BEYOND EVOLUTION: A THEMATIC APPROACH TO TEACHING NOS IN AN UNDERGRADUATE BIOLOGY COURSE

This study reports how NOS is explicitly taught *and* assessed in the context of a biology course taken by elementary education majors. It is an example of putting theory into practice by assuming a thematic approach to NOS instruction throughout multiple units. Teaching about NOS within the context of science content courses has been recommended for helping future teachers learn the content of NOS and experience the pedagogy of teaching NOS within science contexts. They need to understand the integral relationship between NOS and traditional science content. We continue to see examples of addressing NOS within the context of teaching evolution, but have far fewer examples of embedding NOS in other biology subjects. This report provides details of explicitly addressing NOS throughout three units of a biology content course for preservice elementary teachers (genetics, molecular biology, integrated investigation of a human condition). I also describe the effectiveness of the instruction on student conceptions of NOS. Instruction included objectives, explicit and reflective activities, and assessments. Data include pre/post VNOS/VOSI questionnaires. Participant views were placed along a NOS Views Continuum. The Continuum enables representation of dramatic as well as more subtle shifts in views. Results demonstrate improved understanding of targeted NOS aspects. More importantly, students demonstrated increased and appropriate application of science examples from throughout the course to support their NOS views. Overall results are quite encouraging. The thematic approach is recommended for exposing NOS to learners in multiple contexts. Despite repeated examples, peer conversations, whole class discussion, and reflective writings some students were still unable to alter their initial conceptions. Why? The discussion explores the question.

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Purpose And Framework

Teaching about nature of science [NOS] and scientific inquiry are central goals of science education to enhance scientific literacy (AAAS, 1993; NRC, 2000). Despite the vast attempts to improve teachers' and students' understandings of NOS, challenges persist. In a recent review of the literature on NOS learning and teaching, Lederman (2007) demonstrates that teachers of all grade levels continue to struggle with developing contemporary conceptions of NOS and translating conceptions into instruction. Influential factors are many, including the disaggregated contexts of learning science subject matter (science content courses), learning about NOS (science methods courses; professional development programs), and expectations of teaching NOS concurrent with other science content (science content courses/lessons) (Abd-El-Khalick, 2001; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). Most preservice and inservice teachers today experienced science learning environments that were "traditional" teacher-centered settings, without inquiry experiences or exposure to NOS concepts (Gallagher, 1991). These experiences may serve as barriers when these teachers are asked to employ student-centered inquiry instruction with explicit teaching about NOS in their science lessons. It is agreed that simply understanding concepts of NOS and inquiry is insufficient to guarantee successful teaching of these topics within a science classroom (Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, Morrison, & McDuffie, 2006;; Lederman, 1999; Schwartz & Lederman, 2002). Embedding NOS within science content courses demands an inclusive view of NOS as it relates to the science content (Schwartz & Lederman, 2002). Explicit teaching about NOS within the context of science content courses has been recommended for helping future teachers (1) learn the content of NOS and (2) experience the pedagogy of teaching NOS within science contexts (Abd-El-Khalick, 2001; Brickhouse, Dagher, Letts, & Shipman, 2000; Hanuscin, Akerson, & Phillipson-Mower, 2006; Lederman, 2007; Schwartz & Lederman, 2002). This approach makes sense from a situative perspective of learning and knowing (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991) because the learner encounters a similar learning environment as he/she is expected to establish in future science teaching. The present study is an example of putting theory into practice whereby NOS is explicitly and reflectively taught within the context of an undergraduate biology course for future elementary and middle school teachers.

