Table 12, while the teacher asked students questions to clarify their understandings and reinforce concepts (step 3.1) at least 90% of the time, she solicited questions from students (step 3.2) only 3.6% of the time in four classes. The teacher did not solicit questions from students in her first class of the day, one of the classes rated as *below proficient*. Further, the teacher checked students' worksheet responses (step 3.3) and provided feedback (step 3.4) only about half the time. Students were asked to reflect on what they had learned (step 3.5) about three fifths of the time. Hence, actual use of the larger model was 53.8%. Throughout the unit, the teacher adjusted instruction to meet learners' needs (step 3.6) only twice. In both instances, the teacher reported that the tasks needed to be more relevant to the students' everyday experiences.

Table 12

Fidelity of Implementation for Individual Steps in the Larger Model across Thirty-Eight Days

		Class					
	Step	1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	97.0%	93.9%	93.9%	90.9%	93.9%	93.9%
3.2	Solicit and respond to student questions.	0.0%	3.0%	3.0%	3.0%	9.1%	3.6%
3.3	Check students' worksheet responses aloud.	57.6%	57.6%	57.6%	51.5%	48.5%	54.5%
3.4	Provide feedback aloud.	57.6%	57.6%	57.6%	51.5%	48.5%	54.5%
3.5	Ask students to reflect on topic.	62.5%	62.5%	62.5%	62.5%	62.5%	62.5%
Mean Fidelity of Implementation		54.9%	54.9%	54.9%	51.9%	52.5%	**53.8%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Larger model: Unit conclusion. Table 13 presents the fidelity of implementation for the unit conclusion. The teacher assessed the culminating activity (step 4.1) and administered both posttests (steps 4.3 and 4.4) in all five classes. She did not, however, assess the concept map (step 4.2) in any class. Thus, actual use of this model was 75%.

Table 13

Fidelity of Implementation for Individual Steps in the Unit Conclusion

Step		Class 1	2	3	4	5	*M*
4.1	Assess culminating activity	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
4.2	Assess concept map.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
4.3	Administer [and analyze] content knowledge posttest.	100.0%	100.0%	100.0%	100.0	100.0%	100.0%
4.4	Administer [and analyze] attitude towards science and technology posttest.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Mean Fidelity of Implementation		75.0%	75.0%	75.0%	75.0%	75.0%	**75.0%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Larger model with computer-supported activities sub-model. I calculated fidelity of implementation for the larger model when combined with the computer-supported activities sub-model. As Table 14 shows, the teacher asked students questions to clarify their understandings every time in all five classes (step 3.1) but solicited for student questions in only one class (step 3.2), in that case, the last class of the day. The teacher checked students' worksheet responses (step 3.3) and provided feedback (step 3.4) about three fifths of the time, while students were asked to reflect on what they had learned 75% of the time (step 3.5).

Table 14

Fidelity of Implementation for Individual Steps in the Larger Model when Incorporated with the Computer-supported Activities Sub-model across Seventeen Days

Step		Class 1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3.2	Solicit and respond to student questions.	0.0%	0.0%	0.0%	0.0%	6.3%	1.3%
3.3	Check students' worksheet responses aloud.	62.5%	62.5%	62.5%	68.8%	62.5%	63.8%

3.4	Provide feedback aloud.	62.5%	62.5%	62.5%	68.8%	62.5%	63.8%
3.5	Ask students to reflect on topic.	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Mean Fidelity of Implementation		60.0%	60.0%	60.0%	62.5%	61.3%	**60.8%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Larger model with content presentation sub-model. As shown in Table 15, the teacher asked students questions in all five classes (step 3.1); in contrast, she solicited questions from students in only two classes (step 3.2), and then only one day out of the 10 where the design called for use of this sub-model. The teacher asked students in three classes to reflect on what they had learned (step 3.5). These were the two classes rated as *proficient* and the one class rated as *advanced proficient*.

Table 15

Fidelity of Implementation for Individual Steps in the Larger Model when Incorporated with the Content Presentation Sub-model across Ten Days

		Class					
	Step	1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3.2	Solicit and respond to student questions.	0.0%	10.0%	0.0%	10.0%	0.0%	4.0%
3.3	Check students' worksheet responses aloud.	70.0%	70.0%	70.0%	50.0%	50.0%	62.0%
3.4	Provide feedback aloud.	70.0%	70.0%	70.0%	50.0%	50.0%	62.0%
3.5	Ask students to reflect on topic.	0.0%	0.0%	100.0%	100.0%	100.0%	60.0%
Mean Fidelity of Implementation		48.0%	50.0%	68.0%	62.0%	60.0%	**57.6%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Larger model with blended sub-models. Table 16 shows the fidelity of implementation for the larger model with the blended sub-models for days two, five, twelve, and the culminating activity (days 34-38). Step 3.5, *ask students to reflect on topic,* was not included in the table because it was implemented periodically in the course of the unit, and none of those times fell on a day when a blended sub-model was used. Once again, the teacher asked students questions consistently in all five classes (step 3.1) but solicited questions from students (step 3.2) in only one class; one of the classes classified as *proficient*. The teacher failed to implement either of the last two steps: She did not check students' worksheet responses (step 3.3) nor did she provide feedback (step 3.4).

Table 16

Fidelity of Implementation for Individual Steps in the Larger Model when Incorporated with the Blended Sub-models

		Class					
Step		1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3.2	Solicit and respond to student questions.	0.0%	0.0%	25.0%	0.0%	0.0%	5.0%
3.3	Check students' worksheet responses aloud.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3.4	Provide feedback aloud.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mean Fidelity of Implementation		25.0%	25.0%	31.3%	25.0%	25.0%	**26.3%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Larger model with laboratory activities sub-model. As displayed in Table 17, fidelity of implementation for steps in the larger model when incorporated with the laboratory activities sub-model ranged from 0% to 40%. The first time the laboratory activities sub-model was used, the teacher asked students questions in only one class (step 3.1), her first class of the day. In contrast, the teacher solicited questions from students in her last class of the day both days the sub-model was used (step 3.2). She checked students' worksheet responses (step 3.3) and provided feedback (step 3.4) in four classes half the time these steps were required by the model, and she never did these two steps in the last class of the day. The teacher also never asked students in any of the five classes to reflect on what they had learned (step 3.5).

Table 17

Fidelity of Implementation for Individual Steps in the Larger Model when Incorporated with the Laboratory Activities Sub-model across Two Days

	Step	Class 1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	50.0%	0.0%	0.0%	0.0%	0.0%	10.0%
3.2	Solicit and respond to student questions.	0.0%	0.0%	0.0%	0.0%	100.0%	20.0%
3.3	Check students' worksheet responses aloud.	50.0%	50.0%	50.0%	50.0%	0.0%	40.0%
3.4	Provide feedback aloud.	50.0%	50.0%	50.0%	50.0%	0.0%	40.0%
3.5	Ask students to reflect on topic.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mean Fidelity of Implementation		30.0%	20.0%	20.0%	20.0%	20.0%	**22.0%**

Note. Fidelity of implementation expressed above as percentage of days in which a step was actually implemented.

Numerical qualitative data. As discussed in chapter three, the daily classroom observation protocols assessed two attributes for each step in the models/sub-models: *duration* (if the teacher devoted the right amount of time to a step) and *completeness* (if the teacher implemented all events in a step). Steps were made up of one or more *events* the teacher did and duration ratings ranged from 0 (*not done*) to 3 (*enough time devoted*), while completeness ratings ranged from 0 (*not implemented*) to 4 (*everything implemented*). Thus, each step in the model was eligible to receive a maximum of 12 possible points (*teacher devoted enough time to the step* [3] and *teacher implemented all events* [4]). Duration-and-completeness multiplications produced nine possible ratings that equate to percentages of maximum possible points as follows: 0(0%), 1(8.3%), 2(16.7%), 3(25%,), 4(33.3%), 6(50%), 8(66.7%), 9(75%) and 12(100%). I reanalyzed teacher implementation of the models/sub-models using the rubric for duration-and-completeness (see Table 3 in chapter three) as a measure of the extent to which the teacher implemented the models/sub-models as intended/planned. Those data are presented below. Fidelity of implementation as intended/planned is referred to as *adherence* in this section.

Computer-supported activities sub-model. As displayed in Table 18, the teacher did a warm-up activity (step 2.2.1) in all five classes and presented the task (step 2.2.2) almost exactly as prescribed in the instructional sequence. These were the first two steps in the sub-model. The teacher modeled the task (step 2.2.3), provided a worked example (step 2.2.4), and had students perform the task (step 2.2.5) as prescribed slightly above three fifths of the time. These three steps fell in the middle in the sub-model's sequence. While the teacher scaffolded the task (step 2.2.6) over 90% of the time, she asked students to do questions on their worksheets (step 2.2.7) and reviewed the activity (step 2.2.8) only about half the time, on average. These were the last two steps in the sub-model. Thus, adherence for this sub-model was 73.9%.

Table 18

Fidelity of Implementation for Duration and Completeness of Individual Steps in the Computer-supported Activities Sub-model across Seventeen Days

		Class					
Step		1	2	3	4	5	*M*
2.2.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.2	Present authentic task.	95.3%	95.3%	98.4%	93.8%	95.3%	95.6%
2.2.3	Model task.	67.2%	73.4%	70.3%	64.1%	65.6%	68.1%
2.2.4	Provide worked example.	62.5%	71.9%	68.8%	62.5%	65.6%	66.3%
2.2.5	Ask learners to perform task.	53.1%	47.9%	69.3%	77.1%	76.0%	64.7%
2.2.6	Scaffold task.	93.8%	93.8%	93.8%	93.8%	93.8%	93.8%

2.2.7	Ask learners additional questions to elaborate task.	37.5%	34.4%	48.4%	53.6%	54.7%	45.7%
2.2.8	Review activity concepts.	57.8%	57.8%	57.8%	53.1%	57.8%	56.9%
Mean Fidelity of Implementation		70.9%	71.8%	75.8%	74.7%	76.1%	**73.9**%

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Content presentation sub-model. As Table 19 shows, adherence for the content presentation sub-model was 81.9%, slightly more than that of the computer-supported activities sub-model. The teacher did a warm-up exercise (step 2.1.1) and told students the objectives of the lesson (step 2.1.3) as prescribed every time. Fidelity of implementation for the five steps in the middle ranged from 69.8% to 93.7%. The teacher provided feedback to students' responses (step 2.1.8) and reviewed the content (step 2.1.9) about half the time. Once again, these were the last two steps in the sub-model.

Table 19

Fidelity of Implementation for Duration and Completeness of Individual Steps in the Content Presentation Sub-model across Ten Days

		Class					
Step		1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.2	Gain and sustain learners' attention.	90.0%	90.0%	90.0%	100.0%	90.0%	92.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.4	Stimulate recall of prerequisite learning.	85.8%	90.8%	86.7%	86.7%	86.7%	87.3%
2.1.5	Explain content.	80.8%	80.0%	87.5%	92.5%	87.5%	85.7%
2.1.6	Illustrate content.	90.8%	92.5%	95.0%	95.0%	95.0%	93.7%
2.1.7	Elicit answers to specific questions on students' worksheets.	69.2%	50.8%	69.2%	82.5%	77.5%	69.8%
2.1.8	Solicit some responses from students' worksheets and provide feedback aloud.	49.2%	62.5%	65.0%	50.0%	45.0%	54.3%

2.1.9	Review content.	49.2%	62.5%	65.0%	50.0%	45.0%	54.3%
Mean Fidelity of Implementation		79.4%	81.0%	84.3%	84.1%	80.7%	**81.9%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Blended sub-model for day two. Table 20 shows that the teacher implemented nine out of fourteen steps exactly as prescribed in the instructional sequence. These were the first nine steps of the sub-model. While the teacher had students in the first class answer questions on their worksheets (step 2.1.7), to which she provided feedback on their responses (step 2.1.8), she did not implement all events in those two steps. The teacher had students in classes rated as *proficient* and *advanced proficient* complete the task (step 2.2.5) as prescribed, while she asked students in the classes rated as *below proficient* to complete only part of the task. The teacher did not scaffold the task (step 2.2.6) in the first class as prescribed nor did she review the activity (step 2.2.8) in any of the five classes. These were the last two steps of the sub-model, which had adherence of 75.6%.

Table 20

Fidelity of Implementation for Duration and Completeness of Individual Steps in the Blended Sub-model for Day Two

Step		Class					
		1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.2	Gain and sustain learners' attention.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.4	Stimulate recall of prerequisite learning.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.3	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.4	Provide worked example.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.6	Illustrate content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.7	Elicit answers to specific questions on students' worksheets.	25.0%	0.0%	0.0%	0.0%	0.0%	5.0%
2.1.8	Solicit some responses from students' worksheets and provide feedback aloud.	25.0%	0.0%	0.0%	0.0%	0.0%	5.0%
2.2.5	Ask learners to perform task.	8.3%	25.0%	100.0%	100.0%	100.0%	66.7%
2.2.6	Scaffold task.	8.3%	100.0%	100.0%	100.0%	100.0%	81.7%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mean Fidelity of Implementation		69.0%	73.2%	78.6%	78.6%	78.6%	**75.6%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Blended sub-model for day five. The blended sub-model for day five had adherence of 63.3% (see Table 21). While the teacher had students do a warm-up activity (step 2.1.1) in all five classes, she played a video to gain the students' attention in only one class, the first of the day. The teacher did not ask students to make predictions (step 2.3.5) and perform extension tasks (2.3.12), nor did she address the students' misconceptions (step 2.3.11). Students in classes four and five were not asked to form explanations (step 2.3.8) and draw conclusions (step 2.3.9) about their experiments. Classes four and five met before lunch and during the last period, respectively. Adherence for the last four steps in the sub-model ranged from 0% to 28.3%.

Table 21

Fidelity of Implementation for Duration and Completeness of Individual Steps in the Blended Sub-model for Day Five

		Class					
Step		1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

2.1.2	Gain and sustain learners' attention.	100.0%	0.0%	0.0%	0.0%	0.0%	20.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.4	Stimulate recall of prerequisite learning.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.3	Form student groups.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.4	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.5	Ask students to make predictions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.6	Ask group members to collaborate on task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.7	Have students make observations.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.8	Have students use evidence to form explanations.	100.0%	100.0%	100.0%	25.0%	25.0%	70.0%
2.3.9	Have students evaluate explanations and draw conclusions.	100.0%	100.0%	100.0%	25.0%	25.0%	70.0%
2.3.10	Have students share and justify results.	0.0%	100.0%	25.0%	0.0%	0.0%	25.0%
2.3.11	Address misconceptions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.12	Ask learners to perform extension tasks.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.13	Review activity concepts.	0.0%	25.0%	8.3%	100.0%	8.3%	28.3%
Mean Fidelity of Implementation		68.8%	70.3%	64.6%	59.4%	53.6%	**63.3%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Blended sub-model for day twelve. As Table 22 presents, adherence for the blended sub-model for day twelve was 81.7%. She did a warm-up exercise (step 2.1.1) in all five classes but gained the learners' attention (step 2.1.2) in only the first two classes of the day. The teacher did not tell learners the objective of the lesson (step 2.1.3), model the task (step 2.2.3), and provide a worked example (step 2.2.4) as prescribed in the instructional sequence in class five, the last class of the day. She reviewed the activity (step 2.2.8), the last step of the sub-model, in only one class rated as *advanced proficient*.

Table 22

Fidelity of Implementation for Duration and Completeness of Individual Steps in the Blended Sub-model for Day Twelve

Step		Class 1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.2	Gain and sustain learners' attention.	100.0%	100.0%	0.0%	0.0%	0.0%	40%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	33.3%	86.7%
2.1.4	Stimulate recall of prerequisite learning.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.6	Illustrate content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.3	Model task.	100.0%	50.0%	50.0%	100.0%	25.0%	65.0%
2.2.4	Provide worked example.	100.0%	50.0%	50.0%	100.0%	25.0%	65.0%
2.2.5	Ask learners to perform task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.6	Scaffold task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.7	Ask learners additional questions to elaborate task.	100.0%	100.0%	25.0%	100.0%	100.0%	85.0%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	100.0%	0.0%	20.0%
Mean Fidelity of Implementation		92.3%	84.6%	71.2%	92.3%	67.9%	**81.7%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Blended sub-model for the culminating activity. As presented in Table 23, the teacher implemented half of the steps in the sub-model for the culminating activity as prescribed in the instructional sequence. Recall that the 20 steps in this sub-model do not appear in a linear sequence and four steps (2.1.3, 2.1.5, 2.2.8, and 2.3.6) are to be completed more than once. Step 2.1.5 (explain content) occurred three times across the five-day activity: The teacher explained the content only once and she did not review activity concepts (step 2.2.8) in any of the five classes both times this step occurred. As a consequence, this sub-model had adherence of 62.4%.

Table 23

Fidelity of Implementation for Duration and Completeness of Individual Steps in the Blended Sub-model for the Culminating Activity

		Class					
Step		1	2	3	4	5	*M*
2.1.1	Elicit prior understandings of lesson concepts.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	50.0%	50.0%	50.0%	70.0%
2.1.5	Explain content.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.2.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.3	Form student groups.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.3	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.4	Provide worked example.	50.0%	100.0%	100.0%	100.0%	100.0%	90.0%
2.3.6	Ask group members to collaborate on task.	8.3%	8.3%	16.7%	16.7%	8.3%	11.7%
2.2.6	Scaffold task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.7	Ask learners additional questions to elaborate task.	8.3%	8.3%	25.0%	25.0%	16.7%	16.7%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.1.5	Explain content.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.6	Ask group members to collaborate on task.	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.1.5	Explain content.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.6	Ask group members to collaborate on task.	25.0%	25.0%	50.0%	50.0%	25.0%	35.0%
2.1.3	Tell learners the objectives.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.10	Have students share and justify results.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.2.8	Review activity concepts.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mean Fidelity of Implementation		60.8%	63.3%	63.3%	63.3%	61.3%	**62.4%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Laboratory activities sub-model. The adherence for this sub-model was 42.9% as shown in Table 24. The teacher implemented three out of thirteen steps (23.1%) as prescribed in the instructional sequence. She asked students in the first class of the day to do a warm-up exercise (step 2.3.1) only half the time this sub-model was used. Students in the other four classes were never asked to do a warm-up exercise. The teacher also did not ask students in the first two classes, the two classes categorized as *below proficient,* to do extension tasks (step 2.3.12). The adherence for the last six steps of the sub-model ranged from 0% to 40%.

