MODELING INSTRUCTION AND THE NATURE OF SCIENCE

by

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Abstract of Thesis

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Curriculum and Instruction

Modeling Instruction and the Nature of Science

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High school students hold naïve conceptions about the nature of science (NOS), believing that scientific knowledge is absolute, that science is an objective activity without bias, creativity, or imagination, and that theories evolve into laws. The way in which science is taught in schools validates student misconceptions of the nature of science. Modeling instruction in physics is a teaching pedagogy, with Malcolm Wells and Dr. David Hestenes the primary developers, that holds promise for conveying the tentative and empirical nature of scientific knowledge, the creativity and imagination that is required to create scientific knowledge, and the theory-laden nature of scientific knowledge. Research reports the necessity of explicitly referencing NOS themes within the classroom to improve student understanding of these themes.

This investigation reports a quasi-experimental year-long study involving 65 students enrolled in a midwestern suburban high school. All students received modeling instruction, but one group additionally received instruction using explicit reference to NOS themes within the context of the classroom laboratory experience and reflected on NOS themes while writing journals. The Views of Nature of Science-Form C (VNOS-C) measured student understanding in NOS using a pretest-posttest format. The Force Concept Inventory (FCI) assessed whether the NOS interventions adversely affected physics content knowledge of students in the treatment group.

Students in the treatment group scored significantly greater on the VNOS-C ($p < 0.05$) than students in the comparison group. Students who receive explicit instruction in NOS themes are better able to articulate an understanding of NOS themes that is consistent with reform documents published by the American Association for the

Advancement of Science and the National Research Council. Additionally, FCI results show that students who receive NOS interventions at the expense of additional content experience no deficit in their achievement of physics content knowledge, at least in the area of Newtonian mechanics.

Modeling instruction provides a curricular structure that teaches physics students first-year concepts in Newtonian Mechanics. Teachers can enhance the modeling program to explicitly and purposefully target NOS themes within the laboratory context of the course, significantly improving student understanding of NOS without compromising student understanding of the physics content in mechanics.

Chapter 1

Introduction

National and state institutions (American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996; North Carolina Department of Public Instruction, 2003; State of Wisconsin Department of Public Instruction, 2004) have called upon schools to address student understanding of the nature of science (NOS) to produce a more literate public. The American Association for the Advancement of Science (1989) states, "Scientific habits of mind can help people in every walk of life to deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty . . . " (p. 13). Science anecdotes and dramatizations (Abd-El-Khalick & Lederman, 2000; Allchin, 2003; Feldman, 2003; Irwin, 2000; Tao, 2003), inquiry-instruction (Gess-Newsome, 2002; Khishfe & Abd-El-Khalick, 2002; Kurdziel & Libarkin, 2002; Smith, 2000; Spears & Zollman, 1977), authentic environments (Bell et al., 2003; Hogan, 2000; Matkins et al., 2002; Schwartz et al., 2004), and explicit instruction and reflection (Abd-El-Khalick & Lederman, 2000; Feldman, 2003; Gess-Newsome, 2002; Khishfe & Abd-El-Khalick, 2002; Kurdziel & Libarkin, 2002; Matkins et al., 2002; Schwartz et al., 2004; Schwartz et al., 2002) are various teaching interventions that may address the complex task of helping students understand the nature of science.

In order for students to learn and internalize the nature of science, a more authentic approach toward school science is necessary. The American Association for the Advancement of Science (1989) notes, "There is too much scientific content and too little scientific literacy in classrooms. Text and methods of instruction value learning of answers over exploration of questions, memory over critical thought, recitation over argument, reading over doing" (p. 14). One approach that attempts to address the shortcomings of school science is modeling instruction. Modeling instruction (Wells et al., 1995) is a method of teaching physics that allows students to experience authentically the scientific endeavor. Wells, a teacher, approached his advisor, David Hestenes, hoping to do a doctoral dissertation on establishing sound principles for using computers in high school physics. Hestenes had just completed his modeling theory of instruction, a pedagogy based on modeling as the central activity of physical scientists, and was working with a graduate student on a precursor version of the Force Concept Inventory (Hestenes et al., 1992). After administering the Force Concept Inventory to his high school students, Wells became disillusioned with their understanding of physics and determined that his teaching methodology was at fault. Expanding Karplus' (1977) learning cycle into a modeling cycle, Wells incorporated the computer into the classroom as a scientific tool to help students understand physics. Students, through an investigative context, *invent* basic kinematic and dynamic models, including: constant velocity, constant acceleration, equilibrium, constant net force, and energy (Wells et al., 1995). Students use graphs, mathematical models, motion maps, system schema, and energy bar graphs to represent these models. Students use empirical observation as a basis to derive and validate all models, and the locus of authority becomes how *students interpret* nature rather than what the *teacher says about* nature.

Such a learning atmosphere provides a context that allows students to experience the tentative, subjective, and uncertain nature of scientific knowledge (see Table 1 of Schwartz et al., 2004, p. 613). Gilbert (1991) suggests that science should be redefined in the context of models, saying that “Science is a process of constructing predictive conceptual models. This definition unites both processes and product of science, and identifies model building as a superordinate process skill” (p. 73). Gilbert’s results indicate that while students understand that models contain errors and are human constructs that give an artificial representation of nature, students do not hold the same beliefs about scientific knowledge. By redefining science in the context of models, Gilbert argues that students may better understand the nature of scientific knowledge. The Wells, Hestenes, and Swackhamer (1995) modeling methodology approaches school science in this context.

Research Problem and Purpose

While modeling instruction provides a learning environment that is based on authentic scientific discovery and peer collaboration, it does not explicitly ask students to reflect on the epistemology of science. Furthermore, students are not necessarily equipped to spontaneously synthesize their experiences into an articulate picture of the nature of science (Lederman, 1999; Lederman et al., 2002; Schwartz & Lederman, 2002). Modeling instruction lacks explicit references to NOS themes that are illustrated by the authentic scientific activities conducted within the classroom. The purpose of this study is to test the viability of incorporating explicit references to NOS themes within the modeling program context.

Research Hypothesis

How do student improvements in understanding the nature of science vary with the type of physics instruction at the high school level? The research hypothesis asserts that students who receive modeling instruction with explicit references to NOS themes will articulate a stronger understanding of these themes when compared to students who receive modeling instruction without explicit references to NOS themes.

Study Design

This investigation reports a year-long study of a treatment group of high school students who received modeling instruction that made explicit references to NOS themes through the use of student reflection journals and through discussion of NOS themes in the context of the modeling curriculum. A comparison group of students received the standard modeling curriculum without the reflection journals and contextual references to NOS themes. All students were enrolled in either general physics or honors physics. Both groups were given the Views of Nature of Science-Form C (VNOS-C) survey (Lederman et al., 2002) as a pretest and posttest. I used student interviews to create a survey scoring rubric that reflected appropriate NOS understanding and scored responses on the survey to determine each experimental groups' understanding of the targeted NOS themes. I administered the Force Concept Inventory (FCI) as a pretest and posttest to determine whether explicit instruction and reference to NOS jeopardized achievement of physics content knowledge.

Summary

Various teaching strategies purport to create a more scientifically literate student populace. Modeling instruction in physics is a teaching pedagogy in which students use laboratory experience to invent models to understand physics concepts. Modeling instruction is aptly suited to explicitly reference NOS themes in the context of the laboratory experience.

Chapter 2

Review of Research

Nature of Science

Thomas Kuhn (1970) delineated the need for a change in how scientists view their philosophy of science. He defined *normal science* as science that falls under an accepted and long-lasting paradigm. This type of science, Kuhn argues, pursues three classes of problems—“determination of significant fact, matching of facts with theory, and articulation of theory” (Kuhn, 1970, p. 34)—the very type of science taught in schools. *School science* ignores *revolutionary science*, science that is in crisis due to an increasing number of unresolved anomalies. Kuhn further argues that crises create an atmosphere where scientific knowledge and thought become highly suspect, in turn creating a scientific revolution and possibly evoking a new paradigm.