Nature of Science

Nature of science refers to the qualities and assumptions that are inherent to the products of scientific inquiry (i.e. scientific knowledge). Reform documents (AAAS, 1990, 1993; NRC, 1996) and international science education efforts (see, for example, Hodson, 1998; Matthews, 1998; Osborne et al., 2003; Ryan & Aikenhead, 1992) present descriptions of NOS that include common generalities. These general tenets pose little disagreement according to current philosophical perspectives. The following NOS aspects were examined in the present study. These are scientific knowledge is (a) *tentative*, or subject to revision based on new information or new perspective. Reasons for the inherent tentativeness of scientific knowledge stems from several other aspects including: (b) scientific knowledge has basis in *empirical evidence*, (c) collection and interpretation of empirical evidence is influenced by current scientific perspectives (*theory-laden* observations and interpretations) as well as *personal subjectivity* due to scientists' values, knowledge, and prior experiences, (d) scientific knowledge is the product of human *imagination and creativity*, and (e) scientific knowledge involves both *observation and inference*. These aspects also reinforce the durability of scientific knowledge. The empirical nature of science, while this aspect underlies the tentativeness of science, also negates an "anything goes" perspective. Scientific knowledge is founded in data which are subject to interpretation (necessarily a theory-laden and socially influenced negotiation) and accepted within the community based on consistency and strength of argument. It cannot be overlooked that there is variability in the strength of the empirical foundation and argument upon which scientific knowledge is based. The knowledge is tentative, yes, yet nonetheless durable because of these other features. Another feature of scientific knowledge examined in the present study is (f) the functional difference and relative status between *scientific theories and laws.*

Scientific models and modeling are integral components of scientific thinking and scientific knowledge (Gilbert, 1993; Schwartz, 2004). Scientific models are products of creative and inferential thinking, based on empirical observation. Models are explanatory and predictive; are a means of testing ideas as well as means of representing ideas and relationships. There is a natural connection between conceptions of scientific models and NOS. The context of the present study utilized multiple examples of scientific models and modeling practices. Although not a central focus to this paper, students' conceptions of models were examined.

Nature of Scientific Inquiry

The nature of scientific inquiry [NOSI] refers to the processes and elements therein of scientific investigations and methods of justifying knowledge. The NRC (2000), AAAS (1993), the National Academy of Sciences (2002), science educators (e.g Chinn & Malhotra 2002; Hodson, 1998; Minstrell & van Zee, 2000), and researchers who have explored scientists in practice (e.g. Dunbar, 2001; Knorr-Cetina, 1999) and scientists epistemological views (Schwartz, 2004) offer descriptions of nature of scientific inquiry, beyond basic investigative skills, that share commonalties. Three of these commonalties are explored in the present study in addition to the aforementioned NOS aspects. The NOSI aspects examined in this study include: a) multiple methods of scientific investigations (no single scientific method), b) the form of justification of new knowledge (What criteria do scientists use to justify their claims?), c) distinctions between data and evidence (products of observation vs. products of interpretation of those observations).

Literature Review

Teaching NOS in Science Contexts

If NOS is explicitly taught at all, it is often presented as a separate topic, either at the beginning of a science course (Chapter 1: Nature of science), during a methods course, or as part of a professional development program. Within the life sciences, teaching NOS has been tightly linked with the teaching of evolution as a way to address misconceptions about and resistance toward evolutionary theory (Bybee, 2001; Eick, 2000; Farber, 2001; NAS, 1998; Nickels, Nelson, & Beard, 1996; Scharmann & Harris, 1992). These approaches, although often successful, do not necessarily overcome the barriers teachers face in making connections between NOS and all the science subject matter they need to teach. If the only time students hear about NOS is in conjunction with evolution, then it is likely that both NOS *and* evolution are misunderstood. NOS is a unifying theme applied across science subjects and disciplines (NRC, 2000). Yet, elementary and secondary teachers report difficulties seeing connections across contexts (Akerson et al., 2006; Akerson & Abd-El-Khalick, 2004; Schwartz & Lederman, 2002). It should be no surprise then that teachers report having difficulty embedding NOS thematically across their science curriculum. Pedagogical content knowledge for NOS involves knowledge of NOS, knowledge of traditional science content, and knowledge of the pedagogy of explicitly teaching NOS within that context (Schwartz & Lederman, 2002). The blend of these, among other knowledge domains, and the purposeful intentions of teaching about NOS, impact a teacher's success with NOS instruction. What learning experiences facilitate development and integration of these knowledge domains?