Table 24

Fidelity of Implementation for Duration and Completeness of Individual Steps in the Laboratory Activities Sub-model across Two Days

		Class					
Step		1	2	3	4	5	*M*
2.3.1	Elicit prior understandings of lesson concepts.	50.0%	0.0%	0.0%	0.0%	0.0%	10.0%
2.3.2	Present authentic task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.3	Form student groups.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.4	Model task.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
2.3.5	Ask students to make predictions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.6	Ask group members to collaborate on task.	100.0%	87.5%	100.0%	100.0%	100.0%	97.5%
2.3.7	Have students make observations.	100.0%	87.5%	100.0%	100.0%	100.0%	97.5%
2.3.8	Have students use evidence to form explanations.	4.2%	4.2%	4.2%	4.2%	4.2%	4.2%
2.3.9	Have students evaluate explanations and draw conclusions.	4.2%	4.2%	4.2%	4.2%	4.2%	4.2%
2.3.10	Have students share and justify results.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2.3.11	Address misconceptions.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

2.3.12	Ask learners to perform extension tasks.	0.0%	0.0%	12.5%	12.5%	0.0%	5.0%
2.3.13	Review activity concepts.	50.0%	50.0%	50.0%	50.0%	0.0%	40.0%
Mean Fidelity of Implementation		46.8%	41.0%	43.9%	43.9%	39.1%	**42.9%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Larger model: Unit introduction. Table 25 displays adherence for the unit introduction. The teacher administered both pretests (steps 1.1 and 1.2) in all five classes. While she discussed the students' background knowledge (step 1.3) and addressed their misconceptions (step 1.5) in the first three classes, she did not implement these two steps in the last two classes. Hence, adherence for this model was 74.7%.

Table 25

Fidelity of Implementation for Duration Spent on Individual Steps in the Unit Introduction

		Class					
Step		1	2	3	4	5	*M*
1.1	Administer content knowledge pretest.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1.2	Administer attitude towards science and technology pretest.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
1.3	Elicit and discuss prior understandings of unit concepts aloud.	100.0%	100.0%	100.0%	0.0%	0.0%	60.0%
1.4	Elicit additions to the concept map independently.	33.3%	33.3%	66.7%	66.7%	66.7%	53.3%
1.5	Identify misconceptions from student responses.	100.0%	100.0%	100.0%	0.0%	0.0%	60.0%
Mean Fidelity of Implementation		86.7%	86.7%	93.3%	53.3%	53.3%	**74.7%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Larger model: Daily check. As displayed in Table 26, the larger model had adherence of 49.5%. While the teacher asked students questions and responded to their answers almost every time (step 3.1), she hardly ever solicited questions from the students (step 3.2) and not at all in her first class of the day, one of the classes classified as *below proficient*.

Table 26

Fidelity of Implementation for Duration Spent on Individual Steps in the Larger Model across Thirty-Eight Days

		Class					
Step		1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	94.9%	93.9%	93.9%	90.9%	93.9%	93.5%
3.2	Solicit and respond to student questions.	0.0%	3.0%	3.0%	3.0%	9.1%	3.6%
3.3	Check students' worksheet responses aloud.	55.6%	56.6%	57.6%	51.5%	48.5%	53.9%
3.4	Provide feedback aloud.	55.6%	56.6%	57.6%	51.5%	48.5%	53.9%
3.5	Ask students to reflect on topic.	41.7%	41.7%	45.8%	37.5%	45.8%	42.5%
Mean Fidelity of Implementation		49.5%	50.4%	51.6%	46.9%	49.2%	**49.5%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Larger model with computer-supported activities sub-model. When combined with the computer-supported activities sub-model, the larger model had adherence of 50.8% as shown in Table 27. The teacher asked students questions and responded to their answers every time (step 3.1), but only solicited questions from the students (step 3.2) in one class. She asked students to reflect on what they had learned (step 3.5) only a quarter of the time.

Table 27

Fidelity of Implementation for Duration Spent on Individual Steps in the Larger Model when Incorporated with the Computer-supported Activities Sub-model across Seventeen Days

	Step	Class 1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3.2	Solicit and respond to student questions.	0.0%	0.0%	0.0%	0.0%	6.3%	1.3%
3.3	Check students' worksheet responses aloud.	62.5%	62.5%	62.5%	68.8%	62.5%	63.8%
3.4	Provide feedback aloud.	62.5%	62.5%	62.5%	68.8%	62.5%	63.8%
3.5	Ask students to reflect on topic.	25.0%	25.0%	25.0%	25.0%	25.0%	25.0%
Mean Fidelity of Implementation		50.0%	50.0%	50.0%	52.5%	51.3%	**50.8%**

Note. Fidelity of implementation scores expressed above as percentage of days in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Larger model with content presentation sub-model. As shown in Table 28, the larger model when combined with the content presentation sub-model had adherence of 52.8%. Once again the teacher asked students questions and responded to their answers every time (step 3.1), but only solicited questions from the students (step 3.2) in two classes, and then only once.

Table 28

Fidelity of Implementation for Duration Spent on Individual Steps in the Larger Model when Incorporated with the Content Presentation Sub-model across Ten Days

Step		Class 1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
3.2	Solicit and respond to student questions.	0.0%	10.0%	0.0%	10.0%	0.0%	4.0%

3.3	Check students' worksheet responses aloud.	63.3%	66.7%	70.0%	50.0%	50.0%	60.0%
3.4	Provide feedback aloud.	63.3%	66.7%	70.0%	50.0%	50.0%	60.0%
3.5	Ask students to reflect on topic.	0.0%	0.0%	66.7%	66.7%	66.7%	40.0%
Mean Fidelity of Implementation		45.3%	48.7%	61.3%	55.3%	53.3%	**52.8%**

Note. Fidelity of implementation scores expressed above as percentage of classes in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

Larger model with laboratory activities sub-model. Combined with the larger model, the laboratories activities sub-model had adherence of 20.7% (see Table 29). The teacher asked students questions (step 3.1) in only one class (the first of the day) and she solicited questions from students (step 3.2) in only the last class of the day. The teacher did not check students' worksheet responses (step 3.3) and provide feedback (step 3.4) in the last class of the day. In none of the five classes did she have students reflect on what they had learned (step 3.5).

Table 29

Fidelity of Implementation for Duration Spent on Individual Steps in the Larger Model when Incorporated with the Laboratory Activities Sub-model across Two Days

		Class					
Step		1	2	3	4	5	*M*
3.1	Ask questions aloud and respond to student answers.	16.7%	0.0%	0.0%	0.0%	0.0%	3.3%
3.2	Solicit and respond to student questions.	0.0%	0.0%	0.0%	0.0%	100.0%	20.0%
3.3	Check students' worksheet responses aloud.	50.0%	50.0%	50.0%	50.0%	0.0%	40.0%
3.4	Provide feedback aloud.	50.0%	50.0%	50.0%	50.0%	0.0%	40.0%
3.5	Ask students to reflect on topic.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mean Fidelity of Implementation		23.3%	20.0%	20.0%	20.0%	20.0%	**20.7%**

Note. Fidelity of implementation scores expressed above as percentage of classes in which a step was implemented as prescribed in the instructional sequence. 0 = 0%, 1 = 8.3%, 2 = 16.7%, 3 = 25%, 4 = 33.3%, 6 = 50%, 8 = 66.7%, 9 = 75%, 12 = 100%.

As discussed in chapter three, the innovation was a new instructional model for (1) using a GIS to support (2) science inquiry. Hence, I permeated my entire design with the inquiry model. Of the 45 steps in the entire instructional model based on my design, I included 21 steps to support inquiry teaching and learning. Table 30 shows which steps are aligned with which of the two components of this innovation. Steps for the GIS component included all the steps in the computer-supported activities sub-model and those in the science inquiry component included all the steps in the laboratory activities sub-model. I included all the steps in the respective sub-models because I concluded that steps in each individual sub-model worked in conjunction, and not in isolation, to meet the objectives of the day's instruction. Table 30 also shows the percentage of the steps for each component that were implemented in the present study. For the use of GIS component, I calculated the mean fidelity of implementation as intended for only days that used the GIS. Likewise, the mean fidelity of implementation as intended for the science inquiry component was for the days that involved hands-on laboratories.

The unit, as discussed in chapter three, was divided into days, each day had tasks/activities, tasks/activities utilized a specific model/sub-model, the model/sub-model had steps, and steps were made up of one or more events. The use of GIS involved eight steps of which none was implemented with *low* fidelity. Of the 13 steps in the science inquiry component, the teacher implementation of seven steps fell in the *low* fidelity range (see finding 3 above). The teacher implemented as prescribed in the instructional sequence almost three quarters of the steps that involved the use of GIS and just under half of the steps that entailed hands-on science inquiry.

Table 30

Mean Implementation of GIS and Science Inquiry Steps

Component	Steps Involved	Steps with *low* fidelity (0% to ≤ 37.5%)	Mean Implementation
Use of GIS	2.2.1, 2.2.2, 2.2.3, 2.2.4, 2.2.5, 2.2.6, 2.2.7, 2.2.8	--	72.2%
Science inquiry	2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.3.5, 2.3.6, 2.3.7, 2.3.8, 2.3.9, 2.3.10, 2.3.11, 2.3.12, 2.3.13	2.3.5, 2.3.8, 2.3.9, 2.3.10, 2.3.11, 2.3.12, 2.3.13	49.0%

I tallied the duration-and-completeness ratings for the individual models/sub-models to get the overall adherence for the entire instructional model (the intended and planned innovation). I entered the totals for the duration-and-completeness ratings in the appropriate cell in the duration-and-completeness rubric. Table 31 displays percentages of steps rated as implemented for each cell of the duration-and-completeness rubric across the entire study. The percentages are discussed in finding 4 above.

Table 31

Percentages of Steps Rated as Implemented for each Cell of the Rubric across the Entire Study

Duration

Completeness

	Enough time devoted (3)	%	Slightly less time devoted (2)	%	Much less time devoted (1)	%	Not done (0)	%	**Total**
Everything implemented (4)	Teacher devoted the right amount of time to the step and implemented all events that were suggested in the step to accomplish the goals.	68.1	Teacher devoted slightly less time to the step and implemented all events that were suggested in the step to accomplish the goals.	0.1	Teacher devoted much less time to the step and implemented all events that were suggested in the step to accomplish the goals.	0			**68.2**
Many events implemented (3)	Teacher devoted the right amount of time to the step and implemented more than two thirds of the suggested events in the step but not all.	1.6	Teacher devoted slightly less time to the step and implemented more than two thirds of the suggested events in the step but not all.	0.9	Teacher devoted much less time to the step and implemented more than two thirds of the suggested events in the step but not all.	4.0			**6.5**
Quite a few events implemented (2)	Teacher devoted the right amount of time to the step and implemented about two thirds of the suggested events in the step.	2.5	Teacher devoted slightly less time to the step and implemented about two thirds of the suggested events in the step.	0.1	Teacher devoted much less time to the step and implemented about two thirds of the suggested events in the step.	1.0			**3.6**
A few events implemented (1)	Teacher devoted the right amount of time to the step and implemented about a third of the suggested events in the step.	0.5	Teacher devoted slightly less time to the step and implemented about a third of the suggested events in the step.	0	Teacher devoted much less time to the step and implemented about a third of the suggested events in the step.	3.4			**3.9**
Not implemented (0)							Teacher did not do.	17.8	**17.8**
Total		**72.7**		**1.1**		**8.4**		**17.8**	**100%**

Researcher journal. I rated the design, student performance, science instruction and the model in my research journal. I assigned an overall rating for all five classes as a group at the end of the day on a scale ranging from 1 (*extremely badly*) to 5 (*extremely well*). Table 32 presents my mean ratings and standard deviations for the four items in my research journal. One item had a mean rating above 4 and three items' mean ratings ranged between 3 (*about average*) and 4 (*very well*). When the means for the first and last items are expressed as a percentage of the maximum rating, 5, the data triangulate with the actual use and adherence data (see finding 4 above).

Table 32

Mean Researcher's Ratings and Standard Deviations on Items in Daily Researcher Journal

Item	*M* [a]	*SD*
How well did the design work today overall?	4.1	0.9
How well did the students do today overall?	3.8	1.2
How well did the science instruction go today overall?	3.7	1.1
How well did the teacher follow the model today overall?	3.4	0.8
Mean	3.7	1.0

[a]1=Extremely badly, 2=Somewhat badly, 3=About average, 4=Very well, 5=Extremely well

Research Question 1b: What factors account for loss of fidelity?

I addressed the second part of research question one using qualitative data. Following completion of the implementation, I reviewed data from the daily reflective meetings with the teacher, implementation-related comments the teacher made as an aside in individual classes during the period, field notes from my observations, and my research journal entries. I collected data through multiple sources to enhance the validity and reliability of the findings. I compared these data to see whether they match.

According to Maxwell (1996), data triangulation by using multiple data sources and member checks are important because they reduce the risk that conclusions reflect biases or limitations of one specific data collection method (see also Merriam, 1998).

Across 66 days, the teacher made a total of 180 statements either in our daily meetings or in class about the implementation, and field notes from my classroom observations and my research journal contained a total of 156 statements. Of those 180 teacher statements, I identified 39 statements (21.7%) as related to possible causes for loss of fidelity. Of my 156 statements, I identified 30 statements (19.2%) as related to possible causes for loss of fidelity. These 39 statements from the teacher and 30 statements from my field notes and research journal appear to fall under five major factor descriptors: *scope of instruction, time, suitability of materials, eliciting student thoughts,* and *independence*. Table 33 presents the type, numbers and percentages of statements falling under each factor descriptor, ordered by the number of related teacher statements.

Table 33

Number and Percentage of Statements, Categorized by Factor Descriptor and Source

Factor Descriptor	Number of Related Teacher Statements	% of Related Teacher Statements	Number of Related Researcher Statements	% of Related Researcher Statements
Scope of instruction	11	28.2%	8	26.7%
Time	9	23.1%	9	30.0%
Suitability of materials	8	20.5%	2	6.7%
Eliciting student thoughts	6	15.4%	7	23.3%
Independence	5	12.8%	4	13.3%
Total	39	100.0%	30	100.0%

Table 34 presents the factor descriptors I have derived, days for which statements by the teacher or my statements were relevant, name of the model/sub-model in use that day, and the statements I used to derive the name of the factor. I attempted to capture as accurately as possible what the teacher said during our daily reflective meetings, writing her exact words when what she said seemed particularly important and paraphrasing when the sense of the statement seemed more important than the actual words employed. Maxwell (1996) contended that the main threat to valid description in qualitative analysis is the inaccuracy or incompleteness of the data. To control for that threat as Maxwell recommends, I made notes as "rich," detailed, concrete, and chronological as possible. Thick rich descriptions of the data provide a full and revealing picture of what went on and help the readers to understand what was studied and draw their own interpretations about meanings and significance (see also Patton, 2002). Use of quotation marks in Table 34 indicates exact statements by the teacher. Statements not in quotations represent my summative paraphrasing of teacher statements or verbatim statements from my field notes and research journal.

Table 34

Teacher and Journal Statements Categorized by Factors Deemed Related to Loss of Fidelity (with Day of Occurrence and Model/Sub-model Employed)

Factor Descriptor	Day	Model/Sub-model	Teacher Statements	Researcher Statements
Scope of Instruction	1	Larger model: Unit introduction	• Students are overwhelmed with the content pretest. • The content assessment is a lot for the lower level students. • "Day 1 should just be for pretests only then introduction to be done on day 2."	• Having three pretests and unit introduction on the same day was a bit too much for students to handle. • Teacher did not discuss the unit introduction at length/adequately.
	2	Computer-	• "Energy audit has too	• The teacher skipped

Factor Descriptor	Day	Model/Sub-model	Teacher Statements	Researcher Statements
		supported activities	much content. It is not good for first activity especially for lower track students."	the entire worksheet in four classes because there was a lot to cover.
	3	Computer-supported activities	• "Kids are losing interest. The audit is too long and repetitive."	• The audit is taking a toll on the students.
	4	Content and computer-supported activities	------------------------	• Students seem bored of doing audit for 3 days and have not even completed.
	21	Laboratory activities	• I also blended spinach for students to use in the lab when they are done testing the paper pulp. • The upper track can do the extension activity if they finish the main lab.	• Some groups in periods three and four did extension task.
	26	Computer-supported activities	• "The worksheet [natural gas activity] is too long. Reduce worksheet to have time to teach the important concepts." • "Really shorten gas activity because it has the same things as the coal." • "Eliminate questions 4 to 11 because students use the same skills as the coal activity."	• Teacher told students not to do almost half of the questions on the worksheet. She gave them answers to those questions then went over the worksheet.
	31	Laboratory activities	• "I will use my expensive light bulb in period four only."	• The teacher set up an extra station for class four to do extension task.
Time	2	Content and computer-supported activities	• "I skipped the worksheet [understanding electricity activity] to save time and get to	• Lower level classes are lagging behind by far.

Factor Descriptor	Day	Model/Sub-model	Teacher Statements	Researcher Statements
			the audit."	
	4	Computer-supported activities	• "I have to move on with the unit. I need three days for every one day, especially with lower track students."	• The teacher rushed students through the audit and concept map.
	8	Computer-supported activities	------------------------	• Students were still filling out their worksheets at the end of the lesson. • The teacher did not review the lesson in any of the classes.
	14	Computer-supported activities	------------------------	• The teacher did not get time to go over students' worksheet responses or review concepts.
	21	Laboratory activities	• The teacher did not do the warm-up activity because of time constraints. She wanted to devote the whole period to the lab and not use up five minutes in the beginning. • There is no time in one period to do an extension activity.	• The students used the entire period to do the lab and there was no time left for discussion and review.
	24	Content presentation	-----------------------	• The content was not reviewed because students were still filling out their worksheets at the end of the lesson.
	25	Computer-supported activities	• "Shorten the oil activity to fit in one period." • There is not enough time to cover activity in one day and review the take-home	---------------------------

Factor Descriptor	Day	Model/Sub-model	Teacher Statements	Researcher Statements
			message."	
	31	Laboratory activities	• "This lab [efficiency lab] needs more than one day. To save time, I will just go over the questions."	• The teacher introduced temperature probes that both she and the students had never used before. It took time to learn how to use the probes. • The lab took two days and students did not get to the analysis questions on the worksheet. How will students draw conclusions without analyzing their data?
	32	Content presentation	• I asked students to list only two advantages and two disadvantages of each energy source, otherwise the worksheet will take a long time to complete.	------------------------
	39	Larger model: Unit conclusion	• I did not have time to assess the concept maps. I gave students points for handing them [concept maps] in.	---------------------------
Suitability of Materials	2	Content and computer-supported activities	• "There is a lot of difficult vocabulary thrown at students right off the bat." • "I skipped steps 10 [Elicit answers to specific questions on students' worksheets.] and 11 [Solicit some responses from students' worksheets and provide feedback aloud.] because the content was too	• The readability of the content [electricity content] seems high for the students.