Good (2000) and Bauer (1992) likewise classify science into two realms: *early-stage science* that requires creative thinking, and normal science that tests currently accepted knowledge. They suggest that school science addresses only the testing and retesting of current knowledge—where scientific knowledge is reliable and resilient—at the exclusion of early-stage science, where the answers are unknown and the knowledge is unreliable. Students, they argue, learn to attribute reliability and resiliency to *all* science, creating a public that is ill-prepared to understand and effectively use science.

Researchers (Lederman et al., 2002; Moss et al., 2001; Schwartz & Lederman, 2002; Smith & Scharmann, 1999) have tried to create comprehensive indicators of the nature of science. Although the indicators differ in detail, they do contain common themes, including the following concepts: scientific knowledge is tentative, fallible, and approximate; scientific knowledge requires repeatable observation to be valid; science is subjective due to personal and cultural bias and creativity; science is subjective due to its theory-laden nature. National and state organizations (American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996; North Carolina State Department of Public Instruction, 2003; State of Wisconsin Department of Public Instruction, 2004) have created variations of these themes in their call to guide curricula in public schools.

Student Conceptions of Nature of Science

Students with years of formal science education continue to have strong misconceptions regarding NOS. Mackay (1971), in her analysis of results from the Test on Understanding Science (TOUS), finds several deficiencies among Australian students' perceptions of science. Students are deficient in their understanding that science is creative, the scientific process is ongoing and cannot represent absolute truth, past findings have contributed to our current scientific knowledge, and theories play an integral role in how science is done. More recent studies confirm these findings. Smith (2000) studied middle school students and found that they assume scientific knowledge to be factual and certain, assert their beliefs based on authoritative justification rather than on argument or relevant evidence, and believe all differences of opinion in the scientific community stem from inadequate knowledge rather than from the differing personal perspectives of scientists. Many students also subscribe to the belief that there is one single "scientific method" (Griffiths & Barman, 1995; Lederman et al., 2002).

Students also have an idealized image of the nature of evidence, laws, and theories. Studies (Dagher et al., 2004; Lederman et al., 2002) show that students use the word *proof* to describe the underlying nature of scientific evidence, sometimes using proof to indicate an absolute answer, and other times to describe directly-observed evidence. Bell, Blair, Crawford, and Lederman (2003) and Dawkins and Dickerson (2003) found that secondary students rank scientific knowledge in a hierarchy. Students believe that scientific knowledge starts as a hypothesis, then becomes a theory, and after much testing becomes a law. Additionally, students believe that scientists *discover* knowledge to describe phenomena rather than *invent* knowledge (Dawkins & Dickerson, 2003; Mackay, 1971).

Halloun and Hestenes (1998) interviewed high school students about their replies to the Views About Science Survey (VASS). The following student quotations illustrate how students often view scientists as completely objective individuals who use no creativity in their work and who believe that scientific knowledge is absolute truth:

> “I would imagine that physicists rely too heavily on instruments and don’t use their creativity” (p. 561).
>
> “Physicists are completely logical people and cannot accept things that cannot be physically proven” (p. 561).
>
> “ . . . a set of ideas that are kind of like accepted as fact and kind of like taboo. It’s like taboo to go against. They would be accepted over evidence in the real world” (p. 565).

Student misunderstanding of NOS is an international issue. In one multinational study, Tamir (1994) administered the Science Understanding Measure (SUM) to a large sample of students from 25 different countries and showed that secondary students believe scientific theories and scientific models to be absolute and unchanging. Griffiths and Barman (1995) looked at a sample of 32 students drawn from each of three countries: the United States, Canada, and Australia. The researchers found that while the American and Australian students who were studied believed science to be constantly changing, the students attributed this change to better technology rather than to changes in thought. The researchers found that the Canadian students were better able to verbalize the revolutionary nature of science and posit that this effect may have been due to a greater push by the Science Council of Canada for NOS learning in the national curriculum.

Classroom Implications

History of science stories and science anecdotes. As Kuhn (1970) points out, history of science is replete with anecdotes that illustrate the various themes of NOS. Ideally, he proposes, any scientific discovery can be recounted, including all of the errors, myths, and superstitions that contributed to the advance or delay of the discovery. The American Association for the Advancement of Science (1993) agrees with Kuhn's conclusion:

> History provides another avenue to the understanding of how science works . . . it is equally important that students should come to realize that much of the growth of science and technology has resulted from the gradual accumulation of knowledge over many centuries. (p. 4)

Abd-El-Khalick and Lederman (2000) studied the impact of college history of science courses on students' understanding of eight identified NOS themes. Through questionnaires and interviews, the researchers discovered that while students who had the strongest initial understanding of NOS themes illustrated somewhat improved views at the end of the course, most students exhibited little increase in their understanding of NOS.

Kuhn (1970) suggests that rather than learning a simple historical account of a specific scientific discovery, students need to experience the anecdote from within the social context of the time, shifting the focus from a narrative sequence of events to an anecdote that contrasts opposing ideas. Further, he recognizes that the sociocultural environment cultivates paradigms, defining the types of questions that scientists ask and the critical aspects of the subsequent investigations. Abd-El-Khalick and Lederman (2000) hypothesize that one reason history of science courses fail to invoke progress in understanding NOS themes is that students are unable to remove themselves from their current reality to study from a strict historical perspective.

Another study, focusing specifically on atomic theory (Irwin, 2000), considered how a historical approach would affect ninth-grade students' understanding of the creativity of science. The instructor taught the atomic unit to one group of students using a historical perspective and to another group of students using only the final contemporary perspective. A pretest-posttest analysis showed that students in the historical group exhibited no better understanding that atomic structure is inferred from empirical results than did the comparison group. At the same time, Irwin found the treatment group showed no deficiency in content knowledge relative to the comparison group.

Tao (2003) notes that while secondary students who received science instruction with anecdotes and stories of scientific discovery that may have confirmed and reinforced adequate views about NOS, more often the students changed from more adequate views to more inadequate views. Allchin (2003) suggests that scientific anecdotes serve to mislead students about the epistemological foundations of science. By their very nature, he argues, stories about science contain superhuman elements; they monumentalize science, setting unrealistic expectations of the endeavor. They also idealize science, understating the uncertainty of the endeavor, and dramatize science, persuading the audience to a certain point of view. These elements create within students the impression that science unfolds via a special method, that well-designed experiments forestall mistakes, that interpreting evidence yields *yes* or *no* answers, and that science is truth, without uncertainty or error. The American Association for the Advancement of Science (1993) offers a cautionary note about such anecdotes, saying:

> . . . not all of the historical emphasis should be placed on the lives of great scientists, those relatively few figures who, owing to genius and opportunity and good fortune, are best known. Students should learn that all sorts of people . . . have done and continue to do science. (p. 4)

Constructivism and inquiry: Science as a social process. According to Smith and Scharmann (1999), NOS should be embedded within the school science curriculum. Hogan (2000) found that proximal knowledge, or how students gain knowledge in school science, significantly influences students' understanding of distal knowledge, or how scientists do things. Constructivist classrooms, researchers claim, support authentic inquiry where students design their own experiments, generate their own problems, collaborate with peers, and use multiple representations to learn concepts. Such classroom structures allow students to develop and revise their scientific knowledge based on empirical evidence. This atmosphere is in stark contrast to the "rhetoric of conclusions," "stockpiling of facts" (Smith, 2000), and the annual indoctrination of the "scientific method" that is found in the conventional science classroom.

Smith (2000) studied two sixth-grade classes, one taught using a constructivist approach and the other taught using a textbook and lecture approach. Based on results from the Nature of Science Survey, the researcher found that the students in the constructivist classroom showed significantly greater understanding that scientific beliefs, rather than being right or wrong, needed to be evaluated by a complex set of criteria. The constructivist students, he concludes, were better able to delineate the nature and purpose of scientific experiments. These students also mentioned more often that social interaction is a key component of conducting science than did the students in the comparison classroom. Smith (2000) notes that the constructivist classroom was designed to include substantial group work and provided many opportunities for an exchange of views and the development of shared norms.