Embedding NOS within undergraduate science courses, in a manner that models expected practices of the future teachers, may overcome some of the known barriers. Effects of preservice elementary teachers' experiences with inquiry-based science content courses on efficacy, intentions, and practices toward inquiry science teaching are encouraging (Bleicher & Lindren, 2005; Friedrichsen, 2001; Hubbard & Abell, 2005; Weld & Funk, 2005). For example, Hubbard & Abell (2005) investigated beliefs about science of students enrolled in a science methods course, comparing beliefs of those who had experienced an inquiry-based physics course with those who had not. They found that those students who had the inquiry-based physics course prior to their methods course were more better able to recognize and apply inquiry in their lesson planning. Thus, undergraduate science courses that model pedagogy expected in K-12 classrooms have had positive impacts on future science teachers. It only seems reasonable to model NOS pedagogy thematically across the science curriculum of content courses.

Examples instruction that embeds NOS within science subject matter *not* specifically targeting evolution alone, are relatively few, but somewhat successful in advancing learners' NOS views (Abd-El-Khalick, 2001; Brickhouse et al., 2000; Clough, 1997; Howe & Rudge, 2005). Howe and Rudge (2005) describe a series of eight, 2 hour class sessions that targets NOS embedded within an historical study of sickle cell anemia. They report modest gains in preservice teachers' views of scientific theories, tentative NOS, subjective NOS, theories and laws, and observational methods. Abd-El-Khalick (2001) discusses explicit NOS instruction within the context of a physics course for elementary education majors. Through a series of introductory activities and embedded, content-specific activities and reflections, the students advanced views of targeted NOS aspects, but with limitations. Abd-El-Khalick reports that respondents were more successful describing NOS aspects when the NOS assessment items reflected course content. "…the context and content in which preservice teachers learn about NOS influence their ability to apply their understandings to novel contexts and content" (Abd-El-Khalick, 2001, p. 229). Results from such studies demonstrate a need to explore manners and effectiveness of embedding NOS thematically within science content courses.

Effective Teaching of NOS

Effective teaching of NOS in a content course, methods course, workshop, or internship has similar characteristics. The literature on NOS teaching is consistently supportive of an explicit/reflective approach in association with science learning experiences (Abd-El-Khalick & Lederman, 2000; Lederman, 2007). This approach treats NOS as a cognitive learning outcome and is planned for instructionally. Student learning of NOS aspects is valued, taught, and assessed in a similar fashion as other science content. Schwartz and Crawford (2004) characterized three critical elements to effective teaching of NOS. These are: (1) Reflection: Learners need to step out of the role of "inquirer" and into the role of "reflector" to consider how their science learning activities embody NOS elements. (2) Context: Reflection requires a context. Science activities such as hands-on inquiries, historical and contemporary episodes, and modeling through use of manipulatives and technology, may provide effective science contexts for learning about NOS. (3) Learners do not "do" NOS, rather they have learning experiences and prompts that enable them to reflect upon the way scientific knowledge is produced and the qualities of NOS represented within science practices.

Purpose of the Study

This exploratory study aims to describe how NOS explicit/reflective instruction is embedded thematically throughout an undergraduate biology course for elementary education majors (K-8 certification), and discuss the effectiveness of the approach on developing NOS views. The three critical elements informed the instructional and assessment designs. The perspective of NOS embraced for the course is that described above and supported by science education reform documents. The course also addresses scientific models and aspects of the nature of scientific inquiry (NRC, 2003). This approach is relatively unique to college level biology, and little research has been reported about how instructors embed and assess NOS across biology concepts.