Factor Descriptor	Day	Model/Sub-model	Teacher Statements	Researcher Statements
			complicated and overwhelming to students as a first activity so they would not get anything even if they fill the worksheet." • "Students don't care about some activities such as heating and cooling and the furnace." • "Just put things on the audit that are relevant to the students."	
	5	Content and laboratory activities	• The units are still hard for students to understand. • "I skipped it [showing a video clip] because it is not relevant to the lab; it does not provide much useful information for students to use in the lab."	-------------------------
	12	Content and computer-supported activities	• The content [tidal energy content] is too complicated for students to understand. • The Web content does not match the Google Earth activity and worksheet questions.	• They [students] are reading fast through the assigned paragraphs. I wonder whether they are understanding.
Eliciting student thoughts	5	Content and laboratory activities	• Students do not know enough about the concepts in the labs to make sensible predictions.	• The teacher did not ask students to make predictions in the lab activity.
	8	Large model: Daily check	• "These students never have questions."	• I asked the teacher to try it [solicit questions from students] for a few days and see whether

Factor Descriptor	Day	Model/Sub-model	Teacher Statements	Researcher Statements
				students will ask her questions.
	9	Large model: Daily check	• "If students have any questions, they will definitely raise their hands and ask if they do not understand anything."	• The teacher does not ask students whether they have any questions during or at the end of the lesson. She only does so when I request her.
	11	Computer-supported activities	• Students did not have thoughtful questions because they do not know much.	------------------------
	19	Large model: Daily check	• The teacher did not solicit and respond to student questions (step 3.2). She stated, "my students don't have enough background knowledge to ask any questions." • If students had questions they would ask without the teacher having to solicit for them.	• Teacher solicited questions from students in period five.
	21	Laboratory activities	------------------------	• The teacher skipped a lot of steps.
	31	Laboratory activities	------------------------	• The teacher skipped almost half of the steps.
	34	Large model: Daily check	------------------------	• I think the teacher solicited questions from students in the third period for the FIRST time.
Independence	10	Computer-supported activities	• The teacher skipped step 4 [provide worked example] in classes 4 and 5 because she expected "students in the higher level classes to know what to do."	• Students seem to be following the Google Earth activities well.
	17	Computer-	• I skipped steps 3	----------------------------

Factor Descriptor	Day	Model/Sub-model	Teacher Statements	Researcher Statements
		supported activities	[model task] and 4 [provide worked example] because students had done a similar task before and I did not want to 'baby' them. "I want them to understand on their own."	
	26	Computer-supported activities	• The teacher skipped steps 3 [model task] and 4 [provide worked example] because "students need to think and learn how to do task by themselves and learn from their mistakes and not just be like robots looking at me do the task."	• Students just came back from Christmas break and most have forgotten how to use *My World* GIS. They seemed frustrated. Most students needed teacher guidance. • I wish the teacher had modeled the task to refresh their [students'] memory.
	27	Computer-supported activities	• Once again, the teacher skipped steps 3 [model task] and 4 [provide worked example] because "the handout instructions are too easy for them [students] to not think. The emphasis is on thinking and not just to be like little robots." • "Students have many questions if things are done for them. "If they struggle to get it, the light bulb goes on and they get that they can do the activity on their own."	• Students are now using the program [*My World* GIS] without much guidance from the teacher and they are using the handouts.

Below I discuss each of the five factors identified in Table 34. In each section, I discuss why I chose that descriptor name and what about the data sources led me to that choice. I also map the data sources to specific steps and present the percentage of the model/sub-model those steps represented.

Scope of instruction covers statements indicating that activities had more content than was either necessary or could be covered in the amount of time allotted in the instructional sequence. The teacher explained that she did not elicit students' background knowledge (step 1.3) and discuss their misconceptions (step 1.5) in two classes on day one because she decided the content assessment was too much for some students and that the introduction of the unit should not be done on the same day. These two steps constituted 40% of the larger model for the unit introduction. The teacher stated that the activity on day two had too much content, was too long and repetitive, and students were losing interest in the activity by the third day. Thus, the teacher asked students in four classes not to do the questions on their worksheets (step 2.1.7) and consequently, she did not provide feedback to students' worksheet responses (step 2.1.8). These two steps represented 14.3% of the sub-model for day two was a combination of the content presentation and computer-supported activities sub-models. Also on day 26, the teacher asked learners to skip some of the questions on their worksheets (step 2.2.7 which is 12.5% of sub-model).

Time included statements that alluded to the teacher not implementing some steps because she ran out of time at the end of the lesson or activities took too long to complete and she needed to move on to the next task. The teacher reported that she skipped reviewing activity concepts (step 2.2.8) if she was pressed for time at the end of the lesson. The teacher did not review the activity on days two and eight (7.1% of sub-model) nor did she review concepts in the culminating activity (10% of sub-model) in all five classes. On day twelve, she did not review the activity (7.7% of sub-model) in four classes. Also, the teacher did not review the lab concepts (step 2.3.13) on days five and 31 in one class. Reviewing lab concepts represented 6.3% and 7.7%, respectively, of the sub-models used. On other occasions, the teacher stated that she skipped a considerable portion of the task if students were taking too much time to complete the task. Also, students in the two classes rated as *below proficient* tended to take a bit longer to do tasks. The teacher skipped some steps and/or events in those classes but implemented those steps and/or events in the classes categorized as *proficient* and *advance proficient*. On day four, the teacher noted she had to move on to the next task even though students in the two classes classified as *below proficient* were still doing the task (step 2.2.5 that represents 7.1% of sub-model) for day two.

Suitability of materials covers statements suggesting that the content seemed to be of a higher reading level for the students, some vocabulary was difficult, and students may not have understood the content. The teacher reported that she did not ask students in four classes to do the questions on their worksheets (step 2.1.7) on day two because the content was too complicated and overwhelmed the students. This step constituted 7.1% of the sub-model. Also, the teacher judged some materials as not being relevant to the students, while she judged other materials as not relating well to the activities they were intended to exemplify. For example, the teacher stated that she did not show a video clip intended to gain the learners' attention (step 2.1.2, which constitutes 6.3% of the sub-model) on day five because it did not provide information that would help students perform the laboratory activity.

Independence covers statements implying that the teacher wanted students to work independently without much intervention from her once they learned how to use the GIS. She expected students to follow instructions on the handout and perform the task without her having to model the task or provide a worked example every time, especially in the classes that were classified as *proficient* or *advanced proficient*. The teacher reported that she wanted students to think and learn from their mistakes as they learned to do the task on their own. Thus, the teacher not modeling the task (step 2.2.3) or providing a worked example (step 2.2.4) accounted for loss of fidelity in the computer-supported activities sub-model. These two steps constituted 25% of the sub-model.

Eliciting student thoughts included statements suggesting that the teacher did not ask students to share their ideas and thoughts. Apart from performing tasks and filling out worksheets, other student participation activities included asking the teacher questions during the lesson or at the end of the lesson (step 3.2), making predictions before performing experiments (step 2.3.5), forming explanations (step 2.3.8), drawing conclusions (2.3.9), and sharing and justifying laboratory results (step 2.3.10). The teacher skipped quite a few steps that involved students sharing their ideas and thoughts. The teacher reported that her students never had questions and thus, she hardly ever solicited questions from students (step 3.2). This step represented 20% of the larger model and accounted for a substantial loss of fidelity. Students did not make predictions (6.3% of the sub-model) on day five and on the other two days laboratory activities were done (7.7% of the sub-model). Further, students did not share and justify their laboratory results (7.7% of the sub-model).

Quantitative data. I examined if there were any differences in the actual use of the models/sub-models across the five classes. Table 35 shows the proportion of each model/sub-model that was actually implemented in each class. To explore if the differences were significant, I ran a one-way analysis of variance (ANOVA) on the data for the models/sub-models that had at least 10 observations. Weiss (2006) suggested cell sizes of at least 10 scores for research studies. The models/sub-models that met this criterion were the computer-supported activities and content presentation sub-models and the larger model (see finding 7 above).

Table 35

Fidelity of Implementation for Individual Models/Sub-models (Actual Use) by Class

	Class					
Model/Sub-model	1	2	3	4	5	*M*
Computer-supported activities	0.8	0.9	0.9	0.8	0.8	0.8
Content presentation	0.9	0.9	0.9	0.9	0.9	0.9
Day 2	0.9	0.8	0.8	0.8	0.8	0.8
Day 5	0.7	0.8	0.8	0.7	0.7	0.7
Day 12	0.9	0.9	0.8	0.9	0.8	0.9
Culminating activity	0.8	0.8	0.8	0.8	0.8	0.8
Laboratory activities	0.5	0.5	0.5	0.6	0.5	0.5
Unit introduction	1.0	1.0	1.0	0.6	0.6	0.8
Larger	0.5	0.5	0.5	0.5	0.5	0.5
Unit conclusion	0.8	0.8	0.8	0.8	0.8	0.8
Class Mean	0.8	0.8	0.8	0.7	0.7	**0.8**

Note. Fidelity of implementation scores denote the proportion of a model/sub-model that was actually implemented.

Numerical qualitative data. I also investigated if there were any differences in the implementation of the models/sub-models as intended/planned across the five classes.

The results are displayed in Table 36. I ran a one-way ANOVA on the data for the sub-models for computer-supported activities and content presentation and the larger model to explore if the differences in my ratings for the implementation of those models/sub-models as intended/planned were significant (see finding 7 above).

Table 36

Fidelity of Implementation as Intended/Planned for Individual Models/Sub-models (Adherence) by Class

	Class					
Model/Sub-model	1	2	3	4	5	*M*
Computer-supported activities	8.5	8.6	9.1	9.0	9.1	8.9
Content presentation	9.5	9.7	10.1	10.1	9.7	9.8
Day 2	8.3	8.8	9.4	9.4	9.4	9.1
Day 5	8.3	8.4	7.8	7.1	6.4	7.6
Day 12	11.1	10.2	8.5	11.1	8.2	9.8
Culminating activity	7.3	7.6	7.6	7.6	7.4	7.5
Laboratory activities	5.6	4.9	5.3	5.3	4.7	5.2
Unit introduction	10.4	10.4	11.2	6.4	6.4	9.0
Larger	5.9	6.0	6.2	5.6	5.9	5.9
Unit conclusion	9.0	9.0	9.0	9.0	9.0	9.0
Class Mean	8.4	8.4	8.4	8.1	7.6	**8.2**

Note. Fidelity of implementation scores denote the extent to which a model/sub-model was implemented as prescribed in the instructional sequence. The maximum score, as determined by the duration-and-completeness multiplications, was 12.

Research Question 2: What are the strengths and weaknesses of the design?

Research Question 3: What improvements should be made to the design?

Research questions 2 and 3 are closely related and have much overlap; thus, their findings are addressed below simultaneously. Both are answered through qualitative data. To analyze those data, I read through all the entries from the teacher reflective meetings to get an overall perspective. I then read through the data a second time and began making note of the main ideas in the margins of the pages. I read and reviewed the data several times to make sure all data were coded and to check if there were any other emerging ideas. I then sorted the main ideas into similar themes. These qualitative approaches are in keeping with the recommendations of Miles and Huberman (1994) and Patton (2002).

The main ideas were categorized into what I deemed to be four discrete factors: *learner engagement, suitability of materials, design of materials,* and *scope and sequence of instruction.* These factors are discussed in the section below. Beneath each factor are subheadings addressing *teacher-identified strengths, teacher-identified weaknesses, teacher-suggested improvements,* and, where appropriate, *improvements suggested by the project director*. *Teacher-suggested improvements* were suggestions the teacher made about the scope and sequence of the content and how to implement certain learning activities. Some of the suggestions were put into practice while the implementation was taking place and some were meant for future implementation with the same population or with a comparable population. I include *project director-suggested improvements* because he was one of the content specialists and, as director, had the responsibility for setting the scope, sequence, and pacing of the instruction. His comments addressed improvements using his expertise. The four factors are presented in the paragraphs that follow.

Learner engagement.

Teacher-identified strengths. The teacher reported that all three laboratory activities were highly engaging and held the students' interest. During the hydroelectric dam activity the teacher stated that the "dam demo is extremely high interest and students liked it." Also, she reported that the readings on almost all content Web pages engaged the students. On the first day of doing a Google Earth activity (solar GE) the teacher commented, "students were highly engaged with activity and liked it." For subsequent GE activities, the teacher stated that she felt students understood the activities and were highly engaged. Likewise, on the first day of using My World GIS, the teacher stated, "it is a really high interest and engaging activity; students liked the program."

Teacher-identified weaknesses. While the teacher reported that some activities were highly engaging, she also noted that some activities did not engage the learners. In the culminating activity, students were assigned one of three provinces of a fictitious island, the Isle of Navitas, and were required to analyze their province's energy resources and develop an efficient energy policy for their province. The teacher stated that the introduction of the activity did not hold the students' interest and was therefore not engaging.

Teacher-suggested improvements. To make the culminating activity more engaging to the learners, the teacher suggested providing more interesting information about each of the provinces to capture the students' interest. She suggested, "add content that is relevant to the students for Navitas so they take ownership of their province; add additional interesting information about each province."

Suitability of materials.

Teacher-identified strengths. The teacher reported that most materials were suitable or appropriate for the learners. She noted that the content on the pretest was relevant to the unit, the concept map was good, most content was suitable to the learners and the images on the content Web pages were good. She also stated that six out of seven videos that were intended to gain students' attention before the content was presented were "good and described so many things."

Teacher-identified weaknesses. Despite the teacher reporting that the content on the pretest was relevant to the unit, she said that "students were frustrated because they don't know the answers and the content assessment is a lot for the lower-level students." Further, she noted that some students did not understand some words in the content assessment. The teacher also stated that the content on *Understanding Electricity* presented on day 2 was too complicated and overwhelming to students and it was not suitable to be the first activity. Commenting about the content, she said "difficult vocabulary is thrown at students right off the bat." She also reported that the tidal energy "Web content is a bit higher than the students' level."

The teacher noted that the energy audit, which was also introduced on day 2, "has too much content and [is] not good for the introduction especially for lower track students." The energy audit required students to enter in a spreadsheet the number of hours they did certain daily or weekly activities (for instance, watch TV, vacuum the house, and ride in the car) and the number of appliances that were being used at the same time. Students needed a lot of guidance from the teacher on how to fill in numbers for the activities they did not usually do. The teacher identified this as a weakness and contended that "students don't care about some activities on the audit; they don't care about heating, cooling, and the furnace." Lastly, the teacher reported that the photovoltaic cells video was not relevant to the solar laboratory activity it preceded.

Teacher-suggested improvements. The teacher suggested to "just put things on the audit that are relevant to the students, not for the whole family." She stated that students would not know what numbers to enter in the spreadsheet for the activities they did not do or for those activities their parents did. Another suggestion the teacher gave regarding suitability of materials was to replace the photovoltaic cells video with one that would help students understand the solar laboratory activity better.

Project director-suggested improvements. The director suggested creating two versions of the energy audit and their corresponding worksheets. Version one would retain all the original activities and require students to input all their energy use values. Version two would be prefilled with typical household energy use values for the activities that students had trouble filling in. Similarly, worksheet one would be blank and require students to write all the answers while worksheet two would have some answers prefilled. Thus, teachers could choose which audit to use with specific classes of learners.

Design of materials.

Teacher-identified strengths. The teacher reported that handouts were well designed and easy for the students to follow. She stated that "directions were straightforward and easy to follow; students followed really well and worked independently most of the time." Also, she noted that the design and layout of the Web site was good, it was easy to navigate and find materials, and the content Web pages were easy for the students to read. Regarding the student resources Web page, the teacher said "the student resources page is excellent, everything they need is in one place."

Teacher-identified weaknesses. The teacher stated that some worksheet questions did not involve thinking. The questions had students copying values from a table on the computer screen onto their worksheets after doing some manipulations with the GIS. Another weakness the teacher identified was that the tidal energy content "… does not match the activity and the worksheet questions." The *Impacts of Energy Sources* worksheet required students to list the advantages and disadvantages of energy sources and did not specify how many they should list. The teacher noted this activity could take too long if no specific number is given to the students. Another weakness she identified was that the steps on the activities handouts were not explicitly matched with the questions they addressed on the worksheets and she observed that learners tended to lose their place on the handouts if an activity took more than one day.

With regard to the culminating activity, the teacher reported that the materials did not clearly explain the infrastructure required to develop energy from the different energy sources. Further, the energy resources worksheet and the energy policy handout had two-part questions and she observed that students tended to answer only one part of the question. Lastly, the teacher reported that the key for elevation and bathymetry for the Isle of Navitas was not explained in the materials and also the culminating activity did not have adequate scaffolding for both learners and teachers.

Teacher-suggested improvements. The teacher suggested to "reword a few worksheet questions to be analysis questions," specify the number of advantages and disadvantages of energy sources students should list on their worksheet and add content on the student Web pages about the infrastructure needed to develop the different energy sources. Suggestions with regard to the culminating activity included developing scoring guides for the energy policy presentations and instructing teachers (in the teacher materials) to guide learners through the first energy resource for all three provinces. The teacher created her own scoring guides that she used during the students' presentations.

She also suggested separating two-part questions into two separate questions and having students list three requirements for developing each energy source on the *Impacts of Energy Sources* worksheet, since the students needed to use that worksheet to do the culminating activity. In the design, each day began with the teacher asking a question to elicit the students' understandings of that day's lesson concepts. The teacher suggested adding "a bank of warm-up questions in a separate document for different tracks, especially lower track."

Project director-suggested improvements. The director suggested a way to match the steps on the activities handouts with the questions they addressed on the worksheets. He also suggested adding to the teacher support materials scaffolds for the Isle of Navitas which included a screencast that explained the key for elevation and bathymetry, exemplary energy policy presentations developed by students, a screen shot of the Island with important layers such as transportation, rivers, protected areas, and cities turned on. For student scaffolding, the director suggested to add to the instructional sequence an implementation suggestion instructing teachers to guide students through each question for the first energy source and then provide additional modeling, prompts, and guidance as needed.

Scope and sequence of instruction.

Teacher-identified strengths. The teacher stated that the scope of the instruction that involved presenting content was good. Also, she reported that, apart from four days of the unit, the sequence of instruction was well done.

Teacher-identified weaknesses. Day 1 of the unit had been allotted to complete the pretests (three pretests) and the introduction of the unit and the teacher stated that this was too much for the students to do in one day. As discussed earlier, the content on *Understanding Electricity* and the energy audit were introduced on the same day and the teacher reported this was a lot for the students to handle, given that it was just day 2 of the unit. The teacher also reported that there was not enough time to cover most tasks "in one day and review the take-home message," especially the computer-supported (Google Earth, GIS, energy audit) and laboratory activities. The energy audit, for instance, had been assigned two days but students had not finished doing it on day three of the unit. The teacher commented that, "kids were losing interest; the audit is too long and repetitive." The culminating activity was allotted five days but students took 18 days, and, even then, some still did not complete it. In fact the teacher commented "I need three days for every one day with lower track students."

Teacher-suggested improvements. The teacher suggested having pretests only on day 1 of the unit and then having the introduction of the unit on the second day, as well as separating the content on *Understanding Electricity* and the energy audit. Another suggestion was to shorten the activities to fit in one class period. The teacher suggested reducing the questions on some worksheets so as "to have time to teach the important concepts" and also changing the placement of the energy conservation and light bulb laboratory activities on the sequence.

Project director-suggested improvements. The project director suggested that the energy audit be done on day 2 and the content on *Understanding Electricity* be done on day 3, instead of both of them being introduced on the same day. The projector director approved eliminating questions on some worksheets and changing the placement of the energy conservation and light bulb laboratory activities on the sequence.

Teacher meetings. I asked the teacher to rate 10 aspects of the day's lesson, for instance, how well materials matched the student needs and her needs, how well students stayed on task, and how well the lesson went. Table 37 displays mean teacher's ratings and standard deviations of the 10 items in the *Daily Reflective Meeting with Teacher* protocol. The ratings fell between 0.3 and 4.4 with an overall mean rating of 3.5. The teacher assigned 0 to the item *how would you rate the thoughtfulness of student questions today?* on days when students did not ask questions. Students being on task and student teamwork received higher ratings (at least 4) from the teacher. The mean rating for the thoughtfulness of students' questions was less than 1 (see findings 8 & 9 above).