However, Spears and Zollman (1977) conclude that different types of inquiry-based lab instruction, both structured and unstructured, don't play a significant role in students' understanding of the scientific process. Paradoxically, students in the structured lab group showed slightly greater understanding of scientific activities when compared to students in the unstructured lab group. The researchers postulate that students who are operating concretely cannot spontaneously structure their labs using a process that requires formal thinking. Spears and Zollman further postulate that students in the structured lab group were able to complete the lab, thereby gaining greater insight into the activities of scientists, whereas the students in the unstructured group never may have been able to get past the design stage.

A*uthentic environment.* Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) illustrate that many college students, including preservice science teachers, have difficulty synthesizing their laboratory experiences into a coherent picture of the nature of science. In fact, the American Association for the Advancement of Science (1993) notes that "Acquiring scientific knowledge about how the world works does not necessarily lead to an understanding of how science itself works. . . . The challenge for educators is to weave these different aspects of science together so that they reinforce one another" (p. 3).

Implicitly teaching NOS by debating current controversial scientific topics does little to increase student understanding of NOS. Matkins, Bell, Irving, and McNall (2002) studied elementary preservice teachers who learned about the controversial topics of global climate change and global warming. Matkins et al. found that implicit instruction of NOS in this authentic context was not sufficient to increase student understanding of NOS.

Implicitly teaching NOS using an authentic research experience also does little to increase student understanding of NOS. Moss, Abrams, and Robb (2001) studied junior and senior high school students who formed partnerships with research scientists as part of the students' environmental coursework. At the end of the experience, students still illustrated gaps in their understanding of the nature of the scientific enterprise. Bell et al. (2003) studied high-ability high school students who worked with science mentors while participating in an 8-week apprenticeship program. At the end of the experience, students concluded that laws are tested theories, laws are facts, and that scientists use creativity only when designing an experiment. Schwartz, Lederman, and Crawford (2004) placed preservice secondary science teachers into a 10-week science research internship course. Ironically, participants who had the greatest amount of research experience showed little or no gain in their understanding of NOS as well as a poor overall understanding of NOS themes.

Authentic environments may, however, produce measurable changes in at least one NOS theme. Khishfe and Abd-El-Khalick (2002) and Moss et al. (2001) found that students gained a better understanding of the nature of scientific knowledge, specifically that some knowledge is observational while other knowledge is inferential.

Explicit instruction and reflection. While implicit reference to NOS is not sufficient to gain understanding of NOS, explicit reference alone may not be sufficient either. Feldman (2003) had preservice science teachers discuss literature passages that illustrated NOS themes. He found little change in students' understanding of NOS; but, when explicit instruction was used in conjunction with another intervention, student gains in understanding of NOS improved. Kurdziel and Libarkin (2002) and Gess-Newsome (2002) found that college students showed gains in understanding NOS after receiving both inquiry-based study of science content knowledge and explicit instruction in NOS. The combination of authentic inquiry and explicit reflection on the epistemology of science provides students with greater gains in the inferential-observational theme as well as gains in additional aspects of NOS (Khishfe & Abd-El-Khalick, 2002).

Other interventions, when used with explicit teaching methods, also increase student performance in NOS. Students (Abd-El-Khalick & Lederman, 2000) enrolled in history of science classes where NOS themes were explicitly referenced moved their knowledge from a declarative view to a more operational view. Matkins et al. (2002) found that elementary preservice teachers who received explicit instruction in NOS while also learning about a controversial topic in science—global climate change and global warming—experienced gains in their understanding of NOS.

Reflective thinking can be a powerful instrument in helping students to understand not only the content of science, but also the epistemology of science. Halloun and Hestenes (1998) cite lack of reflective thinking as one reason that some students do poorly in physics. This shortcoming, they argue, is also related to how students view science. Halloun and Hestenes compared high-school and college students' gains on the Force Concept Inventory (FCI), a physics concepts test, with the same students' views concerning science as measured by the Views About Science Survey (VASS). Students whose views were most closely related to the views held by professional scientists were more academically successful in their physics courses and showed the greatest gains on the FCI. Halloun and Hestenes suggest that these students were able to independently resolve inconsistencies in their knowledge when faced with observations that contradicted their current knowledge; these students viewed their learning of scientific concepts as independent of authority and dependent upon laboratory investigation.

Conversely, Halloun and Hestenes (1998) showed that students whose views varied considerably from professional scientists showed the smallest gains on the FCI. The researchers suggest that these students viewed their learning as dependent on authority, and they also viewed the learning of science as a passive process. Halloun and Hestenes postulate that without reflection on how they acquired scientific knowledge, students were unable to view scientific knowledge as being a coherent and valid description of nature. Rather, students view scientific knowledge as a collection of unrelated facts. The following student quotations illustrate this finding:

"Just look at the wall, all the formulas" (p. 563).

"Physics is just too much. There are too many formulas" (p. 563).

Bell et al. (2003), while studying high-ability high school students who participated in an 8-week apprenticeship program, noted that the only student who exhibited a positive change in her understanding of NOS was a student who actively reflected on her field experience and tried to make an authentic link between NOS and her experience. Similarly, Schwartz et al. (2004), while studying preservice secondary science teachers enrolled in a science research internship course, found that participants who wrote journal entries reflecting on their research experience exhibited enhanced understanding or major changes in their understanding of NOS by the end of the course. Participants in this study identified the journaling process as the most important factor in guiding their understanding of NOS. The researchers note that while the research itself may not have been the cause of a significant change in understanding NOS, it did create an authentic atmosphere in which the reflection journals were written.

Purposeful intent. The process of reorganizing or replacing students' current incomplete knowledge structure is more than just thinking about discrepant events; it requires both personal reflection and social interaction (Qian & Alvermann, 2000). Scientists, for example, master ideas not explicitly taught to them using an informal socialization process. This socialization occurs within a scientific community whose common purpose is to recognize and resolve inconsistencies (Good, 2000).

Students, in general, do not spontaneously undergo the learning process described by Good (2000). To facilitate the learning process, Khishfe and Abd-Ed-Khalick (2002) propose that NOS themes be taught in the tradition of Karplus' (1977) learning cycle. They suggest that students need to overtly state their views of science, and then be given examples that serve to bring dissatisfaction with this view. The instructor then provides a new view which satisfies the current dilemma and is then applied to novel situations.

Schwartz et al. (2002) studied preservice teachers who were enrolled in Project ICAN (Inquiry, Context, and Nature of Science), a professional development program for secondary teachers. The purpose of this program is to use an explicit and reflective approach to learning nature of science themes in the context of scientific inquiry to entice teachers to incorporate NOS themes into their curricula. One year later, 11 of 13 teachers showed significant improvement illustrating NOS in their lesson plans. Students enrolled in the classes of these eleven teachers showed advances in their own understanding of NOS, particularly that science is subjective, science is empirical, science is tentative, and science is inferential.

Additionally, Schwartz et al. (2002) found that *only* students in courses where the teachers themselves had an understanding of NOS that was consistent with reform documents *and* where the teachers purposefully intended to teach the nature of science exhibited gains in their understanding of NOS. Lederman (1999) also found that NOS themes are not learned by osmosis, even by teachers who model NOS in their classroom practices; the teacher must purposefully intend to teach NOS concepts and build the curriculum around this intent.

Assessing NOS

Assessments of NOS are generally either forced-response or open-response. Lederman et al. (2002) suggest that forced-response assessments, while easy to score, assume that the test takers and the test creators agree on terms and concepts. Aikenhead (1973), in reference to the quantitative Test on Understanding Science (TOUS), questions the significance of a gain in a mean score. Lederman et al. and Qian and Alvermann (2000) assert that credible assessment of NOS necessitates data triangulation using both questionnaires and interviews.