Instructional Context

The biology course is one of six science content courses offered for future elementary and middle school teachers at a large mid-west university. The course is a 15-week lab-based course, usually enrolling from 20-24 students per section. The course meets twice a week for 2 hours, 20 minutes. There are no prerequisites for the course. However, enrolled students are typically upperclassmen who have completed most other science requirements for certification. They are required to take three of the six offered courses for K-8 certification. Students in this class typically are pursuing an integrated science teaching minor, which requires four of the six science courses. There are three units taught during the semester: genetics, molecular biology, and an integrated exploration of a human condition (includes application of cellular, genetic, molecular, ecological, and evolutionary perspectives). The effects of a version of the third unit on NOS views have previously been reported (Howe & Rudge, 2005). The present study examines the effectiveness of a thematic approach during the *whole* course. The researcher was also the instructor of the course.

Method

Participants

Reported here are results for two sections of the course, taught during two sequential semesters by the researcher. Thirty students participated in the present study. There were only three males in the sample. A majority of the students were in their junior or senior year. All were taking the course to fulfill a science requirement for their elementary education major. All had at least one other college level science course prior to their enrollment in the biology course (average of 3.7 prior college science courses/ student). The students had taken these other courses at the same institution (either in the science content series for elementary educators or in nonmajors general education science courses), or at one of several community colleges.

NOS Instruction and Assessment

The NOS and NOSI aspects explicitly taught included: tentativeness, subjectivity, observation/inference, creativity, theory and law, empirical nature, multiple scientific methods, scientific models, and the role of evidence in supporting explanations. For each unit, instruction was based on the following guideline to provide purposeful and planned opportunities to learn.

- <u>Goals and objectives</u> for NOS
- <u>Instruction</u>: Provide experiences, concepts, and vocabulary that enable students to consider NOS in an appropriate way

- Discussions: Relate science and classroom activities to aspects of NOS and activities of scientists
- Questions: Foster critical thinking and building of connections among aspects
- Individual reflection: Students were prompted to formalize their ideas through guided personal reflections
- Group sharing: Provide opportunities for sharing of ideas and experiences (with the guidance of the teacher through focus questions and activities)
- Assessments: Formative and summative

Specific course goals and objectives target NOS and NOSI. As stated in the course syllabus: By the end of this course, students will:

- be able to understand and reflect upon the nature and practices of biology rather than simply learning about disconnected facts to be memorized;
- be able to describe fundamental tenets of the nature of science and the nature of inquiry within the discipline of biology (e.g. role of observation and inference, empirical basis, role of creativity, validity of claims, multiple methods, among others);
- be able to relate current science research, historical episodes, and classroom inquiries in support of their views of nature of science and scientific inquiry;

Table 1 summarizes the sequence of instructional topics and NOS focus during the course. The first three class sessions focus exclusively on introducing NOS. A NOS pre-assessments is given (a version of the VNOS and VOSI (Lederman et al., 2002; Schwartz et al., 2000)). The students receive quiz points for completion of the surveys. They take the posttest (same surveys) during the last week of the semester. Introduction to NOS includes activities from Lederman & Abd-El-Khalick (1998) such as overhead pictures, tricky tracks, “the tube,” the “cubes,” fossils, and explicit/reflective discussions. An introduction to experimental inquiry includes an investigation of paper twirlies, where students can identify variables and study cause/effect relationships. These experiences are provided to introduce concepts of NOS and NOSI. They establish a common basis of vocabulary and examples that are referred to throughout the semester. Also during this introduction period, student groups do a reading about NOS myths (McComas, 1996) and prepare a poster to explain their assigned myth and the accepted perspective (e.g. the myth of a single scientific method). They also create group and individual concept maps of NOS themes. These experiences and class discussions offer opportunities for students to formally examine their personal conceptions and begin to examine the support they have for their views. Peer sharing generates additional options to explore. Appendix B presents examples of explicit/reflective instruction during the introductory series.