Table 37

Mean Teacher's Ratings on Items Asked during Daily Reflective Meetings

Item	M^a	*SD*
How well do you feel students stayed on task today?	4.4	0.6
How well do you think teams worked together today?	4.1	0.6
How good did you feel team presentations were today?	4.0	0
How well did the lesson go today overall?	3.9	0.9
How independently did you feel the students worked today?	3.9	1.0
How well do you think materials matched your needs today?	3.9	1.1
How well do you think students understood vocabulary and meaning today?	3.8	0.9
How well do you think materials matched student needs today?	3.7	1.2
How well did the time allotted for a task match how long it took to complete that task?	3.5	1.6
How would you rate the thoughtfulness of student questions today?	0.3	0.9
Mean	3.5	0.9

[a]0=Not done, 1=Extremely badly, 2=Somewhat badly, 3=About average, 4=Very well, 5=Extremely well

Student performance. As discussed earlier in this chapter, I observed and assessed students in various performances daily to help evaluate the quality of the instructional materials. As displayed in Table 38, the mean ratings of various student performances ranged from 0.8 to 5.0 with an overall rating of 3.0. Just as is the case in the teacher ratings above, students being on task and student teamwork had mean ratings of at least 4 and only a few students were rated as asking thoughtful questions (mean rating below 1). Also, only a few students were rated as giving thoughtful answers (mean rating below 1).

Table 38

Mean Observer Ratings on Student Performances by Class

	Class					
Categories of Performance	1	2	3	4	5	*M*
Team presentation (clarity)	5.0	5.0	5.0	5.0	5.0	5.0
Comprehension	4.2	3.7	4.7	4.7	4.6	4.4
On task	4.2	3.7	4.7	4.8	4.6	4.4
Teamwork	4.1	3.5	4.3	4.6	4.0	4.1
Independence	3.4	3.0	4.1	4.3	4.1	3.8
Task completion	2.5	2.8	3.7	3.9	3.8	3.3
Team presentation (justification)	2.0	1.0	3.0	3.0	3.0	2.4
Student answers (correctness)	1.1	1.1	1.1	1.1	1.1	1.1
Student questions (thoughtfulness)	0.9	1.1	0.9	0.9	0.8	0.9
Student answers (thoughtfulness)	0.8	0.8	0.8	0.8	0.8	0.8
Class Mean	2.8	2.6	3.2	3.3	3.2	**3.0**

Note. 0=Performance not done by students/teams, 1=Performance done by less than 25% of students/teams, 2= Performance done by less than 50% of students/teams, 3= Performance done by about 50% of students/teams, 4= Performance done by more than 50% of students/teams, 5= Performance done by more than 75% of students/teams.

Research Question 4: How does a GIS-supported learning unit affect students' attitudes toward science and technology?

I ran a paired *t*-test to compare the student's scores on the *Energy Unit Science and Technology Survey* instrument before the unit began and after it was completed. As mentioned earlier, the five classes were classified into three tracks: *advanced proficient*,

proficient, and *below proficient*. I did additional analysis of the data by track classification. Table 39 displays the results.

Table 39

Paired t-tests for Student Attitudes toward Science and Technology

	df	*Pretest Mean (SD)*	*Posttest Mean (SD)*	*t*	*d*
Overall	101	64.61 (11.98)	61.30 (13.33)	3.15**	.28
Advanced proficient	29	62.90 (12.15)	56.43 (15.70)	2.59*	.53
Proficient	44	63.91 (11.23)	62.42 (12.12)	1.17	.13
Below proficient	26	67.67 (12.88)	64.85 (11.14)	1.57	.22

**p* < .05. ***p* < .01.

To determine if students' mean scores differed significantly from each other by track, I conducted a one-way repeated measures ANOVA with *time of testing* (pretest and posttest) as the main effect and *track* as the blocking variable to reduce the error variance. I further used paired *t*-tests to do an item-by-item analysis of the items in the instrument to investigate which specific items' mean scores had significant differences. The instrument had a total of 20 items; 10 science items and 10 technology items. Results of the paired *t*-tests are displayed in Table 40 in descending order by mean difference (see finding 11 above).

Table 40

Means and Standard Deviations of Student Attitudes toward Science and Technology Items

	Pretest		Posttest			
Item	*M*[a]	*SD*	*M*[a]	*SD*	*t(101)*	*Diff*[b]
I like spending lots of time outdoors.	4.12	1.05	4.33	0.71	1.96	.21
Solving science problems is fun.	2.77	1.01	2.78	0.99	0.09	.01
I am interested in where things are located in the world.	3.50	1.10	3.47	1.12	0.26	-.03

I like to read books, magazines and Web sites about science.	2.54	1.11	2.43	1.09	0.91	-.11
The use of computer maps will be important to me in my job some day.	3.20	1.22	3.07	1.21	1.00	-.13
I like to close my eyes and visualize objects in three dimensions.	2.88	1.15	2.75	1.17	0.95	-.13
I like using the computer to create maps.	3.09	1.10	2.95	1.09	1.15	-.14
I like to use maps to answer questions about people and places.	3.22	1.14	3.08	1.11	1.15	-.14
I like to use maps to explore and gather information about new places.	3.31	1.02	3.16	1.13	1.21	-.15
I often wonder how satellites, computers, and other advanced technologies work.	3.68	1.13	3.50	1.18	1.50	-.18
I like to think about how to solve environmental problems.	3.17	1.02	2.98	1.02	1.69	-.19
I like science better than I do most other subjects.	2.84	1.23	2.63	1.23	2.01*	-.21
I enjoy talking to people about science.	2.57	1.01	2.35	0.98	2.18*	-.22
Satellites, GPS devices, and remote sensing equipment are cool.	3.72	1.03	3.48	1.10	2.21*	-.24
Learning science will improve my career chances.	3.73	0.92	3.47	1.11	2.37*	-.26
I think science is exciting.	3.69	0.88	3.42	1.09	2.83**	-.27
I have a real desire to learn science.	3.17	1.10	2.89	1.19	2.87**	-.28
I have a good feeling toward science.	3.40	1.02	3.12	1.07	2.79**	-.28
Science is useful for solving problems in my everyday life.	3.44	1.00	3.15	1.05	2.81**	-.29
I like writing about science.	2.59	0.98	2.29	0.97	2.71**	-.30

Note. Presented in descending order by mean difference (Diff).

[a]1=strongly disagree, 2=disagree, 3=no opinion, 4=agree, 5=strongly agree

[b]Refers to posttest mean minus pretest mean.

*$p < .05$. **$p < .01$.

Research Question 5: Does a GIS-supported learning unit affect student science achievement?

I used a paired *t*-test to compare pre- and posttest scores on the *Energy Unit Content Assessmen*t of 39 items. Table 41 presents the results for the paired *t*-tests for all students overall and for each of the three tracks. To explore if there were any differences between the tracks, I ran a one-way repeated measures ANOVA with *time of testing* as the main effect and *track* as the blocking variable. I did further post hoc tests using the Bonferroni adjustment (see finding 12 above).

Table 41

Paired t-tests for Student Science Achievement

	df	*Pretest Mean (SD)*	*Posttest Mean (SD)*	*t*	*d*
Overall	104	14.01 (5.54)	21.69 (6.33)	14.47***	1.39
Advanced proficient	30	17.97 (5.41)	23.68 (5.90)	6.64***	1.05
Proficient	45	12.76 (4.97)	21.98 (5.41)	12.67***	1.86
Below proficient	27	11.68 (4.25)	19.00 (7.38)	6.19***	1.72

***$p < .001$.

CHAPTER 7: DISCUSSION

The previous chapter presented 12 findings, each related directly to the research questions this study sought to answer. In this chapter, I attempt to explain what I think these findings mean and/or why they occurred. While I specifically address the design and implementation of our GIS-supported science Web-based inquiry module, whenever possible I attempt to do so in the broader context of implications for those who design and implement newer curricular approaches. I begin by discussing findings about changes in the students' attitudes toward science and technology and their science achievement. I conclude by discussing what I believe to be the implications of the findings concerning fidelity of implementation of the design.

Students' Attitudes toward Science and Technology

Students' scores on the *Energy Unit Science and Technology Survey* instrument decreased significantly from pretest to posttest. This might lead one to conclude that the designed unit made students hold significantly less favorable attitudes toward science and technology and to like science less. Those decrease in students' scores could, however, be attributed to a number of factors, with one set of causes explaining why the finding might be a valid measure of treatment effects and another set proposing causes other than the treatment (invalid measure of treatment effects).

Valid Measure of Treatment Effects

It is possible that the unit, as designed, was just not interesting to these students and the decrease in the scores was a true reflection of their attitudes toward science and technology. Four components of this explanation might be *technology*, *content covered, length of treatment,* and *the way in which the instructional materials were designed.*

Technology as the cause. The unit was designed around specific geospatial technologies (*My World* GIS and Google Earth) and students were using *My World* GIS for the first time. The unit was computer-intensive and the teacher reported her students had not used computers in previous units. Any novelty or disruption effect had plenty of time to fade, however, since students used computers almost every day for three-and-a-half months. Further, after a few days of students not using it, my observations confirmed that the GIS was not as easy for the students to use as the design team had anticipated. After being away for 11 days, most students needed to learn how to use the GIS all over again. As I noted in my research journal, "Students just came from Christmas break and most have forgotten how to use *My World* GIS. They seem frustrated. Most students need teacher guidance."

In addition, the teacher introduced some unanticipated technologies for students to use. She had students use temperature probes in a lab and a Smart Board to present their final projects. Students had never used either tool before. The introduction of many new technologies in a single unit might have overwhelmed students. Thus, students may simply not have enjoyed using the specific hardware and software involved in this study, affecting their attitudes toward science and technology in the short run, but exhibited in their scores on the immediate attitudes posttest.

Content as the cause. Harmer and Cates (2007) contended that students will engage with inquiry if they feel they are finding solutions to a real, local, and relevant problem. Some of the tasks in the unit included students calculating their personal and household energy consumption, investigating a solar power plant in Pennsylvania, exploring the best location to build a wind farm in the Lehigh Valley, and exploring hydroelectric dams and a nuclear power plant on two rivers in Pennsylvania. While the design team worked hard to make the tasks authentic, local, and relevant to the students, it is possible that the students did not find the activities to be interesting. For instance, the teacher reported that students did not care about activities such as heating and cooling and the furnace in the energy audit activity. On the second day of doing the activity, the teacher said that the students were losing interest and that the activity was too long and repetitive. I noted in my journal that students seemed bored doing the energy audit for three days (see Table 34).

Also, one fifth (20.5%) of the statements the teacher made regarding loss of fidelity related to suitability of materials (see Table 33). It is plausible, as reported by the teacher, that some students may not have understood the content because of difficult vocabulary or the high reading level. Then again, it may just be that the energy content itself did not interest the students, making them hold less favorable attitudes towards science at the end of the unit. Maybe different content could have interested the students more.

Length of unit as the cause. Other units in the curriculum typically lasted between four and six weeks (20 to 30 class days) while this “forty-day” energy unit actually took 66 days, even with the teacher not implementing everything in the design. It is possible that the drop in attitude scores occurred because the unit took so long to complete and students were simply tired of working on the same unit or the same content for long. The unit taking longer than planned may have come about as a result of how the unit was designed and developed. I developed an instructional model to guide me much later after the design team had already set the scope and sequence of the unit. Hence, the scope and sequence were dictated by the content instead of the design. The teacher started to fall behind schedule on day four of the implementation. She realized that the activities were taking more time than planned and she commented, “I have to move on with the unit. I need three days for every one day, especially with lower track students.” Had the instructional model permeated the scope and sequence, maybe the unit might have taken less than 66 days to complete.

It is worth noting that the length of the implementation was also affected by the school’s schedule and other school responsibilities the teacher had. In the course of the implementation, the school had five half days; three afternoons were scheduled for teacher inservice and two afternoons were for parent-teacher association meetings. On those five days, the class periods were shortened to 40 minutes and class four did not have class. Because of the shorter periods, students did not have enough time to finish the tasks and had to complete them on the following day. This led to tasks taking more time than they were allotted. Once, high school counselors came to talk to the students and only class five met that day. On two occasions, the teacher did not teach two classes because she was preparing for inservice. Last but not least, the teacher was away for a conference on one afternoon and on another she was being trained on using a Smart Board. Thus, these factors also contributed to the unit taking longer than planned.

Design of instructional materials as the cause. Some worksheet questions asked students to copy values from the GIS data table on the computer screen onto their worksheets. This mechanical task may have been useful in the beginning, as students were learning how to use the GIS tools. The teacher stated, however, that those questions did not involve thinking. It is quite possible that students did not feel challenged or engaged by such worksheet questions and, hence, found the unit less enjoyable and this might be reflected in their lower scores on the attitudes posttest. Also, the design focused heavily on filling out worksheets. All the tasks had students filling out worksheets and did not incorporate other activities like student discussions or debates of their conclusions. According to Shwartz, et al. (2009), discussions and debates are essential in inquiry because they allow students to construct meaning from evidence, reflect on their own and others' experiences, and develop analytic and argumentation skills (see also Bell, 2004; NRC, 2000).

This heavy focus on filling out worksheets and completing mechanical tasks might have had a bigger negative impact on the students in the class rated as *advanced proficient,* reflected in the fact that their scores decreased more than the other classes and they were the only class, shown by post-hoc analysis, that had a significant decrease in scores. If we assume proficiency track classifications were correct, maybe students in the class categorized as *advanced proficient* expected more stimulating activities than filling out worksheets, such as engaging in discussions and debates and doing more hands-on inquiries and were, therefore, less engaged and interested by the unit.

Invalid Measure of Treatment Effects

Of course, it is also possible that the changes in student scores are not measures of the impact of the treatment here, but rather attributable to causes outside the unit's design and implementation. Such causes might include *time of implementation* and *state test preparation emphasis*. Each is discussed below.

Time of implementation as the cause. The unit was implemented from November through March. This period of the school year usually has more breaks than any other time. We had a five-day break during Thanksgiving, then a break for 11 days for the holidays, and another one-day break for Presidents' Day. In addition to these breaks there were some unscheduled interruptions. Because of inclement weather, students missed school for two days and had a two-hour delay on two other days. Also, there were a total of 31 days between the time students last used the GIS before the holidays and the next activity in which students used the GIS. After 31 days, most students had forgotten how to use the GIS and the teacher had to remind them what to do and provide a lot of guidance. Keiper (1998) noted that one of the barriers to implementing GIS in instruction is student frustration with the technology. The frustration of not recalling how to use the GIS might have caused students to have unfavorable attitudes toward the technology, thus, affecting their posttest scores negatively. Thus, this alternative hypothesis suggests that, if the treatment had been more chronologically contiguous, students might have become less frustrated and would, therefore, have held more favorable post-treatment attitudes.

State test preparation emphasis as the cause. In February, teachers started preparing eighth-grade students for the state's standardized tests in science, reading, and mathematics. The tests were to be taken in April. In the school, successful performance on these tests is considered to be crucial in order to meet the demands of No Child Left Behind legislation. The school principal emphasized that the school's focus was to be on improving scores. Every week students learned and relearned the definitions of seven words or phrases that were commonly used in those tests, for example, *theory, complementary angle, hypotenuse,* and *compare and contrast*. Those words were read and defined aloud during the morning broadcast and each of the seven words was assigned to a period. Every teacher was then required to go through each word and its definition at the beginning of the period the word was assigned.

In addition, the study teacher had students do a warm-up exercise for science vocabulary. She gave students a word that was commonly used in science such as *predict*, *analyze*, and *hypothesis* and had them do different activities for five days using the given word. Students wrote the definition of the assigned word on day one, drew a concept map whose nodes included the synonyms of the word on day two, wrote the word in different forms on day three, provided non-examples of the word on day four, and lastly on day five, students filled in an alphabetical chart with keywords relating to the given word. It is possible that the preparations for the state standardized tests caused students to change their focus from the unit to the upcoming tests. It is also possible that such drill-like preparations negatively affected student attitudes toward testing in general, and science in particular, since it was one of the subjects on which they were going to be tested. This may explain the significant decrease in attitudes toward science on the posttest.

Student Science Achievement

Student scores on the content knowledge increased significantly from pretest to posttest. Given that this instrument measured specific content covered by the unit, it seems likely that its pretest-posttest comparison is a good measure of increased unit content knowledge. This conclusion is reinforced by the validity and reliability confirmations cited earlier. One conclusion might be that the treatment caused this change in content knowledge. Alternatively, one might conclude that the increase in student scores was caused by something other than the treatment. Each conclusion is discussed in its own section below.

Treatment Caused Increased Unit Content Knowledge

Since the unit was part of the new science curriculum for the school, the teacher reported to me that it was unlikely that students were learning similar content in other subjects that might have helped their content knowledge to increase. There appear to be three aspects of the treatment that might support the conclusion that the treatment caused the increase in content knowledge: *inquiry learning,* the *use of GIS to foster inquiry*, and the *way the unit was implemented*. Below I discuss each.

Inquiry learning as the cause. Inquiry teaching and learning entails students being actively engaged in the construction of knowledge as opposed to just being passive recipients of information (Crawford, 2000; NRC, 1996; 2000; Tobin & Tippins, 1993; Windschitl, 2000). As discussed in chapter two, several researchers concluded that the use of inquiry in teaching and learning science increases students' mastery of content and produces positive outcomes on student learning (Mao et al, 1998; Marx et al., 2004; Linn et al., 2006; Parker & Gerber, 2000; Smith, 1996; Songer et al., 2003; Von Secker, 2000). The increase in student science content knowledge in this study supports findings from these previous studies. It is possible that an increase in student science achievement might just be a tangible benefit of inquiry learning. The teacher reported, as noted in the teacher-identified strengths of the design, that the laboratory activities were highly engaging and they held the students' interest. It is also possible that those highly engaging inquiry activities kept students on task, which might have helped them to learn the content, increasing their achievement.

Use of GIS to foster inquiry as the cause. It is also plausible that the use of a GIS to foster inquiry contributed to the increase in student science achievement. This finding echoes previous research studies that implemented a GIS in science inquiry (Baker & White, 2003; Hagevik, 2003) and in geography (Crabb, 2001; Keiper, 1998; Kerski, 2003; Shin, 2006). Those researchers concluded that the use of a GIS increased student outcomes, improved student learning of content, and fostered higher-order analytical thinking. Similarly, the use of a GIS in this study may have helped enhance the students' understanding of science content. The eighth-grade students did not have experience using the particular GIS and on the first day of using it, the teacher commented that the activity was "a really high interest and engaging activity; students liked the program." As noted earlier in this chapter, students had not used computers in previous units. It is possible that integrating technology, specifically the GIS, to foster inquiry might have heightened the students' interest in the activities and in the process students learned the content.

Implementation of the unit as the cause. The increase in student achievement might have been as a result of the way the teacher implemented the unit. Individual aspects of the implementation that might have caused the increase in achievement might be *treatment differentiation and expectations* and the *focus on content-presentation and fidelity of implementation.*

Treatment differentiation and expectations as a cause. The teacher implemented the unit differently across the classes, an instructional practice many good teachers do because of the individual differences of the students (George, 2005; Tomlinson, 2001). She provided more guidance and scaffolding in the two classes rated as *below proficient* and provided little intervention in the other three classes, especially the one categorized as *advanced proficient*. Depending on the class and needs of the students, she adjusted the delivery of instruction along a “much-to-little-or-no-guidance” continuum. For example on day 10, the teacher did not provide a worked example in classes for 4 and 5 because she “expected students in the higher level classes to know what to do” (see Table 34). The data for “model task” in the computer-supported activities sub-model showed that class 2 (rated as *below proficient*) and class 4 (rated as *advanced proficient*) had *adherence* of 73.4% and 64.1% respectively for that step (see Table 18). *Adherence* for modeling the task in the other three classes was different and fell within this range, indicating that she differentiated instruction in the five classes. Consequently, all three proficiency track classifications had significant gains in scores.