Good, Cummins, and Lyon (1999) tested the reliability of the Ideas in Natural Science (INS) survey by giving the survey to college chemistry students and preservice science teachers. The forced-response assessment looked at students’ understanding of a variety of NOS themes including the tentativeness of scientific knowledge, the empirical nature of scientific knowledge, and the “scientific method.” Based on follow-up interviews, Good et al. found the survey to be invalid; students applied different meanings to certain words (such as *confident*, *assume*, and *reliable*) than those intended by the test creators.

Similarly, while field testing the Views of Nature of Science survey (VNOS-Form B) using semistructured interviews, researchers discovered that students often misunderstood the meaning of a word or a set of words (Lederman et al., 2002). The researchers noted that the words *prove* and *creative* held different meanings for the students than for the questioners. The word *science* itself is sometimes referred to as a process and other times referred to as content knowledge (Good, 2000).

Modeling Instruction

Theoretical underpinnings. Hestenes (1992) distinguishes between the *Conceptual World* and the *Physical World*. He argues that students cannot begin to understand Newtonian theory until they firmly understand the concepts of space, time, particles, mass, and force. All other concepts in Newtonian theory are explicitly defined in terms of these primary concepts. Hestenes further argues that the process by which students make sense of these concepts is through a constructivist epistemology where meaning is constructed and matched with experience. The constructivist approach contrasts with the positivist approach, which states that meaning is extracted solely from physical experience (Hestenes, 1992).

Students build meaning in the Conceptual World, Hestenes (1992) claims, by constructing models that represent phenomenon in the Physical World. Experiments provide the link between these two worlds. It is through the Conceptual World, Hestenes argues, that students cyclically interact with the Physical World. Experience provides the empirical observations that undergird the creation of models, and students deploy these models to explain and predict additional phenomenon and to generate additional empirical evidence (Hestenes, 1992).

Hestenes (1992) states that conventional lecture-lab physics instruction is inefficient because although students can state basic kinematic and dynamic concepts after such instruction, they can't apply these concepts correctly. Hestenes additionally states that the biggest reason for the failure of conventional instruction is that it doesn't address student misconceptions. The two main misconceptions that Hestenes identifies are the Impetus Principle, which states that force is an inherent property of objects, and the Dominance Principle, which states that a larger and more active object exerts greater force over a lesser one. In creating cognitive conflict, Hestenes argues that students can begin to address these two misconceptions and later create and adopt a more coherent explanation that fits with Newtonian mechanics. Hestenes further asserts that students must realize that understanding is a creative act and that in order to create models that represent the Physical World, students need to be adept at pattern recognition.

Application. Modeling instruction (Wells et al., 1995) teaches students new concepts using a variation of Karplus' (1977) learning cycle. Karplus determined that the learning cycle originally created for elementary students could be used to help secondary students move from concrete patterns of thought to more formal patterns of thought. The learning cycle has three stages: exploration, concept introduction, and concept application. During exploration, students gain experience with an environment that creates a mental dissonance. During concept introduction, the instructor invokes new patterns of reasoning that resolve the mental dissonance. Finally, during concept application, students apply the new reasoning patterns to new situations, giving the students more time for exploration and self-regulation.

Modeling instruction guides students through a modeling cycle using an inductive-deductive modeling process. During model development, students observe a new phenomenon, identify variables, plan, conduct, and analyze an experiment, and then present the experimental results. After the class has reached consensus about the results, the instructor guides students to induce a generalized model. During model deployment, students use a deductive process. Students validate the model in novel situations and learn to identify effectively the assumptions of the model through a peer-collaboration problem-solving process. This modeling cycle gives students the opportunity to interpret observations, have discourse on the model, and integrate the model into their knowledge structure. One main goal of modeling is to move students from a declarative understanding of scientific knowledge (“This is true”) to an operational understanding of scientific knowledge (“This is true because . . . ”).

Summary

Students plod through their school years with a very limited sense of what the scientific enterprise is all about, often viewing science as a compacted set of “known facts" because science is not often portrayed authentically in schools (American Association for the Advancement of Science, 1993; Bauer, 1992; Good, 2000; Kuhn, 1970; Smith, 2000). Few students get the sense that science is a human endeavor fraught with uncertainty and influenced by subjective patterns of thought (Dawkins & Dickerson, 2003; Mackay, 1971; Smith 2000). Even after years of formal science education, students often view science as a set of unrelated facts, as a knowledge base that does not change, and as an absolute, objective endeavor that is separate from social influences and personal bias (Abd-El-Khalick & Lederman, 2000; Bell et al., 2003; Feldman, 2003; Halloun & Hestenes, 1998; Matkins et al., 2002; Moss et al., 2001; Schwartz et al. 2004; Tamir, 1994).

Various strategies can be used in the classroom to try to improve student understanding of many NOS themes. Students can learn stories of scientific discoveries (Abd-El-Khalick & Lederman, 2000; Allchin, 2003; Kuhn, 1970; Irwin, 2000), construct scientific knowledge through inquiry-based laboratory experiences (Smith, 2000; Spears & Zollman, 1977), participate in authentic scientific experiences (Bell et al, 2003; Khishfe & Abd-El-Khalick, 2002; Moss et al., 2001; Schwartz et al., 2004), and explicitly reflect on NOS themes (Abd-El-Khalick & Lederman, 2000; Bell et al., 2003; Khishfe & Abd-El-Khalick, 2002; Kurdziel & Libarkin, 2002; Matkins et al., 2002; Schwartz et al., 2004). Often, students lack the ability to synthesize their *knowledge of science* with their *scientific knowledge* (Lederman et al., 2002) and require personal reflection (Halloun & Hestenes, 1998; Qian & Alvermann, 2000) and purposeful intent

(Khishfe & Abd-El-Khalick, 2002; Lederman, 1999; Schwartz et al., 2002) to begin to understand the true nature of science.

Assessing NOS is a difficult task. Forced-response tests do not detail the understanding of individual students, and postassessment interviews suggest that such assessments are unreliable in how well they portray student understanding of NOS themes (Good et al., 1999; Lederman et al., 2002). Face-to-face interviews help to clarify student thoughts on this complex cognitive structure (Good, 2000; Lederman et al., 2002; Qian & Alvermann, 2000).

Modeling instruction (Wells et al., 1995) is a pedagogy that requires students to create kinematic and dynamic models and deploy the models to explain a broader range of phenomena. This teaching strategy is grounded in constructivism and utilizes the same scientific modeling processes used by physical scientists (Hestenes, 1992).

Chapter 3

Introduction

The purpose of this study was to test the viability of incorporating explicit references to NOS themes within the modeling program context. This study investigated the following research question: How do student gains in understanding the nature of science vary with the type of physics instruction?

Design

This was a quasi-experimental study. A convenience grouping of two general physics classes and one honors physics class comprised the treatment group (n = 33) and one general physics class and one honors physics class comprised the comparison group (n = 32). The independent variable was the type of instruction; the forms were *Standard Modeling* (comparison) and *Modeling Plus* (treatment). Student pretest and posttest scores on the Views of Nature of Science-Form C questionnaire were the dependent variable. As a check, I measured the content knowledge of each student using the Force Concept Inventory (FCI) (Hestenes et al., 1992). The FCI was given as a pretest and as a posttest to determine whether students in the treatment group exhibited lower content knowledge of Newtonian mechanics than the comparison group.

Subjects

All physics students (N = 65) at a Wisconsin high school participated in this study for an academic school year. Approximately 1,100 students are enrolled at this suburban, four-year high school. Two honors courses (n = 33) and three general courses (n = 32) took part in this study. Honors physics students typically have a strong math background, take advanced-placement courses, and complete most of the science courses offered by the school. General physics students typically are weaker in their math skills and view the course as a necessary requirement for admission to college or as an alternative to taking other offerings in the science department. Males (n = 36) and females (n = 29) participated in the study and most students held either junior or senior status. The high school principal designed the master schedule of classes so that students were enrolled in the same section of physics throughout the school year, which allowed students to stay in the same experimental group for an entire academic year. I taught all sections of physics, and I am also the researcher for this study.