Following this introduction period, instruction focuses on cells, cell theory, and genetics. The second unit is molecular biology, and the third involves an historical investigation of sickle cell anemia (Howe & Rudge, 2005). Within each of these conceptual units, NOS and NOSI are explicitly and reflectively taught. This instruction includes (1) Referencing introductory examples, (2) scaffolding connections between the new science content and NOS aspects, and (3) using guiding questions. The intention is to make explicit the relevant NOS attributes and challenge student thinking by prompting reflection. During the third unit, student written reflections (journals) are guided by questions designed to further challenge students to support their NOS views. Quizzes and exams contained items specifically targeting NOS objectives.

Appendix C contains a sample of when and how NOS was addressed during one of the units (molecular). This is representative of how NOS is thematically approached in the other units as well. Keep in mind that these were not the only activities during the unit. Instruction also targeted molecular content objectives.

Data Collection and Analysis

This study implements a research-based instructional approach and examines student learning about NOS. Primary data sources are pre and post test VNOS and VOSI surveys (Lederman et al., 2002; Schwartz, Lederman, & Thompson, 2000). These surveys elicit participants' views through open-ended questions about NOS and NOSI. (Appendix A). Students earned quiz points for completion of surveys. Secondary data sources include journal entries during unit 3 (prompts based on Howe & Rudge, 2005); quizzes, and three unit exams. The pretest was given during the first class session. The post test was given during the last week of the semester. Journal entries, quizzes, and exam responses serve as secondary data sources, providing information about when (chronologically) students may have changed as well as biological context associated with views. Exam responses also provide information relative to the abilities of the students to make appropriate connections during the course. The course overview in Table 1 indicates when within the course quizzes, exams, and journal assignments occurred. As per course policy, copies of student exams and journal entries were retained by the instructor.

Student interviews would have been desirable to enhance the details of conceptions and learning factors (Lederman et al., 2002), but unfortunately they were not possible in the current study. Reported views and changes are based on written responses only. This researcher is experienced in assessing and evaluating NOS views with and without corresponding interviews. Nonetheless, the lack of interview clarification is a recognized limitation in the study. To facilitate reader understanding of data analysis and interpretation, the results include representative quotes and discussion of researcher interpretations.

NOS Views Continuum

Survey data were examined holistically (Creswell, 1998) to develop pre and post profiles for each aspect for each participant. The targeted NOS and NOSI aspects served as initial codes in the analysis. Responses were considered, compared and contrasted for an overall representation of a position relative to the targeted aspect. These profiles were then compared and represented on the NOS views continuum to characterize shifts for each participant. The entire sample was then examined to create the summary profiles for each targeted aspect.

For the analysis, degrees of understanding were based on respondents' use of examples, elaboration of statements, and demonstrated connections among NOS aspects and science contexts (Schwartz & Lederman, 2002; Lederman, Abd-El-Khalick et al., 2002). Instead of categorizing views as simply "naïve" and "informed," responses were classified according to a continuum representing a range of views from "naïve" to "more informed" (Figure 1). Within the naïve range, scientific knowledge is viewed as objective and culture-free, with truth revealed by the data alone ("seeing is knowing"); whereas a more informed view would describe scientific knowledge as a product of inferential and creative activities that find meaning within data to support conclusions; the knowledge produced in inherently subject to revision. More sophisticated conceptions, represented by elaborations beyond simple affirmation and explicated connections to contexts, are classified according to a multiple "+" system on the continuum that indicates *relative* degrees of informed views.

-----Insert Figure 1. NOS views continuum----

The NOS views continuum is not intended to be quantitative, nor does it intend to suggest unidirectional development of NOS views. The continuum represents a range of types of views individuals within a sample display. These views may shift in either direction. Use of a continuum enables identification of the “in betweens” to be represented as such. “In betweens” are those perspectives that do not totally align with “naïve” or “informed.” Likewise, the continuum enables relative representation of views within the “informed” range (less informed/ more informed/ even more informed/ etc). These views may be in transition between naïve and informed; they may be evidence of a dynamic and contextual nature of views; they may be evidence of cognitive dissonance whereby the respondent is unable to consistently formalize his/her position. The purpose of the present study is not to explore the nature of “emerging” views, but rather to offer a method of representing these “in betweens” on a continuum.