Student achievement for the class rated as *advanced proficient* was significantly different from that of the classes categorized as *proficient* and *below proficient*. Also, that class categorized as *advanced proficient* had the highest mean observer rating on student performance. This may not come as a surprise, given the proficiency categorization of the class as *advanced proficient;* that is, for high-level learners. Classes were assigned to these proficiency tracks based on the assessment of central tendency among the scores of students in the class on the mathematics and reading sections of the state’s standardized tests. Thus, it is possible that the proficiency track classifications correctly reflected the students’ proficiency level.

It is also possible that the significantly different achievement for the class rated as *advanced proficient* may have been as a result of the teacher’s higher expectations of the students in the class rated as *advanced proficient,* evident on occasions when she had them do extension activities in two labs. In contrast, students in one of the classes categorized as *proficient* did such activities on only one occasion and students in the other class rated as *proficient* and the two classes classified as *below proficient* did not do extension activities at all. Also, *adherence* for “Explain content” and “Elicit answers to specific questions on students’ worksheets” in the content presentation sub-model was higher in class 4 (categorized as *advanced proficient)* than the other classes (see Table 19), as was “Ask learners to perform task” in the computer-supported sub-model (see Table 18). It appears that the teacher had higher expectations of the students in class 4 by having them cover more content, do more practice, and complete more GIS activities than the students in the other classes, which might have helped the students in the class rated as *advanced proficient* gain more content knowledge, causing their achievement gains to be significantly different than those of the students in the other classes.

Content-presentation focus and implementation fidelity as a cause. This study was about inquiry-based teaching and learning which was reflected in the design of both the GIS and laboratory activities. But, of the three sub-models for delivering instruction, the content presentation sub-model had the highest fidelity of implementation of both types (*actual use* and *adherence*). Given that the teacher did not implement the design with 100% adherence and yet the students still had significant gains on the content knowledge assessment, it might be possible that my instructional model had no effect on the implementation. Perhaps the teacher implemented her own instructional model or only the components of my model that matched her teaching style. Hence, the teacher’s model, and not the design, produced the significant increase in unit content knowledge, as measured by the posttest. On the other hand, it is also possible my instructional model did play a key role. The teacher *adapted* my design to fit the needs of the learners across the three proficiency tracks. Recall from chapter three that teachers adapt innovations to the setting (Hall & Loucks, 1978; Mowbray et al., 2003; O'Donnell, 2008; Penuel & Means, 2004). For example, the teacher modeled tasks and provided worked examples in the classes rated as *below proficient* more than she did in the other classes. However, she did not implement or adapt some components of my design in any of the classes, omitting them all together. Thus, the teacher's 82.2% *actual use* of my design and 68.1% *adherence* to my instructional model was effective enough to have helped the students learn the content. If this is the case, gains on the posttest might actually have been bigger had the fidelity of implementation also been higher. Another plausible explanation is that the interaction between my design and the teacher's instructional model might have caused the students to learn the content better, making them have significant gains on the posttest.

Some Factor Other Than the Treatment Caused Increased Unit Content Knowledge

Alternatively, the significant increase in student content knowledge scores may have been caused by something other than the treatment. The most likely alternative explanation appears to be the influence of the *state test preparation* during the implementation of the unit.

State test preparation as the cause. It is possible that the preparations that were being done for the upcoming state's standardized tests may have caused students to perform better on the posttest. Though I conjectured above that students might have developed a negative attitude toward testing, it is also possible that these very same preparations might have caused students to develop a test-taking mindset and the desire to perform better on tests. Students might have thought through the posttest questions and multiple choices carefully before selecting their responses, as opposed to just rushing through the test, causing them to perform better than they did on the pretest.

Fidelity of Implementation of the Design

The teacher in this study was quite dedicated to the project. She was a member of the design team and attended design meetings after school and even during the summer when schools were not in session. She reviewed instructional materials during the development stage and provided feedback. During the implementation, she and I held reflective meetings daily to discuss how well the instruction went and she implemented the entire unit, even though it took one-and-a-half times longer than planned. The teacher went well beyond what an average teacher would likely be willing to do and put up with. This is clear evidence that she wanted the project to work.

As discussed in chapter 6, the teacher implemented specified steps of the instructional model (*actual use*) with *high* fidelity (82.2%) and she followed the design's instructional sequence in implementing individual steps in the instructional model (*adherence*) with *medium* fidelity (68.1%, which –by the statistical definition of fidelity presented in chapter 3– is at the high end of the medium fidelity range). Given these percentages, one might conclude that the implementation was faithful. But this conclusion requires a bit more explication. Conversely, one might conclude that the implementation was not faithful because the design was unrealistic and certain crucial components of the design were lost during implementation. The evidence for these two conclusions is discussed in separate sections below.

Evidence for Faithful Implementation

There are two types of evidence for a faithful implementation: *all major components of the unit were implemented* and the fact that the unit *achieved its principal desired learning outcome*, as evidenced by significant increase on the content knowledge posttest. Each type of evidence is discussed below.

All major components of the unit were implemented. The teacher implemented all components of the unit. These included both pre- and posttests, content readings, GIS tasks, and laboratory activities. The teacher implemented the unit in its entirety with varying degrees of fidelity for the individual models/sub-models, with greatest *actual use* and *adherence* fidelity on the days that used the content presentation sub-model. That sub-model was derived from Gagné's Nine Significant Events Model, a sequence that many teachers use in direct instruction (Gerstern, Keating, & Becker, 1988; Joyce, Weil, & Showers, 1992). I used Gagné's model as a framework because the unit had a strong direct instruction component in the form of the teacher presenting the content, giving examples, and providing feedback as learners practice. A possible explanation for the high fidelity of implementation of the three sub-models that utilized the content presentation sub-model is that the teacher's main model was direct instruction. Thus, it was more comfortable for her to implement the content presentation instructional sub-model because it was well-matched to her present instructional model.

The unit achieved its principal desired learning outcome. My goal was to design an instructional model that could be used with students in all three proficiency track categorizations and that could best bring about desirable student outcomes. One might conclude that the implementation was faithful because its principal desired learning outcome was achieved: Increased student science achievement. The teacher did not review the content knowledge pretest after its administration, neither did she teach to the posttest, suggesting that students' content knowledge may have increased as a result of the treatment. The classes rated as *proficient* made bigger gains on the posttest, followed by the classes rated as *below proficient*, and then the class categorized as *advanced proficient*. Interestingly, while fidelity of implementation of both types was slightly different across the classes, there does not seem to be a direct correlation between a higher fidelity of implementation and a higher gain. However, the class classified as *advanced proficient* in which the teacher implemented the design with lower fidelity had a smaller gain in achievement than the other classes. Possibly, if the teacher had adhered to the instructional model in that class, the gain might have been much bigger.

Evidence for Unfaithful Implementation

The evidence for why the implementation was not faithful includes the fact that it may well have been an *unrealistic design* and the fact that the *implementation omitted key elements of the design*. I discuss each of these two types of evidence below.

Unrealistic design. The teacher could not have implemented the unit with fidelity if the design was unrealistic. There appear to be two factors that made the design unrealistic: the *process by which the unit was designed* and the *lack of a comprehensive implementation plan*, discussed below.

Process by which the unit was designed. Seeking to examine how a Web-based module might best be developed to enhance science inquiry supported by a GIS, I worked with a design team consisting of subject matter experts in science education, Earth and environmental science, environmental education, GIS, and an eighth-grade science teacher to develop a science inquiry unit on energy that is supported by a GIS. Using the *Understanding by Design* framework (Wiggins & McTighe, 2005), together we identified the content, assessments, and instructional activities. We also established the scope and sequence of instruction.

Some members of the design team initially did not understand the role of an instructional designer, however. They assumed I would develop the materials and then simply be the teacher's aide in the classroom during the implementation. I was a novice instructional designer and this was my first real-world design project. Given my lack of experience, I had not been proactive in selecting or creating a suitable instructional model, nor had I discussed key instructional design issues with the design team. Instead, I was largely reactive, employing a content-driven development approach in which I did not question design team decisions. Instead, I undertook the development of materials that implemented those decisions.

I felt, however, that perhaps I needed to play a greater role in the design than I was currently playing and I sought outside design guidance from my dissertation adviser, himself a highly experienced instructional designer. I shared with him the initial drafts of instructional materials and he was very surprised we did not have an instructional design model to guide us. The drafts I shared had many faults, ranging from poor readability, to too much text on a page, to no graphics and illustrations. With his advice and consultation, I analyzed different instructional theories and design models and developed the instructional model and meta-design principles, presented in chapter 4 of this document. He attended a design team meeting with me in which I presented my carefully derived model to the design team and he helped to clarify for the entire team the role of an instructional design model, as well as the role of an instructional designer. This meeting represented a turning point in the design team's awareness of what role I might play and how important the instructional design model was to the unit's likely success. My role evolved from simply being a developer of the instructional materials to being a designer.

The now-approved instructional model affected the subsequent design of the materials, but the design team had already organized and structured the content to be covered and decided when in the unit's sequence various pieces of content were to be covered and how much time was to be devoted to covering each. Thus, the design model did not affect the scope and sequence of instruction. This meant that, while the instructional design model specified what the teacher was to do, the amount of content to be covered and the pacing at which that content was to be covered had already been established, independent of that instructional model. Unfortunately, as reported by the teacher, there was more content than she felt could be covered in the amount of time assigned in the instructional sequence and that sequence did not necessarily accommodate the completion of all the steps in my model.

Lack of a comprehensive implementation plan. As designers and developers, we had implementation blind spots. For example, we did not create a coherent and comprehensive implementation plan for the design. Such a plan could have provided guidelines of how to stay within the implementation timeline, how to manage a large scope of instruction, how to handle time pressure, how to accommodate technology failure, and how to use the instructional model. In four sections below, I discuss what I perceive to be key problems with our implementation plan: *unrealistic implementation* *timeline, excessively large scope of instruction and incorrect pacing, failure to anticipate technology failure,* and *insufficient professional development.*

Unrealistic implementation timeline. We had an implementation timeline that was based on the projected length of the unit (40 days). We started the unit in the second week of November and we anticipated the implementation to end by the last week of January, bearing in mind time for the holidays and maybe school closures due to inclement weather. The implementation was, however, completed in the second week of March (66 days). The teacher implemented 82.2% of the unit in those 66 days. Thus, assuming her pacing was constant, she would have implemented 100% of the unit in 80 days (exactly twice as long as planned). This may well explain the loss of fidelity. We did not include in the design any strategies for staying within the planned implementation time. In fact, we were lucky to work with a teacher who was willing to implement the unit for as long as she did.

Excessively large scope of instruction and incorrect pacing. On the second day of the implementation, students were scheduled to read content on *Understanding Electricity* and to start entering their energy consumption values in the energy audit spreadsheet. The teacher skipped the entire content worksheet. She reported that the scope was too big for that day and the content was complicated and overwhelming to students as a first activity. We separated the two activities, revised the sequence, and revisited the content readings on day five of the implementation, causing us to fall a day behind schedule. From then on, we continued to fall behind schedule by more and more days, mainly because some activities took longer than they were allotted in the instructional sequence. In fact, scope of instruction and time were the top two factors that accounted for loss of fidelity.

Given the pressures of scope of instruction and time that the teacher had in this study, one might reasonably argue that the teacher *adapted* the design in order to meet the constraints of the instructional setting and learners. The larger model was a variation of Dick and Carey's formative evaluation whose intent was to assess whether the instruction was effective, to identify any weaknesses, and identify where instruction needed to be revised and improved. According to Fullan (2001), *adaptation* is making modifications to a new program as one works. Program implementers choose components of the program that are appropriate for them and their situations (see also Blakely et al., 1987). Adaptation can be likened to what Rogers (2003) refers to as re-invention, which is "the degree to which an innovation is changed or modified by a user in the process of adoption and implementation" (p. 17). But I observed that, for the most part, the teacher did not change or modify the *content* or *activities* while she was teaching. Instead, she adapted the design by simply not implementing some events or steps in the models/sub-models and many of her decisions seemed more closely related to time pressures than to modifications designed to enhance instructional effectiveness. For instance, on day 2 the teacher "skipped the worksheet to save time and get to the audit," on day 21 she reported that she did not do the warm-up activity because of time constraints, and on day 26 she asked students to skip more than half the worksheet questions (see Table 34).

Regardless, adaptation introduces the possibility of important loss of fidelity in an implementation. As Dusenbury et al. (2003) asserted, while adaptation may be necessary to meet the needs of a particular setting, there is a possibility that critical, effective components of a program may be lost when the program is modified.

Thus, while we might assert that we designed the materials well and that tasks were allotted the right amount of time if the teacher followed the instructional model as prescribed, the data in this study seem to suggest clearly that our plan was simply unrealistic. Regardless, we did not develop guidelines for the teacher on what to do when she was faced with the pressures of too much material and too little time so she would be able to stay on schedule.

Failure to anticipate technology failure. We also did not have a plan for technology glitches, which we encountered a few times in the course of the implementation. On the first day of using Google Earth, the network was very slow and files took about three to five minutes to download. We experienced the same intermittent Internet connection and slow file downloads during a GIS activity on the following day. It appeared that there were a lot of other people using the network at the same time in addition to the 13 to 32 students that were trying to download files. To resolve this issue, the technology support staff assigned the students' laptops a specific IP address. Hence, we did not have any network problems during the rest of the implementation. But the GIS software tended to use so much battery power that, by the third period, most of the students' laptops needed to be charged. There were only 10 power outlets in the classroom and they could not be easily accessed by all students. We placed an extension cord across the middle of the classroom for students to charge their laptops if they ran out of power. Although we were fortunate not to encounter any larger technology problems, having a plan for technology problems in advance could have helped us save some valuable time.

Insufficient professional development. We conducted a professional development workshop three-and-a-half months prior to the implementation but we did not train the teacher well on using the new instructional model. At that workshop we presented an overview of the new instructional model but did not specifically train the teacher on how to use it, neither did we explain the value of each of the steps we included in the model. Then during the implementation, the teacher received professional development for implementing the GIS activities, but not for using the instructional model.

In two case studies, team members were trained on how to implement the positive behavior strategies before the implementation. Initially, the team members scored 80% fidelity after their first training session and with more training, they implemented the strategies consistently with 100% fidelity, yielding positive changes in the students' behaviors. Reflecting on their findings from the two case studies on positive behavior support (Dunlap, Iovannone, Wilson, Kincaid, & Strain, 2010) during the 2011 Distinguished Lecture Series panel on *Challenging Behavior in Young Children: Preventative Strategies and Solutions* at Lehigh University, Dr. Phillip Strain of the University of Colorado at Denver claimed that "80% implementation gets you 0% change and 100% implementation gets you real change." He acknowledged that this is a high bar but it is what works; do 100% of all the steps and get the results.

Anderson (2002) wrote that teachers considering new instructional approaches face many dilemmas relating to their beliefs and values regarding students, teaching, and the purposes of education. Had we trained the teacher adequately on how to use the instructional model, explained the rationale for including each step in the model, and provided sustained professional development for the model throughout the implementation, it is possible that the teacher might have implemented the design with higher fidelity, perhaps even 100% fidelity, which could have led to better outcomes and helped her reach Strain's high bar for implementation fidelity.

Implementation omitted key elements of the design. The teacher omitted three key elements of my design. These elements are discussed below under the headings *loss of inquiry, failure to identify and clarify students' misunderstandings,* and *omission of critical thinking*.

Loss of inquiry. While the principal desired outcome of increasing student achievement was achieved, the underlying intent of the design, inquiry learning, was not fully achieved. This was a study on inquiry teaching and learning and, as reported in the previous chapter, the teacher skipped some crucial steps when implementing the inquiry sub-model and that sub-model was the least faithfully implemented of all components of the design. The reason for including the sub-model was to have students actively engaged with hands-on activities so that they would learn science by doing, just like real scientists. According to the National Research Council (2000), inquiry teaching and learning has five essential features (see chapter two) and "teaching approaches and instructional materials that make full use of inquiry include all five of these essential features" (p. 28). In our study, however, the teacher did not involve the students fully in all five elements of the inquiry process. While students were actively engaged with scientifically oriented questions (element 1) and sought empirical evidence from observations (element 2), they did not adequately use evidence to form explanations, evaluate their explanations, and draw conclusions (element 3, which had *low* fidelity of 4.2%). The teacher did not also ask students to make predictions (element 4), neither did she have students share and justify their explanations (element 5).

The Cognition and Technology Group at Vanderbilt (2003) argued “a critical feature of effective teaching is that it elicits from students their preexisting understanding of the subject matter to be taught and provides opportunities to build on, or challenge, the initial understanding” (p. 176). Having students make predictions is one way a teacher might use to elicit students’ prior knowledge and having students share and justify results while the teacher addresses misconceptions could help students build on their initial understanding. The NRC (2000) asserted that sharing explanations can strengthen the connections students make among the evidence, initial understanding, and their own explanations. Clearly, some critical steps in the inquiry model were omitted. Settlage, Meadows, Olson, and Blanchard (2008) asserted that a teacher’s beliefs about teaching and learning can support or hinder the use of inquiry-based teaching. Given that the labs took more time than they were allotted and the teacher did not implement these steps, it appears that the teacher may have skipped steps she did not either understand or value and, as suggested earlier, may have fallen back to her implicit instructional model.

Then again, given that the steps that had *low* fidelity or that the steps the teacher skipped in the laboratory activities sub-model were typically the last steps, it is possible that the teacher simply ran out of time towards the end of the class periods. Some researchers have reported that inquiry-based teaching and learning takes more time than traditional content delivery through direct instruction (Pierce, 2001; Settlage et al., 2008). Yore et al. (2008) agreed and noted that “it is difficult for teachers to fully implement their lesson plans as designed because of the time factor" (p. 62). Thus, this study may be substantiating the finding that inquiry-based approaches take more time.

Failure to identify and clarify students' misunderstandings. Modell, Michael, and Wenderoth (2005) asserted that identifying and clarifying students' misunderstandings is important because it helps students construct or reconstruct the correct framework for their knowledge (see also Committee on Undergraduate Science Education, 1997). Teachers could use questions and discussion to probe for students' misunderstandings. Step 3.2 in our larger model, *solicit and respond to student questions*, accounted for a considerable loss of fidelity for the larger model (see Table 26). As discussed in chapter six, the teacher reported that her students never had questions and, if they did, they would ask without her soliciting. Despite the teacher's assertion, I asked her to try soliciting questions from students for a period of time to see if this practice would encourage students to ask questions. She solicited student questions four times across the entire study, whenever she remembered to do so, and only once did a student respond. On two occasions, students initiated asking questions on their own accord. It is possible that some students had questions but did not want to appear foolish to their peers or they just wanted the lesson to be over and did not want to elongate it by asking questions.