Comparison Group. Standard Modeling (Wells et al., 1995) guides students through an inductive-deductive modeling cycle. During model development, students observe a new phenomenon, identify variables, plan, conduct, and analyze an experiment, and present the experimental results. After the class has reached consensus about the results, the instructor guides students to induce a generalized model. Students later deploy models using a deductive process and validate models in novel situations through a peer-collaboration problem-solving process. This modeling cycle gives students the opportunity to interpret observations, have discourse on the model, and integrate the model into their knowledge structure.

Treatment Group. Modeling Plus instruction uses Standard Modeling as its base, but it adds frequent explicit reference to NOS themes within the context of authentic laboratory investigations and model validation. As the class creates new knowledge, students reflect on the following four NOS themes: scientific knowledge is tentative, fallible, and approximate; scientific knowledge requires repeatable observation to be valid; science is subjective due to personal bias and creativity; science is subjective due to its theory-laden nature. Students create scientific knowledge from their laboratory experiences. For example, when students draw conclusions, the instructor often asks "What is your evidence?" thereby emphasizing the observational nature of science. Students have discourse on the assumptions and the limitations of each model, emphasizing the tentative and approximate nature of science. Data analysis goes beyond the numbers, requiring students to interpret the data, usually within an existing context. Students create knowledge that goes beyond the data, but explicitly discern that this process is done with a bias or within the context of an existing theoretical structure, providing students an authentic context to address the creative side of science as well as the biased and theory-laden nature of science. In addition to reflecting on their laboratory practices in the context of NOS, students also reflected on NOS concepts embedded in quotes from scientists and philosophers (see Appendix C). Students wrote reflections on these quotes in journals that became a means by which each student and I could have discourse on the targeted NOS themes.

Measures

I chose 9 of 10 questions from the VNOS-C questionnaire (Lederman et al., 2002, see Appendix A), which students completed as a pretest and as a posttest. The question from the VNOS-C that was not administered related to the sociocultural aspect of science, which was not one of the NOS themes explicitly addressed in this study. I administered individual semistructured interviews to two students from each section following both the pretest and the posttest. I used the results of these interviews to help create a scoring rubric for the VNOS-C (see Appendix B) and also created a syllabus that detailed the interventions used throughout the school year as well as interventions unique to each study group.

The Force Concept Inventory (FCI), developed by Hestenes, Wells, and Swackhamer (1992), is a 30-question multiple-choice assessment used to determine student understanding of basic Newtonian concepts that are typically taught in a first-year physics course.

Procedure

During the first week of school, students completed the FCI pretest. I allowed students to see their raw scores on the test but did not allow students to see which specific questions were missed and did not discuss the answers to the test questions. Several weeks into the school year students also completed the VNOS-C questionnaire. I generated a random sample of two students from each section, and on the school day immediately following administration of the survey, I conducted a semistructured interview with these students to clarify their responses to the survey.

The treatment group contained two sections of general physics (n = 10 and n = 13) and one section of honors physics (n = 17). The comparison group contained one section of general physics (n = 16) and one section of honors physics (n = 17). These class sizes are different from the sample size of the study. The reasons for the mortality of students participating in the study are identified in Chapter 4.

In addition to receiving explicit reference to NOS within the context of classroom activities, students in the treatment group also wrote journal entries two to three times each month which focused on various quotes and media presentations (see Appendix C for a list of quotes and media resources used). Students identified the underlying scientific theme behind the quote, stated whether they agreed or disagreed with the quote, and stated their reasoning. In some cases, several different quotes were given together and students looked for a common science theme among them. Students wrote responses for 10 minutes, then I randomly chose students to share their responses. Through the ensuing discussion, I elicited the NOS themes illustrated by the quotes. Three different times during the school year, I graded notebook entries for completeness and also responded to student writings, thus allowing students further opportunity to reflect on their thinking.

Near the end of the academic school year, all students completed the VNOS-C questionnaire. I generated a random sample of two students from each section, but did not include students who were interviewed at the beginning of the year. On the school day immediately following the administration of the survey, I conducted semistructured interviews with these students to clarify their responses to the survey; the interview questions were identical to the questions used at the beginning of the school year. Students also completed the FCI posttest at the end of the school year. I did not forewarn students that the FCI would be administered as a posttest. Although I scored the FCI, I told students that their scores would not be included in the course grade.

Analysis

I created a rubric to facilitate scoring the VNOS-C questionnaire (see Appendix B). In quantifying this tool, I assigned points for positive indications of the targeted NOS themes. The design of the rubric uses some of the findings from Lederman et al. (2002). For example, interviews by Lederman et al. indicate that students often use the word *proof* in the same context as *evidence*. If evidence was the key component being elicited by a question, then I assigned one point to that response. I assigned an additional point if students did not use the term *proof* or *fact* (or any variation of these words). If, instead, students used *validate* to describe the role of evidence, they better addressed the tentative nature of scientific knowledge.

I coded the surveys with a random number generated by Microsoft Excel. A student services employee in the high school held the key that linked each random number with an experimental group, so I scored the surveys in random order without any knowledge of which surveys belonged to which experimental group. In order to facilitate regularity in the scoring process, I scored the pretest and posttest surveys simultaneously, one test item at a time. I scored the FCI via Scantron.

The research question asks how student gains in understanding the nature of science vary with the type of physics instruction. The null hypothesis for this study states that the VNOS-C mean score of the treatment group is significantly lower than or does not differ significantly from the VNOS-C mean score of the comparison group ($H_0 : M_T \leq M_C$). The alternative hypothesis states that the VNOS-C mean score of the treatment group is significantly higher than the VNOS-C mean score of the comparison group ($H_A : M_T > M_C$). I used Microsoft Excel to determine the mean VNOS-C score for each experimental group and apply *t* tests to the mean scores. A two-tail *t* test of unequal variance determined whether the pretest mean scores of the two experimental groups were significantly different. A one-tail *t* test of unequal variance determined whether the posttest mean score of the treatment group was significantly higher than the posttest mean score of the comparison group.

Summary

I applied this quasi-experimental design to my high school physics students for an academic year. One group of students received explicit instruction and reference to NOS themes within the modeling context while another group of students did not receive explicit instruction in NOS themes. This study measured student understanding of NOS themes using the Views of Nature of Science-Form C questionnaire and student achievement of physics content knowledge using the Force Concept Inventory.

Chapter 4

Introduction

Although the high school principal designed the master schedule of classes so that students were enrolled in the same section of physics throughout the school year, the sample population experienced attrition. Seven students dropped the class due to early graduation, scheduling conflicts, or a lack of desire to continue with the course. These numbers are consistent with past years and were evenly distributed between the two experimental groups. Four additional students, predominately from the comparison group, changed experimental groups at the beginning of the second semester due to irreconcilable scheduling conflicts, so I also dropped these students from the study. One additional student switched sections at the beginning of the second semester but was able to switch into a class that received the same treatment, so I retained this student for the study. I dropped three additional students from the final analysis because they left one or more pages of the presurvey or postsurvey blank.

Views of Nature of Science (VNOS)

The table below shows the pretest and posttest VNOS-C mean scores for the treatment and for the comparison groups. A two-tail *t* test of unequal variance comparing the pretest VNOS-C mean scores of the two experimental groups shows no statistically significant difference ($p > 0.05$). A one-tail *t* test of unequal variance comparing the posttest VNOS-C mean scores shows the higher mean score of the treatment group to be statistically significant ($p < 0.05$), therefore I reject the null hypothesis.

VNOS-C Mean Scores

		Pretest		Posttest	
Group	*n*	*M*	*SD*	*M*	*SD*
Treatment	33	15.4	3.1	18.5*	3.2
Comparison	32	15.1	3.4	15.7	3.5

* $p < 0.05$

See Appendix D for a complete comparison of pretest and posttest mean scores disaggregated by experimental group, course, and gender.