Analyzing views of experiment, scientific models, and justification

Survey responses were holistically examined for ideas related to justification of scientific knowledge, scientific models, and experiments. These data were reviewed and coded based with respect to the broad categories, rather than placing responses along a views continuum. Descriptive codes are based on participants’ choice of words. These results are presented, but only briefly discussed here.

Results

Results for participants in the two classes were analyzed separately and then compared. No overall differences were evident in the results between the two class sections. As such, data for both sections were combined.

The summary profiles of changes per aspect are presented in tables 2-8. Tables 9-11 summarize conceptions of experiments, models and justification. The use of the NOS views continuum enables representation of major and subtle shifts of the sample. For all of the aspects, the predominant positions for the pretest profiles are toward the left of the continuum. The initial NOS conceptions were typical of learners who have experienced science instruction without explicit NOS (Lederman, 2007). For example, overwhelmingly, the students reported views that science provides proof through experimentation, and that scientific laws are proven truths.

Although these initial results are not surprising, they are alarming, given the fact that these preservice teachers were nearing the end of their undergraduate program. Most were taking their last science course required for certification. Comments from students indicated they had rarely, if ever, been challenged to consider these NOS concepts in previous courses, at least not to the extent they were in the present course. When looking at the post test positions, we see more representation toward the right side of the continuum. These results depict positive gains overall.

These results are not surprising given the explicit/reflective attention during the semester. More interesting is an examination of how their views were expressed, as well as the types of shifts present *and* absent. Further, participant use of examples to support their views differed from pre to post (Table 12). Results for each aspect are discussed here, with representative quotes to explain positioning within the continuum. Because of the holistic nature of analysis, a response to a single survey item does not necessarily determine final placement along the NOS continuum.

Changes in NOS views

Tentativeness

Twenty of the thirty participants held naïve conceptions of the tentative NOS at the beginning of the course, with only three of the remaining ten voicing a view within the informed range. By the end of the course, 16 fall within the informed range. Use of absolutist terminology (e.g. 100% proof, truth) to describe certainty in scientific knowledge lessoned from pre to post.

> Naïve range: “Science is different from religion or philosophy because it looks at cold, hard proven facts as opposed to speculations, assumptions, and beliefs.”
>
> “A law is proven 100% true.”
>
> + range: “[re scientific knowledge changing]: “Yes [science will change] because science is tentative. It changes as new knowledge and new evidence comes into play.”
>
> Slightly more informed: “[Science] can be tested…and even though it can’t be proved as an absolute, there can be significant evidence supporting it.”

This third example demonstrates a connection between views of tentative NOS and empirical NOS. Thus it is deemed a more sophisticated position. This is in contrast to someone in the middle range of the continuum who accepts science as tentative, but assumes a more naive relativistic view where scientific knowledge can change on a whim because "everyone has their own ideas."

Creativity

Table 3 depicts shifts in participants' views of the creative NOS. Substantial gains are apparent, from initial ideas that scientists only use creativity in planning stages to understanding science as a creative human endeavor, requiring imagination and inference to develop meaning from data. None of the participants' fell within the naïve range at the end of the course. This is the only NOS aspect that had such success. Twenty-seven of the 30 participants demonstrated views in the informed range, with seven advancing to more sophisticated positions. Those representing the more sophisticated views demonstrated connections between views of creativity and other NOS aspects. They were also able to support their views with appropriate examples.