Omission of critical thinking. Recall from chapter two that critical thinking is important because it helps students solve problems and make decisions based on sound judgment (Facione, 1990; Raths et al., 1967). The first questions on the worksheets (with an exception of the content presentation worksheets) usually involved students writing their responses after querying the GIS or conducting a lab. Those questions addressed mainly the knowledge, comprehension, and application levels in the cognitive domain of Bloom's taxonomy of educational objectives (Bloom et al., 1956). Only the last few questions on the worksheets addressed the upper levels of analysis, synthesis, and evaluation. Anderson et al. (2001) contended that the three upper levels of Bloom's taxonomy address key processes, such as critical thinking and problem solving (see chapter two). If the scope of instruction was too big or if students took too long to complete a task, the teacher moved on to the next task without the learners finishing worksheet questions. On one occasion, the teacher asked learners do only the first few questions on the worksheet and then gave students the answers to the later questions. She reported to me that the reason she told learners to skip the questions was because the activity was similar to the one preceding it. By not completing some tasks, students may not have been stimulated to engage in critical thinking, thus reducing the fidelity of the implementation and failing to address a key component of my design.

CHAPTER 8: RECOMMENDATIONS AND FUTURE RESEARCH

This study began with the premise that Geographic Information Systems have the potential to foster authentic inquiry-based learning environments in which students think more critically, analytically, and synergistically (see, for instance, Baker & White, 2003; Hall-Wallace & McAuliffe, 2002; and Kerski, 2003). I found that the science content knowledge of eighth graders who completed the energy unit we designed went up significantly and that their attitudes toward science and technology went down significantly. My findings about the extent to which students engaged in the critical thinking and inquiry learning we had hoped would occur were mixed. I concluded that, taken as a whole, our design was unrealistic in terms of its expectations for what might be covered and it failed to anticipate the likely pressures on teachers in terms of what they could cover. We also failed to lay out a comprehensive plan for how to reduce scope and modify activities in order to accommodate those demands, leaving all such decisions to the teacher. Lastly, I concluded that such a comprehensive plan should have included better training for the teacher in terms of the instructional design model and a systematic back-up plan in the event of technology-related problems.

This study culminates 33 months of design, development, preliminary field-testing of parts, revisions, full unit implementation, data collection and analysis and, finally, write-up of findings and conclusions. I began this project knowing much less about real-world design than I do now and I wish I had known then what I know now. For this reason, in the next section I present my recommendations for designers and developers, offering them the advice I wish I had read before I began. In the section after that, I discuss areas for possible future research. Lastly, I conclude with a reflection on the relationship between formative evaluation and implementation fidelity.

Recommendations

Implementation is about more than just content and scope and sequence. Instructional systems design is about the entire system, whose components --including the learners, the instructor, the instructional materials and the learning environment-- work together to achieve a goal (Dick, Carey & Carey, 2009). It appears the likelihood of achieving a high fidelity implementation without controlling for variables such as the design, content, teacher, students, and technology is low. Thus, to achieve higher fidelity implementations, designers need to develop comprehensive implementation plans for their designs that address key design and implementation elements.

Based on the discussions of my findings in the previous chapter, below I address these key elements through four recommendations for others who seek to design and implement curricular innovations, particularly those which make heavy use of technology. Each recommendation is presented under a separate heading, with the heading stating the recommendation and its section discussing practical design strategies for designing and implementing newer curricular approaches.

Clarify the Relationship between Instructional Design and the End Product to All Key Players

The scope and sequence in this study were driven by the content and not the instructional model, most likely contributing to the unit taking one-and-a-half times longer than planned. In fact, had the teacher implemented everything as prescribed in the instructional sequence at the same pace, the unit would almost certainly have taken about twice as long as scheduled to complete. As noted in chapter 7, one main reason for the scope and sequence in this implementation was the fact that I played less of a role in early stages of the design than I should have. By the time I had (1) designed an appropriate instructional design for the project and (2) presented it to the design team and (3) made them aware of what role I should play, almost all crucial, decisions about content and sequence were already finalized.

The intent of instructional design is to increase the likelihood of achieving the desired outcome. Hence, designers should be actively involved from the beginning of the project and they need to make sure that, early on, they clarify for content experts and other stakeholders what an instructional designer does and why it is important. This entails working closely with subject matter experts and teachers (or implementers) to control the scope and sequence of instruction especially when it involves a new instructional model and new technology. Also, novice instructional designers should seek counsel from expert designers from the onset of the project and throughout the instructional systems design process.

Identify and Incorporate Desirable Teacher's Beliefs and Values and Provide Sustained Professional Development

If you are working with teachers to implement a new instructional model, first identify their beliefs and values about teaching and learning and then incorporate the beliefs and values that contribute to the intent of the design, and lastly, provide ongoing professional development. Fullan (2001) contended that the extent to which the underlying assumptions of the innovation match the beliefs and values of the potential adopting population can play a major role in whether or not the innovation will be adopted. The innovation in this study was a new instructional model for using a GIS to enhance science inquiry. As discussed in the previous chapter, it seems likely the teacher fell back to her implicit instructional model when she was pressed for time or when she did not understand or value the steps in the models/sub-models.

Had our instructional model incorporated aspects of the teacher's model that were well-matched with the goal of the design, the fidelity of implementation might have been higher. We did not, however, know the teacher's beliefs about teaching and learning, neither did we know her beliefs about using technology in teaching and learning. Maor and Taylor (1995) concluded that, although the use of computers in inquiry-based science classrooms offers the potential to facilitate students' higher-level learning, teachers' epistemologies continue to play a central role in mediating the quality of student learning. Therefore, before designing a new instructional model, instructional designers should ask teachers about their beliefs and values about teaching and learning and incorporate into the design the beliefs and values that will foster achieving the desired intent of the design.

Teachers should then be trained not only on the content but also on how to use the instructional model and on the importance of each step in the model, especially if an innovation entails a new instructional model or new technology. Professional development should be conducted before the implementation and periodically throughout the implementation process. Before the implementation of the unit, we held a professional development workshop in which we gave an overview of the instructional model and mainly concentrated on training the teacher how to do the GIS tasks and the laboratory activities. During the study, the teacher also received professional development on doing the GIS tasks, but not on the instructional model. Clearly, giving the teacher an overview of the instructional model three-and-a-half months before the implementation was not sufficient. The one-time training would not have provided the same benefits as an ongoing professional development would. Thus, designers should not expect teachers to implement a model with 100% fidelity if they are not well trained.

Professional development on the instructional model should include a discussion of how the teacher's beliefs and values that match the intent of the design were incorporated into the new design. Training should also address which steps of the model are crucial to achieve the intent of the design and should, therefore, not be omitted and which steps are optional. It may not be practical, however, for designers to be physically present every time to conduct professional development during the implementation. Thus, designers might develop guidelines of how to use the model, including the importance of each step and build into the design when teachers should review the guidelines after the initial training. The guidelines could be print-based or digital, --for instance, a podcast-- or could be provided in both media.

Since teachers are the implementers of the design at the classroom level, they need to be involved from the beginning of the project. Teachers know the abilities of the learners and the strengths and limitations of the learning environment, information a designer needs in the **A**nalyze phase of the ADDIE instructional development process model. Also, teachers should participate in setting the scope and sequence of instruction because their day-to-day experiences in the classroom may enable them to estimate the amount of content that can be covered in one class period. This should decrease the chances of having a big scope of instruction. The information teachers might provide about the instructional setting and the learners might help the designer create a more realistic design, thus, increasing the likelihood of high implementation fidelity.

Design a Low-technology Back-up Plan

The design must accommodate technology glitches. Instructional designers should include a low-technology backup design for when things do not work out as planned during the implementation. Such a back-up plan might entail having files on USB drives or CD-ROMs for use in case of technology failure, an inexpensive solution, given how little USB drives and CDRW discs cost. For example, on the first day of using Google Earth and the GIS, we experienced a slow Internet connection that caused the files to download slowly, costing us valuable time. Had we had those files on several USB drives, the teacher could have passed them around the class for students to copy the files onto their computers. Also, implementers should work with technology support staff before the implementation to test the technology that will be used. This should help prevent some technical problems during implementation. For instance, we did not know that the laptop batteries, because of their age, did not have enough power to last for even three class periods. The back-up plan might have been to have some extra batteries and power adapters, or at the very least to have enough power strips to allow portions of each class of students to run on AC while the remainder ran on battery power.

Develop a Plan to Manage the Pressures of Time and Scope of Instruction

Time and scope of instruction contributed heavily to the loss of fidelity in this study. Designers should include a plan to accommodate the pressures of time and scope and other demands and practical realities of the school settings that could interfere with the scope and sequence, such as early dismissals and shortened class periods. Tessmer and Wedman (1990) developed a Layers-of-Necessity instructional development model that takes into consideration the time and resources available to a developer. That model comprises different layers of design and development activities and each layer is an independent instructional development model. The developer selects the layer to use based on the availability of time and resources. Developers may choose the simplest layer for instructional projects that have severe time and resource limitations and choose a more sophisticated layer for projects with more time and resources.

While the Layers-of-Necessity model is a *process* model for developing instruction, it seems that the same concept could be applied when designing and implementing instruction. Designers could include in their designs a plan that specifies the elements that are crucial to the design and should not be omitted and elements that could be omitted and still achieve the goal of instruction. Teachers could then use this plan to make decisions about what to leave out in order to manage time and scope of instruction pressures. In this study, some crucial elements of our design, like the hands-on inquiry and critical thinking, were not fully implemented. As designers, developers, and implementers, we need to make clear which are crucial components of an innovation and provide rules and guidelines for how to modify the design in the face of pressures within the instructional settings in which the implementation is to take place.

Future Research

Besides continuing my current research on principles for designing effective instruction for innovative technologies, with a focus on providing adequate scaffolding for both learners and teachers, I would like to explore further how to define and measure fidelity of implementation in terms of instructional design.

While I had a lot of fidelity of implementation data to analyze, I lacked a framework to guide interpretation of those data. There is no widely accepted way to analyze and report fidelity of implementation neither is there a guideline for the thresholds for high and low fidelity. Some researchers used Hall and Hord's (1987) Concerns-Based Adoption Model (CBAM) with its three elements for assessing and facilitating implementation: (1) *Stages of Concern* assesses users' perceptions about an innovation; (2) *Levels of Use* measures current performance of each implementer; and (3) *Innovation Configuration* assesses variations in how an innovation is used. The CBAM is, however, not well suited for measuring the extent to which teachers' implementation of an *instructional model* is faithful. Thus, I am interested in developing a conceptual framework for measuring fidelity of implementation for instructional innovations, particularly, newer instructional models. A framework that incorporates key issues in instructional theory and design might also prove of value to researchers conducting evaluations of instructional innovations.

School settings often have unpredictable demands and limitations that might affect the implementation schedule and the pacing and duration of instruction and may hinder achieving the intended goal of the design. I am interested, therefore, in researching which components of an instructional design model might most easily be dropped and which must not be dropped when demands of an instructional setting place the design under pressure. Such research would represent an extension of Tessmer and Wedman's Layers-of-Necessity model approach. Additional future research might explore how best to design comprehensive implementation plans for curricular innovations, plans that are sufficiently robust and are flexible enough to increase the likelihood of faithful implementations.

Last Words

The findings of this study clearly suggest the teacher worked diligently, was thoughtful and dedicated and did her best to implement our design. It is less clear whether what she did constitutes a faithful implementation. It is important to remember, however, that the title of this dissertation is, "Design, Development, and Formative Evaluation of a Geographic Information System-supported Science Web-based Inquiry Module" and the study's intent was not to determine fidelity of implementation for a *finalized* design and product. Instead, it was a formative evaluation pilot study. Thus, its intent was not to make a final judgment on implementation fidelity but to help us revise our product and design in order to enhance subsequent implementations. In this, our study appears to have succeeded in providing data, findings, and recommendations that we found helpful and which should be of use to future designers in creating finalized designs for which we hope implementation fidelity will be high.

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Appendix A

ENERGY UNIT SCIENCE AND TECHNOLOGY SURVEY

The purpose of this survey is to see what you think about science and technology. **Keep in mind:** This is a survey, not a test. You will not get a grade. Your answers are very important, however. We need to understand what your whole class thinks about science and technology. Please answer the questions truthfully. Do your best.
Read each statement below. Decide how much you agree with it. There are no right or wrong answers. MARK THE CIRCLE that tells how much you agree.

A. Background Information

Name: ________________________________

ID Number: ____________________________

B. What do you think about science and technology?

	YES ◄			► NO
	Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree
I think science is exciting.	○	○	○	○	○
I like using the computer to create maps.	○	○	○	○	○
Solving science problems is fun.	○	○	○	○	○
I like to use maps to answer questions about people and places.	○	○	○	○	○
I like science better than I do most other subjects.	○	○	○	○	○
Satellites, GPS devices, and remote sensing equipment are cool.	○	○	○	○	○
I have a real desire to learn science.	○	○	○	○	○
The use of computer maps will be important to me in my job some day.	○	○	○	○	○

	YES ◄				► NO
Science is useful for solving problems in my everyday life.	○	○	○	○	○
I like to use maps to explore and gather information about new places.	○	○	○	○	○
Learning science will improve my career chances.	○	○	○	○	○
I like to think about how to solve environmental problems.	○	○	○	○	○
I have a good feeling toward science.	○	○	○	○	○
I like spending lots of time outdoors.	○	○	○	○	○
I enjoy talking to people about science.	○	○	○	○	○
I am interested in where things are located in the world.	○	○	○	○	○
I like writing about science.	○	○	○	○	○
I often wonder how satellites, computers, and other advanced technologies work.	○	○	○	○	○
I like to read books, magazines and Web sites about science.	○	○	○	○	○
I like to close my eyes and visualize objects in three dimensions.	○	○	○	○	○

Appendix B

Energy Unit Framework

Driving Question: How do we plan for future energy use?

Enduring Understandings:
Distinguish among forms of energy (e.g. nuclear, electrical, gravitational), sources of energy (e.g., electrical, mechanical, chemical, light, sound) and usable energy resources (oil, gas, coal, active/passive solar, wind, hydroelectric, biomass, tidal, geothermal, fission (U), fusion (H)).

What is energy? ENERGY IS THE ABILITY TO DO WORK!

IA. Energy Acquisition - Renewable and Nonrenewable Energy Resources
IA1. Some resources are not renewable or renew very slowly. Fuels already accumulated in the earth, for instance will become more difficult to obtain as the most readily available resources run out. How long the resources will last, however, is difficult to predict. The ultimate limit may be the prohibitive cost of obtaining them. (8C/M10 SFAA)
IA2. Energy from the sun (and the wind and water energy derived from it) is available indefinitely. Because the transfer of energy from these resources is weak and variable, systems are needed to collect and concentrate the energy. (8C/M5)

IB. Energy Generation, Storage, and Transport
IB1. Energy can be stored in various forms for subsequent use (gravitational, chemical, electrical, mechanical, etc.).
IB2. Transport of energy depends on the form of energy.
IB3. Energy resources are more useful if they are concentrated and easy to transport. (8C/M9)
IB4. People have invented ingenious ways of deliberately bringing about energy transformations that are useful to them. (8C/M8 SFAA)
IB5. Electrical energy can be generated from a variety of energy resources and can be transformed into almost any other form of energy. (8C/M4)
IB6. Electric circuits are used to distribute energy quickly and conveniently to distant locations. (8C/M4)
IB7. In many instances, manufacturing and other technological activities are performed at a site close to an energy resource because of losses in transmission. Some forms of energy are transported easily and others are not. (8C/M3)

IC. Energy Consumption and Conservation
IC1. Energy is required to do anything (including technological processes, such as manufacturing). (8C/M7 SFAA)
IC2. Industry, transportation, urban development, agriculture, and most other human activities are closely tied to the amount and kind of energy available. Different parts of

the world have different amounts and kinds of energy resources to use and use them for different purposes. (8C/M6)
IC3. There are different ways of obtaining, transforming, and distributing energy, and each has environmental consequences. Each of these has trade-offs pertaining to energy dependence and the impacts of organisms (particularly humans) on the environment (8C/M2)
IC4. By burning fossil fuels, people are releasing large amounts of carbon dioxide and other greenhouse gases into the atmosphere that traps extra solar energy and affects the environment through climate change. (8C/M11 BSL)
IC5. There are ways to conserve energy by reducing waste in everyday activities.

ID. Geospatial skills
How to analyze the spatial distribution of the world's energy resources.
Spatial distribution of world's energy consumption.

Essential Questions:

IA. Energy Acquisition - Renewable and Nonrenewable Energy Resources
What makes an energy resource renewable or nonrenewable?
What are the various forms of renewable and nonrenewable energy?
What are the various renewable and nonrenewable energy sources and resources?
At what rate are the various renewable energy resource renewed?
Which will be the primary energy resources in the future?
What is the environmental impact of utilizing different energy resources?
How does the distribution of natural resources affect energy choices?
How do we use a Geographic Information System to enable us to view the distribution of energy resources historically and today?

IB. Energy Generation, Storage, and Transport
How is energy transported from original resource to where it is needed?
How can energy resources be concentrated and stored for future use?
How are the various energy resources transformed into useful fuels and electricity?
How do man-made systems affect the management, distribution, and availability of energy resources?
How does a Geographic Information System enable us to explore the worldwide production patterns and transport of energy resources?

IC. Energy Consumption and Conservation
What is my energy consumption?
How can I manage and conserve energy resources?
How can I make more energy efficient consumer choices, for fuel and electricity choices?
What kinds of waste do I generate from my use of energy?
What personal choices, based on geographic location and resource availability, can be made to decrease energy consumption?
How does a Geographic Information System enable us to explore the worldwide consumption patterns of energy resources?

Topical questions:

IA. Energy Acquisition - Renewable and Nonrenewable Energy Resources
Which energy resources do we use today?
What are the various types of energy resources?
What is the source of the energy stored in fossil fuels?
Which sources of energy will we likely use in our homes 25 years from now?
Why are scientists looking at new sources of energy for the future?
Where should our energy come from in the next 10 years? In the next 25 years? In the next century?

1B. Energy Generation, Storage, and Transport
How does oil make its way from being discovered in a well to a car's gas tank?
How is a reservoir like a battery?
How is energy transformed when we use fossil fuels?
How do you determine the efficiencies in energy use?
How does a power plant's fuel source impact the environment?
What are the pros and cons of using more nuclear power?
How much energy does the US import? How has this changed in the last 10 years?
How is energy transformed when we use fossil fuels?