Item analysis of the questionnaire indicates that students in the treatment group showed a marked gain in describing science and how it is different from other forms of inquiry, particularly in delineating that science is based on repeatable observation, a feature missing from many other forms of inquiry, particularly religion. While students in the treatment group showed no appreciable gain in their understanding that theories change, they did show improvement in their understanding that theories and laws are not part of a hierarchy. Student answers to VNOS-C, Question 5 illustrate this finding. For example, some students in the treatment group minimally recognized that theories are continually recrafted whereas laws tend to be more permanent:

> “The Laws of Gravity work 99% of the time and the Theory of Relativity works on only a large scale.”
>
> “Yes, laws are permanent, theories are not.”
>
> “Yes, laws are proven to be true, theories are not proven to be false.”

> “A theory is something we believe is true but have no way of verifying it. A law is something we know is true and can verify it.”

Other students in the treatment group better stated that theories explain broader phenomena and are composed of related laws:

> “A theory is a big idea that is made up of, or is the larger picture of, many laws.”
>
> “A scientific theory synthesizes many laws to explain the world around us.”
>
> “The difference between a theory and a law is that laws provide the structure / basis on which theories are made.”
>
> “Yes, a scientific theory is a broad idea of science (like Newtonian Mechanics), then within that theory, there are different laws.”

Students in the comparison group generally implied that theories are unproven and become laws when proven, or they suggested that theories are mere guesses.

> “Yes, theories are not yet proven to be true. Laws have been proven.”
>
> “Yes, theory isn’t proven. Laws are.”
>
> “Yes. A scientific theory isn’t always recognized as true. It’s been disproven . . . A scientific law, like the law of gravity or Newton’s laws, is generally recognized as true and accurate.”
>
> “A theory is a well-educated guess whereas a law is proven fact.”
>
> “A law is based more on evidence (experiments, etc.), rather than a theory, which is more so a ‘guess.’”

Students in the treatment group showed gains in their understanding of the inferential nature of scientific knowledge. They were better at delineating the uncertainty of the structure of the atom because it had not been directly observed, and expressing that our knowledge of atomic structure is based on interpretation of the available evidence. Students showed no greater understanding of the certainty of the definition of *species*. Students stated that scientists are far more certain of the definition of species than they are of atomic structure because unlike the atom, species can be directly observed. Very few students clearly delineated that species, rather than being a real characterization of nature, is a definition created by scientists in order to classify organisms.

Both experimental groups showed marked gains in their understanding of the creative nature of science, indicating that creativity is used not only in the design stage of an experiment, but also in the data collection, analysis, and interpretation stages of an investigation. Both study groups also showed gains in their understanding that imagination and creativity allow scientists to create different theories from the same set of data.

Force Concept Inventory (FCI)

While the pretest FCI mean score of the treatment group (*M* = 7.8) was lower than the pretest FCI mean score of the comparison group (*M* = 8.6), the posttest FCI mean score of the treatment group (*M* = 23.2) was higher than the posttest FCI mean score of the comparison group (*M* = 21.6). Although the treatment group received less content instruction than the comparison group so that they could receive interventions relating to

NOS, the results of the FCI indicate that the content knowledge of the treatment group was not adversely affected. It should be noted that while the posttest FCI mean score of females (*M* = 16.1) in the comparison group is noticeably lower than for males (*M* = 25.8) in the comparison group, the posttest FCI mean scores of the females (*M* = 23.1) and males (*M* = 23.2) in the treatment group are nearly equal. See Appendix E for a complete comparison of pretest and posttest FCI mean scores disaggregated by experimental group, course, and gender.

Summary

Students who receive modeling instruction with explicit reference to NOS themes articulate a stronger understanding of these themes when compared to students who receive modeling instruction without explicit reference to NOS themes. The results of this study corroborate the findings of Gess-Newsome (2002), Kurdziel and Libarkin (2002), Khishfe and Abd-El-Khalick (2002), and Lederman et al. (2002). Performance of the comparison group on the VNOS-C corroborates the findings of Lederman (1999); students learn NOS themes through purposeful intent rather than through osmosis. Student performance on the Force Concept Inventory suggests that although some content instruction is replaced with NOS instruction, students' content knowledge is not adversely affected.

Chapter 5

Limitations

One limitation of this study is that the results cannot be generalized. The sample size was small, the assignment of subjects to experimental groups was convenient rather than random, and the physics students are generally not representative of the general student population.

A second limitation of this study is my dual role as researcher and instructor. Although I took steps to minimize bias during scoring of the VNOS surveys, the grading rubric was based on key points that I accentuated with the treatment group. Students in this group could have chosen to include key words or phrases in their responses that may have superficially inflated their scores.

A third limitation is the small class size in two of the sections in the treatment group. Two sections in the treatment group (n = 10 and n = 13) were smaller than each of the sections in the comparison group (n = 16 and n = 17). Higher VNOS scores in the treatment group could be the result of a smaller student-teacher ratio than the comparison group.

A fourth limitation is that Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) designed VNOS as a qualitative assessment. They provide evidence of the validity of this assessment, but that is based in part on triangulating data from the questionnaire and from student interviews, allowing the researchers to generate a NOS profile for students. Although I did interview a sample of students, I only used the interviews to validate the findings of prior research (Good et al., 1999; Lederman et al, 2002; Qian & Alvermann,

2000) and to aid in creating a scoring rubric that reflects proper NOS understanding. One concern derived from this limitation is understanding what a mean score gain really means, particularly when the gain, although statistically significant, is small. Aikenhead (1973) raises this same concern when referencing the quantitative Test on Understanding Science (TOUS).

A fifth limitation of this study is that I assessed student understanding of NOS from within the context of my own understanding. Various studies (Feldman, 2003; Gess-Newsome, 2002; Matkins et al., 2002; Schwartz et al., 2004; Schwartz et al., 2002) show that teachers and preservice teachers have a poor or ill-defined understanding of NOS and that student performance is dictated by the degree of teacher understanding of NOS themes.

Implications

Nature of Science

Both study groups were able to show gains in their understanding of the creativity of science. This NOS theme seems amenable to being communicated implicitly, possibly due to it being so concretely evident when doing labs in an authentic atmosphere such as Standard Modeling provides. In contrast, the role of evidence in creating scientific knowledge and the tentative nature of this knowledge appears to be a more abstract construct that is only learned through explicit instruction.

While the pretest VNOS mean scores of the experimental groups showed no statistically significant difference, the higher posttest VNOS mean score of the treatment group was statistically significant. But the VNOS mean gain score of the treatment group was small—3.1 out of 37 points. This small gain could be because students completed the surveys near the end of the year and did not feel compelled to spend adequate time answering their questions completely. This result would highlight a failure of one of the goals of modeling—to move students from declarative knowledge to operational knowledge. The small gain could also be the result of the slow process surrounding student understanding of NOS. I don't expect to overturn quickly years of misunderstanding and misconceptions brought about by an entire career of public school education.

The results of this study are consistent with the findings of other researchers. Gains in understanding of NOS themes are, at best, incremental over small periods of time, but gains are visible when students are given explicit instruction in NOS and when this is done in an authentic environment. Modeling Plus, the treatment used in this study, is different from many other studies in that the interventions occur over an academic year and the NOS interventions are relatively minor. I did not, as a general rule, devote entire classroom periods to NOS themes, nor did I devote large portions of classroom time to these ideas. Exceptions to this occurred when I asked students to respond to the article *Nailing Down Gravity: New Ideas About the Most Mysterious Power in the Universe* and the video *NOVA: The Elegant Universe* (see Appendix C). Rather, 10 minute digressions several times a week, either through journaling on quotes or reflecting on laboratory or analytical practices, seemed sufficient to provide some gains in the understanding of the nature of science, at least when done over an academic year. One final aspect of

Modeling Plus is that I purposefully embedded discussion and reflection of NOS themes within authentic activities already existing in the Standard Modeling curriculum.