Naïve range:

> "Scientists use imagination and creativity in their planning part…when they have an idea for an investigation they have to be pretty lofty to try something new."
>
> "Science and art are different because art is a reflection of your own creativity."
>
> [No, imagination and creativity is not part of science] "Science is not about what you make up/imagine. Science is what is actually out there, what really exists in the real world."

+ range:

> "When you are making observations, you need to use your imagination and past experiences to think of a conclusion."

More informed range:

> "Creativity is used to make models to try and explain things."
>
> [Yes, imagination and creativity is part of science] "Absolutely! They must use creativity to come up with answers to their scientific questions. For example, Watson and Crick came up with the model for DNA through creativity."

Observation and Inference

Initially, 24 of the 30 participants failed to consistently recognize the role of inference in science. By the end of the course, 26 did recognize the inferential NOS, with 19 of these shifting toward a more sophisticated conception.

> Naïve range: [regarding 9b, acceptance of knowledge based about phenomena scientists cannot directly see] “I think we should consider them, but we do not have to accept them. They can still be questioned.”

Note that this quote alludes to the possibility of unquestionable claims, an absolutist position. Claims based on inference are seen here as flimsy, whereas claims based on direct observation would be of higher status and certainty. This person’s views of scientific theory and law as having different status levels is consistent with this interpretation.

> + range: [#9a] “Scientists know these things by making inferences and collective decisions from other areas of knowledge they have.”

> More informed: [#9a and b] “This information is based on other observations that that can be made. From those observations they are able to predict/infer what it looks like. [We should accept scientists’ explanations of things they have not seen] because even though we cannot see it, the scientists have solid evidence-based claims to support their explanations.”

Subjectivity

Initially, only four participants were within the informed range regarding views of the subjective/theory-laden NOS. Initial views are spread out a bit more, with intermediate ranges represented. Intermediates are determined by views that do not cluster with one of the more discrete groupings. There are inconsistencies or statements that indicate more or less conviction of a view relative to others in the sample. The post views for subjectivity also span a range, but toward the right side of the continuum, representing gains overall for the sample. Of the 23 who ended the course in the informed range, five demonstrated views to the right of “+”.

Some participants struggled with the idea of investigating past events [dinosaur extinction]. More naive conception about how scientists could come to different conclusions stemmed from seeing a lack of data and “no direct observation” as problematic.

> Naïve range: [#8, dinosaur extinction] “We were not here at this time and doe not know what happened. Therefore we have different viewpoints on how dinosaurs became extinct.”

Participants falling within the + range acknowledged the influence of different backgrounds and knowledge on making conclusions.

> + range: "Scientists have a different way of thinking and interpret data in different ways. People come from different backgrounds, leading to different interpretations based on this."

There were five participants within the "more informed" range on the NOS continuum at the end of the course. These were able to demonstrate multiple connections with other NOS aspects, elaborate their views in their own words, and make connections with science examples. The following response indicates a connected view of subjectivity, empirical NOS, inference and creativity. This participant was placed toward the "more informed" side of the continuum.

> More informed: [7a and b] "No [dinosaur extinction is not surprising] because no one was there to witness what took place. Scientists just look at the evidence that existed at that time and make predictions as to what happened. They sometimes have an opinion as to what happened prior to viewing the data and this shapes how they will interpret the data.[Scientists] often have bias or prior knowledge before viewing the data.so this shapes how each scientist interprets the data, which means that they will arrive at different conclusions. In addition, they are all creative when making conclusions, which will also alter the conclusions they make."

Although many participants recognized that different conclusions could come from the data set of data, some of their views suggested an "anything goes" position. There is evidence for a shift from seeing science as data = knowledge (scientism) to a naïve relativist perspective (Abd-El-Khalick, 2001).

> [#8] "Scientists all interpret information differently. People will always disagree because they have different views and interpretations."