1C. Energy Consumption and Conservation
How are energy resources used?
Why is the value of energy conservation?
How has the use of our energy resources in the past 10 years changed their availability?
How may energy consumption impact the availability of resources?
How can we manage and conserve renewable and nonrenewable resources?
How does my energy use impact the environment?
How much energy do I use in a day? In a week? In a month? In a year? In a lifetime?
What are my conservation practices?
How much energy does my school use? How can it become more energy efficient?
Topical understandings for this unit (Are specific to the unit topic. Involve generalizations derived from the specific content knowledge and skills of the unit):
The plants of vast forests that once covered earth provide the energy stored in fuels. A fuel is a material that contains stored potential energy. Some of the fuels we use today were made from materials that were formed hundreds of millions of years ago. Those fuels are called fossil fuels.
Fossil fuels include coal, oil, and natural gas. Fossil fuels supply much of the energy we use in our everyday lives. Examples include energy to light and heat your home and to run the family car. Fossil fuels make up the majority of earth's energy resources. Fossil fuels are created from the remains of dead animals and plants. Most countries rely on coal and oil that are mined or drilled from the earth to produce the energy they need.
Energy from the sun (solar energy) is constant and is not limited, and is the ultimate source of most energy that we use. It becomes available to us in many ways: The energy in sunlight is captured directly in plants, and it heats the air, land, and water to cause

wind and rain. But the flux of energy if fairly weak, and large collection systems are necessary to concentrate energy for most technological uses. Hydroelectric energy technology uses rainwater from rivers, windmills use the flow of air produced by the heating of large land and ocean surfaces, and electricity generated from wind power and directly from sunlight falling on light sensitive surfaces require very large collection systems. Energy from the sun can be used to heat buildings and to produce electricity. Solar energy can last for a long time if it is used well. The winds and waters of the earth are energy sources that can last for a long time.

In this century, it has been common to use energy sources to generate electricity, which can deliver energy almost instantly along wires far from the source. Electricity, moreover, can conveniently be transformed into and from other kinds of energy.

The need for alternative sources of energy is growing because of our increased energy needs, pollution problems, and because supplies of fuels are running out. Fusion is the energy that powers the stars. Fusion could supply a source of energy that is clean, not expensive, and will never run out. But fusion requires very high temperatures. When using fusion becomes possible, it will be able to fulfill all our energy needs.

Renewable resources are forms of energy that will be replaced if they are managed well. The sun, wind, water, and trees are examples of renewable resources. Nonrenewable resources are forms of energy that can never be replaced once they are used up. Coal, oil, natural gas, iron, cooper, and aluminum are examples of nonrenewable resources.

The growth of technology has led to increase use of resources. As resources are depleted, they may be more difficult and costly to obtain; and the use of resources is associated with environmental risks. All burning of fossil fuels emits waste products that may threaten health and life. The mining of coal underground is hazardous to the health and safety of miners. Oil spills can endanger marine life.

The waste products of fission are highly radioactive and remain so for thousands of years. We must conserve energy resources and make energy efficiency a consideration our own choices and uses of technology (for example, turning out lights and driving high-efficiency cars). That means that we must use energy resources wisely so they last longer. We can conserve resources by finding other materials to replace them and by recycling. Recycling is collecting and processing a product again to make new products. Recycling also includes the purchase of products made from recycled materials.

Consistent with the general differences in the global distribution of wealth and development, energy is used at highly unequal rates in different parts of the world. Industrialized nations use tremendous amounts of energy for chemical and mechanical processes in factories, creating synthetic materials, producing fertilizer for agriculture, powering industrial and personal transportation, heating and cooling buildings, lighting, and communications. The demand for energy at a still greater rate is likely as the world's population grows and more nations industrialize. Along with large-scale use, there is large-scale waste (for example, vehicles with more power than their function warrants and buildings insufficiently insulated against heat transfer). But other factors, especially an increase in the efficiency of energy use, can help reduce the demand for additional energy.

What key knowledge and skills will students acquire as a result of this unit? (Students will know….; Students will be able to….)

Students will identify the various forms of energy resources.
Students will identify the sources and availability of the various energy resources.
Students will explain how different energy resources are used.
Students will explain what renewable resources are.
Students will explain what nonrenewable resources are.
Students will explain why scientists are looking at solar, wind, and water energy as an energy source for the future.
Students will be able to describe and discuss the need for alternative energy sources (geothermal, tidal, biomass, and solar).
Students will explain why energy resources should be conserved.
Students will determine how energy consumption may impact the availability of resources.
Students will explain how we can manage and conserve renewable and nonrenewable resources.
Students will develop an energy policy for future energy use in for an island province.

ACCEPTABLE EVIDENCE

What evidence will show that students understand? (e.g., tests, quizzes, prompts, work samples, observations)

Pretest and posttest assessment of energy resources (forms, sources, and conservation) and spatial thinking skills aligned to objectives described above.
Completion of *Energy Resources* geospatial analysis activities.
Completion of *Energy* laboratory investigations and activities.

Performance Tasks: Through what authentic performance task will students demonstrate understanding?

Students will use My World GIS to analyze annual average sunshine data to determine good locations for solar plants.
Students will analyze "newly planned" solar power plant locations in 2009 and will determine optimal locations to build new very large solar power plants.
Students will use My World GIS to examine wind speed and land use patterns in Pennsylvania to determine the best place to locate a new wind farm in the Lehigh Valley and in Pennsylvania.
Students will use Google Earth to analyze the shapes of four water bodies to determine if these would be good places to locate a tidal power plant.
Using Google Earth, students will explore features of “hot Earth” areas in Iceland and in the United States. They will determine the best place to locate a geothermal power plant in the Northwest United States.

Students will analyze energy consumption data across the industrial, transportation, commercial, and residential sectors. They will analyze electricity distribution data to understand that the current US grid for electricity distribution is not efficient.
Students will use My World GIS to investigate fossil fuel production and consumption for different countries. They will examine how fossil fuel consumption and production have changed over a 20-year period, both worldwide and in the US.
Students will analyze energy resources for Navitas Isle, a small island inhabited by 12,000,000 people. They will develop an energy policy for the island that has an efficient energy-resources mix with minimal impact on the environment. Students will apply and use GIS tools and knowledge from past activities to make decisions for placement of solar power plants, wind farms, tidal power plants, geothermal power plants, using biomass, etc.

By what criteria will student products and performances be evaluated?
Criterion-based rubrics for Navitas Isle energy policy plan and presentation.
Successful completion of laboratory and geospatial learning activities.

Prerequisite knowledge:

Enduring Understandings:
Energy is involved in chemical and physical changes.

Topical questions:
What is a physical change?
What is a chemical change?
How are changes in matter related to changes in energy?
How are the different forms of energy related?
What is the law of conservation of energy?
What is the law of conservation of matter?

Topical enduring understandings:
Matter is anything that has mass and takes up space. All the "stuff" around you is matter. Air, plastic, wood, glass, paper, and cloth, including you, are matter. Matter can have many different properties. Materials can be hard or soft, rough or smooth, hot or cold. Materials can be liquid, solid, or gas. Some materials catch fire easily and others do not burn.
Most matter on earth exists in three states. Those states are solid, liquid, and gas. The particles that make up a solid are packed together in fairly fixed positions. Particles of a solid cannot move out of their positions. Particles of a solid can only vibrate back and forth. This is why solids retain a fixed shape and volume. The particles that make a liquid are close together.
Particles of a liquid are not held together as tightly as those of a solid. Liquids don't have a definite shape because particles of a liquid can move around. But liquids do have a definite volume. Particles of gases move so fast that they don't even stay close together. Gases expand to fill all the space available. Gases do not have a fixed shape or volume.

Eligible Content (Pennsylvania Standards)

S8.C.2.1.1 Distinguish among forms of energy (e.g., electrical, mechanical, chemical, light, sound, nuclear) and sources of energy (i.e., renewable and nonrenewable energy).

S8.C.2.2.1 Describe the sun as the major source of energy that impacts the environment.

S8C.2.2.2 Compare the time spans of renewability for fossil fuels and alternative fuels.

S8C.2.2.3 Describe the waste (quantity, kind, and potential to cause environmental impacts) derived from the use of renewable and nonrenewable energy sources and their potential impact on the environment.

Pennsylvania Academic Standards

7.1.3.A Identify geographic tools and their uses.
- Characteristics and purposes of different geographic representations
- Maps and basic map elements
- Globes
- Geographic representations to display spatial information
  - Thematic maps

7.1.3.B Identify and locate places and regions.
- Human features
- Countries (i.e., United States. Mexico, Canada)

7.1.6.A Describe geographic tools and their uses.
- Geographic representations to display spatial information
  - Absolute location

7.1.9.A Explain geographic tools and their uses.
- Development and use of geographic tools
  - Geographic Information Systems [GIS]
  - Access to computer-based geographic data (e.g., Internet, CD-ROMs)

7.3.3.D Identify the human characteristics of places and regions by their economic activities.
  - Spatial distribution of resources
  - Non-renewable resources
  - Renewable resources

Appendix C: Observation Protocols

Teacher Implementation Fidelity: Computer-supported activity sub-model

DATE: ____________________ **DAY:** ________ **ACTIVITY:** ____________________________

SEQUENCE: Step1 ☐ Step2 ☐ Step3 ☐ Step4 ☐ Step5 ☐ Step6 ☐ Step7 ☐ Step8 ☐

STEP		WORST ⟷				BEST
STEP 1: Elicit prior understandings of lesson concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 2: Present authentic task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 3: Model task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 4: Provide worked example.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 5: Ask learners to perform task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 6: Scaffold task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included

STEP 7: Ask learners additional questions to elaborate task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 8: Review activity concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
Comments:						

Teacher Implementation Fidelity: Content presentation sub-model

DATE: ______________________ **DAY:** ________ **ACTIVITY:** ______________________________

SEQUENCE : Step 1 ☐ Step 2 ☐ Step 3 ☐ Step 4 ☐ Step 5 ☐ Step 6 ☐ Step 7 ☐ Step 8 ☐ Step 9 ☐

STEP		WORST ⟵				⟶ BEST
STEP 1: Elicit prior understandings of lesson concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 2: Gain and sustain learners' attention.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 3: Tell learners the objectives.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 4: Stimulate recall of prerequisite learning.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 5: Explain content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 6: Illustrate content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 7: Elicit answers to specific questions on students' worksheets.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 8: Solicit some responses from students' worksheets and provide feedback aloud.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 9: Review content.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**

STEP 9: Review content.	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
Comments:						

Teacher Implementation Fidelity: Content presentation and computer-supported activity sub-models

DATE: ____________________ **DAY:** 2 **ACTIVITY:** ____________________

SEQUENCE:	Step1	Step2	Step3	Step4	Step5	Step6	Step7	Step8	Step9	Step10	Step11	Step12	Step13	Step14
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

STEP		WORST ◄				► BEST
STEP 1: Elicit prior understandings of lesson concepts.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 2: Gain and sustain learners' attention.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**

STEP 2: Gain and sustain learners' attention.	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 3: Tell learners the objectives.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 4: Stimulate recall of prerequisite learning.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 5: Present authentic task.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 6: Model task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 7: Provide worked example.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 8: Explain content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 9: Illustrate content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 10: Elicit answers to specific questions on students' worksheets.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 11: Solicit some responses from students' worksheets and provide feedback aloud.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 12: Ask learners to perform task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 13: Scaffold task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 14: Review activity concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
Comments:						

Teacher Implementation Fidelity: Content presentation and laboratory activity sub-models

DATE: ______________________ **DAY:** 5 **ACTIVITY:** ______________________

SEQUENCE: Step1 ☐ Step2 ☐ Step3 ☐ Step4 ☐ Step5 ☐ Step6 ☐ Step7 ☐ Step8 ☐ Step9 ☐ Step10 ☐ Step11 ☐ Step12 ☐ Step13 ☐ Step 14 ☐ Step15 ☐ Step16 ☐

STEP		WORST ◄				► BEST
STEP 1: Elicit prior understandings of lesson concepts.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 2: Gain and sustain learners' attention.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**

STEP 3: Tell learners the objectives. (Present authentic task)	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 4: Stimulate recall of prerequisite learning.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 5: Explain content.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**

STEP 6: Form student groups.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 7: Model task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 8: Ask students to make predictions.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 9: Ask group members to collaborate on task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 10: Have students make observations.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 11: Have students use evidence to form explanations.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 12: Have students evaluate explanations and draw conclusions.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 13: Have students share and justify results.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 14: Address misconceptions.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 15: Ask learners to perform extension tasks.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 16: Review activity concepts.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
Comments:						

Teacher Implementation Fidelity: Content presentation and computer-supported activity sub-models

DATE: ______________________ **DAY:** 12 **ACTIVITY:** ______________________

SEQUENCE:	Step1	Step2	Step3	Step4	Step5	Step6	Step7	Step8	Step9	Step10	Step11	Step12	Step13
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

STEP		WORST ←				→ BEST
STEP 1: Elicit prior understandings of lesson concepts.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 2: Gain and sustain learners' attention.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
STEP 2: Gain and sustain learners' attention.	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**

STEP 3: Tell learners the objectives.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 4: Stimulate recall of prerequisite learning.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 5: Explain content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 6: Illustrate content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 7: Present authentic task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 8: Model task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 9: Provide worked example.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 10: Ask learners to perform task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 11: Scaffold task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 12: Ask learners additional questions to elaborate task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 13: Review activity concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
Comments:						

Teacher Implementation Fidelity: Content presentation and computer-supported activity sub-models

DATE: ____________________ **DAY:** 34-38 **ACTIVITY:** ____________________

SEQUENCE: Step1 ☐ Step2 ☐ Step3 ☐ Step4 ☐ Step5 ☐ Step6 ☐ Step7 ☐ Step8 ☐ Step9 ☐ Step10 ☐ Step11 ☐ Step12 ☐ Step13 ☐

STEP		WORST ←				→ BEST
STEP 1: Elicit prior understandings of lesson concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 2: Gain and sustain learners' attention.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 3: Tell learners the objectives.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 4: Stimulate recall of prerequisite learning.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 5: Explain content.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 6: Present authentic task.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 7: Form student groups.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 8: Model task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 9: Provide worked example.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 10: Ask learners to perform task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 11: Scaffold task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 12: Ask learners to perform task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 13: Scaffold task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 14: Ask learners additional questions to elaborate task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 15: Present authentic task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 16: Review activity concepts.	Durtion	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included

STEP 17: Explain content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 18: Ask learners to perform task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 19: Explain content.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included

STEP 20: Ask learners additional questions to elaborate task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
STEP 8: Review activity concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included
Comments:						

Teacher Implementation Fidelity: Laboratory activity sub-model

DATE: ______________________ **DAY:** __________ **ACTIVITY:** ______________________________

SEQUENCE:	Step1	Step2	Step3	Step4	Step5	Step6	Step7	Step8	Step9	Step10	Step11	Step12	Step13
	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

STEP		WORST ←				→ BEST
STEP 1: Elicit prior understandings of lesson concepts.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 2: Present authentic task.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
STEP 2: Present authentic task.	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 3: Form student groups.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**

	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 4: Model task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 5: Ask students to make predictions.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 6: Ask group members to collaborate on task.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 7: Have students make observations.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 8: Have students use evidence to form explanations.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**
STEP 9: Have students evaluate explanations and draw conclusions.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Completeness	**Many things omitted**	**Quite a few things omitted**	**About half omitted**	**A few things omitted**	**Everything included.**

STEP 10: Have students share and justify results.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 11: Address misconceptions.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
STEP 12: Ask learners to perform extension tasks.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.

STEP 13: Review activity concepts.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Completeness	Many things omitted	Quite a few things omitted	About half omitted	A few things omitted	Everything included.
Comments:						

Teacher Implementation Fidelity: Larger Instructional Model

DATE: ______________________ **DAY:** 1 **ACTIVITY:** Pretests and Introduction to Unit

SEQUENCE : Step 1.1 ☐ Step 1.2 ☐ Step 1.3 ☐ Step 1.5 ☐

STEP		WORST ←				→ BEST
STEP 1.1: Administer content knowledge pretest.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Comments:					
STEP 1.2: Administer attitude towards science and technology pretest.	Duration	Nowhere near enough time	More time was needed	Just barely enough time	Slightly less time than needed	Right amount of time
	Comments:					

STEP 1.3: Elicit and discuss prior understandings of unit concepts aloud.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments:					
STEP 1.5: Identify misconceptions from student responses.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments:					
Overall Comments:						

Teacher Implementation Fidelity: Larger Instructional Model DAILY CHECK

DATE: ______________________________ **DAY:** ___________ **ACTIVITY:** ____

SEQUENCE: Step 3.1 ☐ Step 3.2 ☐ Step 3.3 & Step 3.4 ☐ Step 3.5 ☐ Step 3.6 ☐

STEP		WORST ⟵				⟶ BEST
STEP 3.1: Ask questions aloud and respond to student answers.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments: (What T Qs about. Clarity of teacher responses.)					
STEP 3.2: Solicit and respond to student questions.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments: (What ST Qs about. Clarity of teacher responses.)					

STEP 3.3 Check students' worksheet responses aloud. ---and--- STEP 3.4 Provide feedback aloud.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments: (Nature and quality of feedback.)					
STEP 3.5: Ask students to reflect on topic. ☐ No reflection.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments: (Nature of ST Qs. How activity goes.)					

STEP 3.6: Adjust instruction to meet learners' needs.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments: (How different from other classes. Changes from model or sequence.)					
Overall Comments:						

Teacher Implementation Fidelity: Larger Instructional Model Final Assessment

DATE: ______________________ **DAY:** __________ **ACTIVITY:** ______________________________

SEQUENCE: Step 4.1 ☐ Step 4.2 ☐ Step 4.3 ☐ Step 4.4 ☐

STEP		WORST ⟷ BEST				
STEP 4.1: Assess culminating activity. (Student presentations)	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments:					
STEP 4.2: Assess concept map. (Students submissions)	**Comments**:					

STEPS 4.3 Administer [and analyze] content knowledge posttest.	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments:					
STEP 4.4 Administer [and analyze] attitude towards science and technology posttest	Duration	**Nowhere near enough time**	**More time was needed**	**Just barely enough time**	**Slightly less time than needed**	**Right amount of time**
	Comments:					
Overall Comments:						

Student Behaviors: Daily Check

DATE: ______________________________ **DAY:** ___________ **ACTIVITY:** ____

ISSUE	WORST ⟷ BEST				
	<25%	<50%	About Half	>50%	>75%
Comprehension (vocabulary/meaning)	Less than 25% of students appear to understand.	Less than half of students appear to understand.	About half of the class appears to understand/seem confused.	More than half of students appear to understand.	More than 75% of students appear to understand.
Student Questions	Less than 25% of students ask insightful questions. Almost all questions are mechanical or what-is-on-the-test questions.	Less than half of students ask insightful questions. Most ask mechanical questions.	Questions divided about equally between mechanical and insightful questions.	More than half of students ask insightful questions.	More than 75% of students ask insightful questions to extend the learning.
Student Answers **(Correctness)** (STs paying attention and understand content)	Less than 25% of the answers given are correct.	Less than half of the answers given are correct.	About half of the answers given are correct.	More than half of answers given are correct.	More than 75% of the answers given are correct.

Student Answers **(Thoughtfulness)** (STs going beyond simply getting it right. Critical thinking.)	Less than 25% of the answers given are thoughtful.	Less than half of the answers given are thoughtful.	About half of the answers given are thoughtful.	More than half of the answers given are thoughtful.	More than 75% of answers given are thoughtful.
On Task	Less than 25% of students doing activity and most all talking and wandering around.	Less than half of the students do activity. Many students talking and wandering.	About half of the class do activity and a half do not. Some talking and wandering around.	More than half of the students do activity. A little talking and/or wandering around.	More than 75% of students do the activity. Very quiet room, very little wandering around.
Task Completion	Less than 25% of students complete task in allotted time.	Less than half of students complete task in allotted time.	About half of the class completes task in allotted time.	More than half of student complete task in time allotted.	More than 75% of students complete in allotted time.
Teamwork ☐ No teamwork used.	Less than 25% of teams are sharing and discussing the activity.	Less than half of teams are sharing and discussing the activity.	About half of teams are sharing and discussing the activity.	More than half of teams are sharing and discussing the activity.	More than 75% of teams are sharing and discussing the activity.
Team Presentation **(Clarity)** ☐ No teamwork used.	Less than 25% of teams present clearly.	Less than half of teams present clearly.	About half of teams present clearly.	More than half of teams present clearly.	More than 75% of teams present clearly.