When looking at the VNOS mean scores of the experimental groups disaggregated by course and gender, both levels of physics and both genders showed gains. Further research might address whether students in different course levels or whether either gender responds better to the NOS treatment utilized in this study.

Content Understanding

One potential drawback of explicitly adding NOS into an existing curriculum is that students will receive less content instruction. Some would argue that this is an equitable trade-off in light of the bleak nature of students' understanding of the nature of science. Using the Force Concept Inventory as a basis for measuring student understanding of physics concepts learned over the course of one year, I find that students in the treatment group suffered no ill effects in their understanding of Newtonian mechanics relative to the comparison group. I was not surprised that the honors students in the treatment group scored higher on the posttest (M = 25.4) than the general physics students in the treatment group (M = 21.1). Honors students are, as a rule, more willing to accept new ideas and take extra time to try to learn concepts. They also are able to use greater mathematical rigor to validate scientific models.

Most interesting, and most unexpected, was the gender difference found in the FCI scores. In the comparison group, the pretest FCI mean score of females (M = 5.8) was noticeably lower than the pretest FCI mean score of males (M = 10.7), and the posttest FCI mean score of females (M = 16.1) was also noticeably lower than the posttest

FCI mean score of males (M = 25.8). In the treatment group, in contrast, while the pretest FCI mean score of females (M = 6.7) was lower than the pretest FCI mean score of males (M = 8.7), the posttest FCI mean score of females (M = 23.1) was nearly equal to the posttest FCI mean score of males (M = 23.2). In other words, the treatment females closed the gap on the treatment males with regard to their performance on the FCI, while the comparison females lost ground when compared with the males.

A historical comparison of FCI posttest scores aggregated by gender within my classroom reveals a similar trend. The posttest FCI mean scores by gender are as follows: 1999-2000, $M_M = 21.2, M_F = 17.8$; 2001-2002, $M_M = 24.2, M_F = 19.9$; 2002-2003, $M_M = 24.1, M_F = 18.8$. Data was not available for the 2000-2001 school year. In my classroom, females have scored lower on the FCI posttest than males, a trend confirmed by females in the comparison group and nullified by females who received Modeling Plus instruction.

While the correlation between increased performance on the FCI and enhanced understanding of science is consistent with the results of the Views About Science Survey (Halloun & Hestenes, 1998), the stronger performance on the FCI for females in the treatment group relative to females in the comparison group was unexpected. I do not suggest that the FCI contains gender bias. Rather, the gender difference in FCI scores may be due to understanding of content or access to content. A further question for research could address whether there is a gender difference in linking the epistemology of science to science content.

Summary

The results of this study corroborate the findings of numerous other studies; students increase their understanding of NOS themes when learning through inquiry-based instruction and when receiving explicit reference to NOS themes. Modeling instruction is a teaching pedagogy that has been applied to physics, but which can also be applied to other physical sciences. This teaching methodology allows the teacher to purposefully target NOS themes within the context of the curriculum. Teaching NOS in this context does not compromise the fundamental content knowledge of the course.

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Appendix A

Views of Nature of Science-Form C

Views of Nature of Science-Form C

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
2. What is an experiment?
3. Does the development of scientific knowledge **require** experiments?
    - If yes, explain why. Give an example to defend your position.
    - If no, explain why. Give an example to defend your position.
4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
    - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
    - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.
5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example?

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence **do you think** scientists use to determine what an atom looks like?
7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?
8. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
    - If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and designing, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
    - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

9. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

Appendix B

Views of Nature of Science Scoring Rubric

Views of Nature of Science Scoring Rubric

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)? (4 points possible)

    a. 1 pt = science is study of natural world / universe / things around us or how things work / how things happen or attempt to understand / explain our surroundings.

    0 pt = if suggests that science is exclusive to the study of Earth.

    b. 1 pt = science and religion are similar because both require imagination / creativity,

    1 pt = BUT science requires evidence / experimentation or science makes predictions that must be validated or science must ask an answerable question.

    or

    1 pt = science is different from religion / philosophy because it uses evidence to create knowledge or must validate predictions based on the knowledge,

    1 pt = religion / philosophy are based solely on faith.

    c. 1 pt = not using any of the following words: proof, facts, correct, exact, truth

Scoring notes:

- "World" was assumed to refer to a broader environment than the earth.
- Words such as "proof" were assumed to mean that evidence was required for an answerable question.
- Did not accept science = "why things happen."
- 1 point given for saying that science changes and religion does not.
- Did not accept "science asks how" and "religion asks why".

2. What is an experiment? (5 points possible)

    1 pt = test / demonstration / process / procedure / observation / setup / investigation to answer a question or study of two variables or a way of checking a theory.

    1 pt = methodical / reproducible / controlled / systematic / trials

    1 pt = collect data / evidence / make observations / measure / gather information

    1 pt = conclusions or analyze to reach a conclusion or help predict occurrences or find patterns.

    1 pt = not using "proof" (or other variations) of knowledge

Scoring notes:

- Did not accept vague references like "something done to check something."
- "Controlled" assumed to imply reproducible.

3. Does the development of scientific knowledge require experiments?

- If yes, explain why. Give an example to defend your position.
- If no, explain why. Give an example to defend your position.

(4 points possible)

1 pt = yes (stated or implied)

1 pt = data / observations are the basis of scientific knowledge or provides a basis for making further predictions.

1 pt = example or illustration that is clear, pertinent, and illustrates the use of data / evidence or illustrates drawing a specific knowledge claim.

1 pt = not using the words prove, facts, truth, etc.

Scoring notes:

- “Prove” was accepted in the context that data is necessary to support the knowledge.
- Some answers were “No” because they indicated the development of knowledge could be in lecture form; I did not accept this as development of knowledge.
- It was very difficult to evaluate the example piece. I did not accept math examples (1 apple + 1 apple = 2 apples) or sailing around the world to show that it is not flat. I did accept examples showing the advancement of medicine or specific technology that have a basis in fundamental science.

- To say that they're necessary because science is changing was not accepted because it was not clear whether nature was changing or our approach was changing.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?

    ▪ If you believe that scientific theories do not change, explain why. Defend your answer with examples.

    ▪ If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

(4 points possible)

1 pt = yes (not static)

1 pt = change because of new observations / information that don't fit with current theory

1 pt = theories provide basis / guideline for further experimentation or put knowledge together to broaden our understanding or to answer the "how" and "why" or to generate new ideas

1 pt = example that illustrates why change or why learn theories

Scoring notes:

- Did not accept the idea that old theories continue to exist, we just add new theories.
- Accepted as a changed theory the idea that an altered theory is a new theory

- Did not accept a changed hypothesis (flat earth) as an example.
- An example needed a reference for specific evidence; I did not accept that Theory A has changed over time.
- Did not accept new knowledge or new learning as basis for changing theory but did accept new information or new discoveries.
- "Changing world" generally not accepted because unclear whether this reflects a change in nature or a change in how we interact with nature.
- "New way of thinking" usually not accepted as a reason for changing a theory unless it referenced validation by data.
- "More and better technology" may or may not have been accepted for why theories change; it depended on whether this allowed for additional / new data.
- I accepted some technological changes as an example of a changing theory if its foundation was rooted on basic science.
- Did not accept that theories are "as close to the truth as possible" as a reason for learning them.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example? (5 points possible)

   a. 1 pt = law is a statement of an observation or on a more solid standing than a theory (generally accepted) because of a large volume of evidence.

or

1 pt = law has never been observed to the contrary

b. 1 pt = theory is based on creativity or is someone's idea / guess / belief / assumption

c. 1 pt = theory is based on evidence

d. 1 pt = a theory is composed of laws or attempts to explain "why" or how something works

e. 1 pt = example that illustrates the difference between law and theory or correctly identifies both a law/model and theory by name or by specific description.