Team Presentation **(Justification)** (Quality of justification) ☐ No teamwork used.	**Less than 25% of teams justify results.**	**Less than half of teams justify results.**	**About half of teams justify results.**	**More than half of teams justify results.**	**More than 75% of teams justify their results.**
Independence	**More than 75% of the time, students unable to work alone Or more than 75% of students unable to work alone.**	**Less than half of the time students are able to work independently. Or more than half of students require teacher intervention.**	**About half the time students are able to work without teacher intervention. Or about half the students able to work independently.**	**More than half of the time students able to work independently. Or more than half of students able to work without teacher intervention.**	**More than 75% of the time students working without intervention from teacher. Or more than 75% of the students without intervention.**
Comments:					

Appendix D

Daily Reflective Meeting with Teacher

DATE: ____________ **TIME:** ________ **DAY:** ______ **ACTIVITY:** ________________________

	Extremely badly	Somewhat badly	About average	Very well	Extremely well
How well did the lesson go today OVERALL?					
What went best?					
What went worst?					
How well do you think materials MATCHED STUDENT NEEDS today?					
Comments: (Details of issues + improvements)					
How well do you think materials MATCHED YOUR NEEDS today?					
Comments: (Details of issues + improvements)					
How well do you think students UNDERSTOOD VOCABULARY AND MEANING today?					
Comments:					

(Details of issues + improvements)						
How would you rate the THOUGHTFULNESS OF STUDENT QUESTIONS today?						
Comments: (Details of issues + improvements)						
How well do you feel students STAYED ON TASK today?						
Comments: (Details of issues + improvements)						
How well did the TIME ALLOTTED FOR A TASK match how long it took to complete that task?						
Comments: (Details of issues + improvements)						
How well do you think TEAMS WORKED TOGETHER today?						
Comments: ☐ No teamwork used. (Details of issues + improvements)						
How good did you feel TEAM PRESENTATIONS were today?						
Comments: ☐ No team presentations used.						

(Details of issues + improvements)					
How INDEPENDENTLY did you feel the students worked today?					
Comments: (Details of issues + improvements)					
QUESTIONS ABOUT OMITTED MODEL STEPS OR CHANGES IN SEQUENCE:					
I noticed you skipped Step ____ today? Can you tell me why? ☐ No steps skipped.					
I noticed you skipped Step ____ today? Can you tell me why?					
I noticed you skipped Step ____ today? Can you tell me why?					
I noticed you skipped Step ____ today? Can you tell me why?					
I noticed that you CHANGED SEQUENCE today. Can you tell me why? ☐ Sequence not changed.					
Dr. Bodzin's Larger View Questions: ☐ Dr. Bodzin did not attend.					
Overall Comments:					

Appendix F

Appendix E

Daily Journal

DATE: ________________ **DAY:** _________ **ACTIVITY:** ______________________________

		Extremely badly	Somewhat badly	About average	Very well	Extremely well
How well did the students do today OVERALL?						
What went well?						
What went worst?						
What did I hear that was particularly illuminating?						
How well did the teacher follow the model today OVERALL?						
What went well?						
What went worst?						
What did the teacher do that was particularly illuminating?						
How well did the design work today OVERALL?						
What were the strengths of the design?						
What were the weaknesses of the design?						

What did I like?	
What did I dislike?	
To what extent did I participate?	

How well did the science instruction go today OVERALL?					
How well did students learn science?					
How well did students do the GIS activity? ☐ No GIS activity.					
How well did students do the computer-supported activity? ☐ No computer-supported activity.					
How well did students do the laboratory activity? ☐ No laboratory activity.					

What is the cumulative effect of the unit on the teacher and students?
Overall Comments:
How did I feel today (for example, happy, nervous, rushed, confused, concerned, bored, satisfied, disappointed, etc.) and **why**?

Violet Kulo

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Research Interests

- Designing effective instruction with a focus on providing adequate scaffolding for both learners and teachers.
- Integrating innovative technologies in learning environments.
- Enhancing fidelity of implementation of innovative curricular.

Educational Background

2011	Ed.D., Lehigh University Educational Technology
2004	M.S., Lehigh University Instructional Design and Development
1999	B.Ed., Moi University, Kenya Mathematics and Economics

Professional Experience

2008-2011 — **Research Assistant,** Lehigh University

Web-enhanced Environmental Literacy and Inquiry Modules (WELIM) for Middle School Learners (Dr. Alec Bodzin, Principal Investigator)

The goal of this project is to create, implement, and evaluate innovative interdisciplinary environmental science instruction using geospatial technologies and the Web.

- Design and develop instruction.
- Conduct implementation studies in eighth grade classrooms.
- Provide professional development for classroom teachers.
- Conduct classroom observations and analyze data.
- Disseminate research findings at conferences and in publications.
  - See http://www.ei.lehigh.edu/eli/energy for publications and presentations.

2004, 2006-2011 — **Graduate Assistant,** Lehigh University

- Support faculty and students with the use of Web and instructional technology applications.

- Create both print and Web-based documentation for using various instructional technology applications.
- Scan and upload course materials to the learning management system.
- Maintain the department's resources Web site.
- Install and update software on the desktops and laptops.

2010, 2009 — **Teaching Assistant**, Lehigh University
Course: Website and Resource Development for Learning
- Moderated on-campus Web conferencing sessions when instructor was in remote locations.
- Taught sessions on creating and editing video projects and assisted students with their class projects.

2009 — **Guest Instructor**, Lehigh University
Course: Curricular Design and Innovation
Course: Secondary Science Methods
- Taught graduate-level course sessions on designing and developing instruction supported by geospatial technologies.

2004 — **Intern**, Northampton Community College
- Reviewed distance-learning courses from an instructional technology, quality-assurance perspective.
- Made and documented recommendations on revitalizing the courses.
- Implemented approved recommendations.

2001-2002 — **Teacher,** Makini Academy, Nairobi, Kenya
- Taught mathematics, business education, commerce, and economics in 9th to 11th grades and in 1st year International Baccalaureate (IB). Makini Academy is an urban private high school with inclusive classrooms.

1999-2000 — **Teacher,** Makini School, Nairobi, Kenya
- Taught mathematics and business education in 6th to 8th grades. Makini School is an urban private primary school with inclusive classrooms.

Publications in Referred Journals

Kulo, **V.,** & Bodzin, A. (in press). Integrating geospatial technologies in an energy unit. *Journal of Geography.*

Cates, W. M., & **Kulo, V**. (2009). Avoiding the perils of "teacher-proof" online design: A content analysis. *Computers in the Schools, 26,* 48-62.

Publications in Peer-reviewed Books

Bodzin, A., Anastasio, D., & **Kulo, V.** (in press). Designing Google Earth activities for learning Earth and Environmental Science. In J. MaKinster, N. Trautmann, & M. Barnett (Eds.), *Teaching Science and Investigating Environmental Issues with Geospatial Technology: Designing Effective Professional Development for Teachers*. Dordrecht, Netherlands: Springer.

Hobson, D., & **Kulo, V.** (2009). As the world spins, technology spins faster: A global long distance education program. In C. Maddux (Ed.), *Research Highlights in Technology and Teacher Education 2009* (pp. 109-116). Chesapeake, VA: Society for Information Technology and Teacher Education.

Manuscripts in Editorial Review

Kulo, V., Bodzin, A., McKeon, R., Anastasio, D., Peffer, T., & Sahagian, D. (in review). The Isle of Navitas: Towards a better understanding of energy and decision-making using GIS. In M. Barnett & J. MaKinster, (Eds.), *Learning Science through the innovative use of geospatial technologies: Designing effective learning tools and programs for K-16 settings.*

Kulo, V., Bodzin, A., McKeon, R., Anastasio, D., Peffer, T., & Sahagian, D. (in review). The Isle of Navitas: Planning for energy use with GIS. *Science Scope.*

Peffer, T., Bodzin, A., **Kulo, V.,** Cirucci, L., Anastasio, D., & Sahagian, D. (in review). Personal energy audit: Building awareness, taking action. *Science Scope.*

Manuscripts in Preparation

Kulo, **V.,** & Cates, W. M. (in preparation). Measuring implementation fidelity for newer instructional models: A conceptual framework.

Kulo, V., & Bodzin, A. (in preparation). Integrating geospatial technologies in an inquiry energy unit with urban middle schools.

Bodzin, A., **Kulo, V.,** & Peffer, T. (in preparation). Educative curriculum materials as science teacher professional development for environmental curriculum adoption.

Instructional Website Project

Energy. (2010). http://www.ei.lehigh.edu/eli/energy/. **Kulo. V.,** Bodzin, A., Anastasio, D., Sahagian, D., Cirucci, L., Peffer, T., Turner, L., Maderas, R., McKeon, R., Dempsey, C., Bressler, D., & Bennet, M.
Role: I am the instructional designer and lead content developer.
External validation: National Science Digital Library (NSDL), Digital Library for Earth System Science (DLESE), National Science Teachers Association (NSTA) SciLinks, Pennsylvania Department of Education.

Published Conference Proceedings

Kulo, V., Cates, W. M., & Bodzin, A. (2009). Designing for geospatial information technologies. *Proceedings of the 2009 national convention of the Association for Educational Communications and Technology: Vol. 1: Selected research and development papers, 32,* 291-300.

Hobson, D., & **Kulo, V.** (2009). As the world spins, technology spins faster: A global long distance education program. In I. Gibson et al. (Eds.), *Proceedings of the Society for Information Technology & Teacher Education International Conference 2009* (1872-1879). Chesapeake, VA: AACE.

Hobson, D., & **Kulo, V.** (2008). As the world spins, technology spins faster: A global long distance education program. *E-Learn 2008 Proceedings: World Conference on E-Learning in Corporate, Government, Healthcare, & Higher Education* (367-372). Chesapeake, VA: AACE.

Kulo, V., & Cates, W. M. (2006). Perils of "teacher-proof" online design: Study findings from science Web-based inquiry activities. *Proceedings of the 2006 national convention of the Association for Educational Communications and Technology: Vol. 1: Selected research and development papers, 29,* 194-203.

Presentations at International and National Conventions

Kulo, V., & Cates, W. M. (2011, November). *Measuring implementation fidelity for newer instructional models: A conceptual framework.* Paper to be presented at the annual convention of the Association for Educational Communications and Technology, Jacksonville, FL.

Kulo, V., Bodzin, A., Cirucci, L., Anastasio, D., Sahagian, D., & Peffer, T. (2011, June). *Integrating geospatial technologies with inquiry-based learning to investigate energy.* Paper to be presented at the annual convention of the International Society for Technology in Education, Philadelphia, PA.

Bodzin, A., **Kulo, V.,** Peffer, T., Cirucci, L., Anastasio, D., & Sahagian, D. (2011, June). *Teaching "spatially" with geospatial learning technologies to investigate environmental*

issues. Paper to be presented at the annual convention of the International Society for Technology in Education, Philadelphia, PA.

Kulo, V., & Bodzin, A. (2011, April). *Integrating geospatial technologies in an inquiry energy unit with urban middle schools.* Paper presented at the annual convention of the National Association for Research in Science Teaching, Orlando, FL.

Bodzin, A., **Kulo, V.,** & Peffer, T. (2011, January). *Educative curriculum materials as science teacher professional development for environmental curriculum adoption.* Paper presented at the annual convention of the Association for Science Teacher Education, Minneapolis, MN.

Kulo, V., & Cates, W. M. (2010, October). *Geospatial information technologies in support of science inquiry: Implementation study findings.* Presentation at the annual convention of the Association for Educational Communications and Technology, Anaheim, CA.

Peffer, T., Bodzin, A., **Kulo, V.,** McKeon R., Anastasio, D., & Sahagian, D. (2010, September). *Innovative investigations of energy issues with instructional and geospatial technologies.* Presentation at the annual convention of the North American Association for Environmental Education, Buffalo, NY.

Peffer, T., Bodzin, A., **Kulo, V.,** Sahagian, D., & Anastasio, D. (2010, September). *The personal energy audit: Examine, analyze, and reduce your energy use.* Presentation at the annual convention of the North American Association for Environmental Education, Buffalo, NY.

Kulo, V., Bodzin, A., Anastasio, D., Peffer, T., Sahagian, D., & Cirucci, L. (2010, March). *Examining the implementation of a geospatial information technologies-supported energy unit in an urban middle school.* Presentation at the annual convention of the National Association for Research in Science Teaching, Philadelphia, PA.

Peffer, T., Bodzin, A., & **Kulo, V.** (2010, March). *Design, implementation, and assessment of a geospatial science-technological pedagogical content knowledge professional development model.* Interactive poster presentation at the annual convention of the National Association for Research in Science Teaching, Philadelphia, PA.

Kulo, V., Bodzin, A., Anastasio, D., Cirruci, L. Sahagian, D., & Peffer, T. (2010, March). *Using Google Earth to investigate energy resources.* Presentation at the annual convention of the National Science Teachers Association, Philadelphia, PA.

Peffer, T., Bodzin, A., **Kulo, V.,** Sahagian, D., Anastasio, D., & Cirruci, L. (2010, March). *The personal energy audit activity: Analyzing personal energy use, resource availability, and conservation practices.* Presentation at the annual convention of the National Science Teachers Association, Philadelphia, PA.

Peffer, T., Bodzin, A., **Kulo, V.,** & Cirruci, L. (2010, January). The Environmental Literacy and Inquiry (ELI) professional development model: Enhancing the teaching and learning of energy with technology-integrated professional development. Poster presentation at the annual convention of the Association for Science Teacher Education, Sacramento, CA.

McKeon, R., **Kulo, V.,** Anastasio, D., Bodzin, A., Peffer, T. & Sahagian, D. (2009, October). *The Isle of Navitas: Towards a better understanding of energy and decision-making using GIS.* Poster presentation at the annual convention of the Geological Society of America, Portland, OR.

Kulo, V., Bodzin, A., Peffer, T., Anastasio, D., & Sahagian, D. (2009, June). *Using GIS in the classroom to investigate energy.* Presentation at the annual convention of the National Educational Computing Conference, Washington, DC.

Hobson, D., & **Kulo, V.** (2009, March). *Teachers or technology: Who is fueling the future?* Paper presented at the annual convention of the Comparative and International Education Society, Charleston, SC.

Kulo, V. (2006, June). *Strategic operations of professional organizations: The Association for Educational Communications & Technology.* Paper presented at the annual meeting of the Board of Directors of the Association for Educational Communications and Technology, Bloomington, IN.

Presentations at Regional Conventions

Bodzin, A., Peffer, T., & **Kulo, V.** (2009, October). *The role of educative curriculum materials in science teacher professional development.* Paper presented at the annual convention of the Association for Science Teacher Education Northeast Region, Dingman's Ferry, PA.

Professional Development Inservice Sessions

October 11, 2010 — Bodzin, A., Peffer, T., Cirucci, L., & **Kulo, V.** *Renewable energy resources laboratories.* A 1-day professional development institute presented to 16 Lehigh Valley middle school science teachers and science supervisors.

September 28, 2010 — **Kulo, V.,** Bodzin, A., Cirucci, L., & Peffer, T. *The Isle of Navitas: Towards a better understanding of energy and decision-making using GIS.* A 1/2-day professional development institute presented to 18 Lehigh Valley middle school science teachers, science supervisors, and technology integration specialists.

September 21, 2010 — **Kulo, V.,** Bodzin, A., Cirucci, L., & Peffer, T. *Investigating geothermal and fossil fuel energy with geospatial technologies.* A 1/2-day professional development institute presented to 18 Lehigh

Valley middle school science teachers, science supervisors, and technology integration specialists.

September 15, 2010	**Kulo, V.,** Bodzin, A., Cirucci, L., & Peffer, T. *Investigating wind, hydroelectric, and tidal energy with geospatial technologies.* A 1/2-day professional development institute presented to 18 Lehigh Valley middle school science teachers, science supervisors, and technology integration specialists.
September 07, 2010	**Kulo, V.,** Bodzin, A., Cirucci, L., & Peffer, T. *Exploring solar energy with geospatial technologies.* A 1/2-day professional development institute presented to 18 Lehigh Valley middle school science teachers, science supervisors, and technology integration specialists.
October 12, 2009	**Kulo, V.,** Bodzin, A., Cirucci, L., & Peffer, T. *The Isle of Navitas: Towards a better understanding of energy and decision-making using GIS.* A 1-day professional development institute presented to 5 middle school science teachers.
September 17, 2009	**Kulo, V.,** Bodzin, A., Cirucci, L., & Peffer, T. *Investigating energy resources with geospatial technologies.* A 1-day professional development institute presented to 3 middle school science teachers.
July 21-23, 2009	**Kulo, V.,** Bodzin, A., Cirucci, L., & Peffer, T. *Investigating energy resources with geospatial technologies.* A 3-day professional development institute presented to 5 middle school science teachers.

Awards and Honors

2010	Featured in the 2009-2010 *Lehigh Research News* Website and magazine for outstanding research, Lehigh University
2010, 2009, 2006	College of Education Student Travel Grant Award, Lehigh University
2010	Graduate Student Senate Travel Grant Award, Lehigh University
2009	Phi Beta Delta International Scholar Award
2007	Recognized for outstanding research and scholarship for the College of Education Student Research Exhibition, Lehigh University

2005, 2004	Thomas/Brucker Endowed Minority Doctoral Scholarship, Lehigh University
2001	Certificate of Merit in recognition of outstanding performance in mathematics in the 2000 national examinations, Makini School
2000	Certificate of Merit in recognition of exemplary service and positive contribution towards the schools excellent 1999 national examination results, Makini School

Professional Activities and Service

2010	**Participant**, University-wide Teacher Development Program, Lehigh University
2008-2009	**Tutor/Mentor**, Launch-IT Program, Lehigh University Launch-IT is a program sponsored by the National Science Foundation (NSF) and the Pennsylvania Infrastructure Technology Alliance (PITA) designed to launch at-risk Lehigh Valley students toward college and careers in Information Technology. I tutored and mentored students in 10^{th}-12^{th} grades.
2006-2008	**Unit Representative,** Graduate Student Senate, Lehigh University
2007-2008	**Volunteer**, Broughal Middle School Assisted 7^{th} grade science students to collect data around the school and local community using hand-held GPS.
2006-2007	**Member,** Teaching, Learning, and Technology Faculty Search Committee, Lehigh University
2005-2007	**Member,** Student Life Enhancement Committee, Lehigh University
2005-2007	**Member,** College of Education Diversity Committee, Lehigh University

Professional Affiliations and Academic Honoraries

Association for Educational Communications and Technology (AECT)

International Society of Technology in Education (ISTE)

Phi Beta Delta, Beta Pi Chapter

- Student vice president