Scoring notes:

- "Law of Gravity" was assumed to mean Law of Universal Gravitation.
- Did not accept "proven" for a description of a law.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists use to determine what an atom looks like? (4 points possible)

1 pt = our ideas are still subject to change

1 pt = structure is a product of creatively stringing together experimental results or guess based on experimental results

1 pt = we've never seen an atom

1 pt = any 1 of the following: experimental probes, chemical behavior, behaviors based on prediction, experiment by name

Scoring notes:

- I assumed the terms “fairly certain”, “relatively certain”, and “educated guess” inferred that the idea is still subject to change. Also accepted up to 95 % certain as indicating change was more than remotely possible.
- I did not accept that scientists are certain but the student is uncertain.
- I did not accept atom smasher or particle accelerator as an experiment.

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence do you think scientists used to determine what a species is? (4 points possible)

1 pt = very or 100% certain

1 pt = scientists created the definition or scientists agreed upon the definition

2 pt = observations (of physical traits/characteristics and reproductive ability) or evidence is not used, but rather concept is defined based on observed physical traits/characteristics and reproductive ability.

Scoring notes:

- Did not accept “developed” as a synonym for “defined”.

- Did not accept the student's certain acceptance of the definition as an answer to the certainty of scientists.

8. Scientists perform experiments / investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?

    - If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and designing, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
    - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

    (4 points possible)

    a. 1 pt = yes, for at least one phase (or unclear as to whether it applies to all phases)

    or

    2 pt = yes, creative in all phases / entire process

    b. 1 pt = choosing a theory / model to work under or interpret / figure out/determine meaning of / come up with results.

    c. 1 pt = any other pertinent examples of how scientists are creative.

    Scoring notes:

    - "whole procedure" not interpreted as "all phases" because it seemed that it might apply to creating the data collection process only.

- “always using” or “in everything” not interpreted as synonymous with “all phases”.
- “writing or producing a conclusion” not accepted as that may be interpreted literally.
- “some” scientists use creativity not accepted as a “yes” answer.
- “creating a theory” not accepted as synonymous with interpreting results because the wording usually implied that scientists are always doing this.
- Accepted for 1 pt. references to new ideas, and uniqueness but did not accept “think outside the box.”

9. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these different conclusions possible if scientists in both groups have access to and use the same set of data to derive their conclusions? (3 points possible)
   a. 1 pt = data only approximates the situation or have limited data / facts or both situations have similar characteristics
   b. 1 pt = conclusion process is the result of creative interpretation of the data or scientists guess / interpret / assume / come up with ideas

c. 1 pt = scientists subjectively choose the camp that best matches their understanding of nature or scientists believe or feel one conclusion is better or scientists choose to focus on one aspect over another or scientists are led by their own bias

or

1 pt = both are acceptable until data validates one and disproves the other

Scoring notes:

- Did not accept “no one was there” or “both show that the earth was destroyed” or “all they know is that the dinosaurs were wiped out” as a substitute for limited data
- Accepted “pros and cons” for third point because it implies a judgment is needed.
- Did not accept “both fit the data” because it doesn’t address WHY both fit the data.
- Did not accept “vague” as a synonym for “approximate”
- Did accept “no solid evidence” as data being approximate.
- Opinion generally interpreted to relate to interpretation of data.
- For point one, accepted any hint that the two events can be linked.

Appendix C

NOS Quotes and Media Resources for Journal Reflections

NOS Quotes and Media Resources for Journal Reflections

1. "What's most depressing is the realization that everything we believe will be disproved in a few years." Sidney Harris cartoon of two scientists standing at a chalkboard
2.
    a. "Equipped with his five senses, man explores the universe around him and calls the adventure Science." Edwin Powell Hubble
    b. "Science is nothing but perception." Plato
3. "The reason I call myself by my childhood name is to remind myself that a scientists must be absolutely like a child. If he sees a thing, he must say that he sees it, whether it was what he thought he was going to see or not. See first, think later, then test. But always see first. Otherwise you will only see what you were expecting. Most scientists forget that. I call myself Wonko the Sane so that people will think I am a fool. That allows me to say what I see when I see it. You can't possibly be a scientist if you mind people thinking that you're a fool." Adams, D. (1999). *So Long, and Thanks for All the Fish.* New York: Ballantine Books.
4. A fuzzy and non-distinct picture of a cow that is usually only distinctive once it is outlined and shown explicitly.
5. A drawing that can be interpreted as a young woman with her head turned back to the side or as an old woman with her head looking forward and down.

6.

   a. “The most exciting phrase to hear in science, the one that heralds new discoveries, is not ‘Eureka !’ (I found it!) but ‘That’s funny…’” Isaac Asimov

   b. “Science is a cemetery of dead ideas.” Miguel de Unamuno

7. “Science can only ascertain what <u>is</u>, but not what <u>should be</u>, and outside of its domain value judgements of all kinds remain necessary.” Albert Einstein

8. “Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house.” Henri Poincare’

9.

   a. “It is wrong to think that the task of physics is to find out how Nature is. Physics concerns what we say about Nature.” Niels Bohr

   b. “Art and science have their meeting point in method.” Edward Bulwer-Lytton

10. “All scientific men were formerly accused of practicing magic. And no wonder, for each said to himself: “I have carried human intelligence as far as it will go, and yet So-and-so has gone further than I. <u>Ergo</u>, he has taken to sorcery.” Montesquieu

11.

   a. “True science teaches, above all, to doubt and to be ignorant.” Miguel de Unamuno

   b. Meteorology: the science of being up in the air and all at sea." E.L. Hawke
   c. Human science is uncertain guess." Matthew Prior

12. Response to magazine article. Folger, T. (2003, October). Nailing down gravity: New ideas about the most mysterious power in the universe. *Discover, 24,* 34-40.
13. Response to reading excerpt. Zukav, G. (1979). *The dancing Wu Li masters: An overview of the new physics*, pp. 30-31. New York: Bantam Books.
14. Upon hearing that an experimental result had supported a theory of his, Einstein was asked by a student what he would have done had there been no confirmation. He replied, "Then I would have to pity the dear Lord. The theory is correct anyway."
15. Response to the video *NOVA: The Elegant Universe, Part I*.

Appendix D

VNOS-C Pretest and Posttest Mean Scores by Experimental Group, Course, and Gender

VNOS-C Pretest and Posttest Mean Scores by Experimental Group, Course, and Gender

		Pretest		Posttest	
Group	*n*	*M*	*SD*	*M*	*SD*
Treatment	33	15.4	3.1	18.5*	3.2
Honors	16	16.4	2.3	20.1	2.9
General	17	14.4	3.4	16.9	2.7
Male	18	14.6	3.0	17.6	3.1
Female	15	16.3	2.9	19.6	3.1
Comparison	32	15.1	3.4	15.7	3.5
Honors	17	14.4	3.3	15.1	3.4
General	15	15.9	3.3	16.4	3.6
Male	18	14.5	3.4	15.9	3.5
Female	14	15.9	3.2	15.5	3.5

* $p < 0.05$

Appendix E

FCI Pretest and Posttest Mean Scores by Experimental Group, Course, and Gender

FCI Pretest and Posttest Mean Scores by Experimental Group, Course, and Gender

		Pretest		Posttest	
Group	*n*	*M*	*SD*	*M*	*SD*
Treatment	33	7.8	3.0	23.2	4.9
Honors	16	8.3	3.2	25.4	3.4
General	17	7.4	2.7	21.1	5.1
Male	18	8.7	3.2	23.2	4.8
Female	15	6.7	2.2	23.1	4.9
Comparison	32	8.6	3.9	21.6	6.1
Honors	17	10.2	4.2	24.5	4.9
General	15	6.7	2.6	18.3	5.6
Male	18	10.7	3.7	25.8	3.3
Female	14	5.8	2.0	16.1	4.1

Note. Maximum score on the FCI = 30.