Empirical NOS

The observed shifts in understanding the empirical NOS were somewhat more subtle than shifts within other aspect categories. The initial views fell fairly equally within the "-" to "+" range. The final views fell predominately within the "(+)" to "+" range. A naïve view was inferred from the following type of response that indicates scientists claims' should be accepted based on authority alone. There is no mention of requiring evidentiary basis for scientific claims:

> Naïve range: [#9b] [We should accept scientists claims] because scientists are good at what they do. That is just like asking 'should we believe the weather man is right?' We trust they are experts and will tell us right."

Responses that gave attention to data or connections to the real world fell within the informed range:

> + range: [#2 science and art] "Science and art both use creativity. Scientists use creativity when looking at data for explanation. They are different because art doesn't have to be real."

Those representing more sophisticated views voiced ideas that extended beyond mere affirmation that data are required in science. The following response to the same "science and art" question as above suggests a more sophisticated understanding of the balance between open creativity and real-world empirical data.

> More informed range: [#2 science vs art]. "Science and art are similar in the fact that they both require creativity and imagination. They are different because art really has no limit on creativity, whereas science has limits and the creativity must be within limits of the empirical data that exists."

Connections to other NOS aspects as well as examples similarly suggested more informed views:

> [#4b, This investigations *is* scientific because] "anytime you do something to come to a conclusion and you gather data, you are being scientific. What he did is like what Watson & Crick did."

Distinctions Between Scientific Theory and Scientific Law

Results for "theory and law" demonstrate initial views fell primarily in the "-" range. This range represents views of a hierarchical relationship between scientific theories and laws, where laws are proven theories (proven through repeated testing) and not subject to revision. The hierarchical view if typical of science learners of all ages (Lederman, 2007). In the post test, we see more of a spreading of views throughout the continuum. There are positive gains, but various types of changes.

> Naïve range:
> "A theory is just a theory until proven."
> "A theory is an idea not proven 100%."
> "A law is a theory that has been proven."

> "A theory is a scientists' belief as to a certain topic. A law is something that must be obeyed. It is flawless, like Newton's law of motion."
> "A law is something that can be proven over and over again. Like gravity. There is no disputing it."

The 10 participants still within the "(+)" range report views that are suggestive of a non-hierarchical difference in theory and law, but examples or other statements indicate inconsistencies or lack of conviction to this view. The following example reinforces why use of the NOS views continuum can be more representative of subtle differences amongst participants' views.

> (+) range: "A scientific theory is an inferred explanation of something that happens. It has support and evidence to help back it up. An example would be the big bang theory which explains why no dinosaurs are left. It's not proven so it can only be considered a theory. A Scientific law explains and describes relationships between observed scientific happenings. An example of scientific law would be Boyle's law which has the backing of a scientific theory so it has support and backed up evidence (molecular theory)."

A more acceptable response regarding the distinction between theory and law depicts theories as research-based explanations for phenomena and laws as described relationships between observable phenomena. While none fell into this range on the pretest, six participants were placed here on the post test.

> + range: "A scientific theory is the explanation of why something is the way it is. A scientific law is what you observe, the purpose of the explanation."

Five participants demonstrated slightly more sophisticated understandings of theory and law. These further shifts were represented by consistency of terminology use throughout the survey and explication of appropriate supporting examples.

> More informed range: "A scientific theory is an explanation for why something happens or acts the way it does….A theory is used in science when science is trying to explain certain phenomenons [sic]. An example of a scientific theory would be the gene theory. This is a theory because it attempts to explain why the Laws of Genetics happen."

Participants used a variety of examples to support their views of theory and law. There were fewer examples in the pretest. Those mentioned were sometimes appropriate (Big Bang theory, Plate Tectonics, Newton's Laws, Law if Gravity) and sometimes not. For example, one participant provided the example of a theory as "the earth's core is solid." Justification for this example stemmed from the view of theory as a guess that cannot be known for sure. Regarding scientific laws, this same participant provided the example of "Humans need oxygen to survive." She described this as a known fact, a truth. This participant made notable gains on her posttest responses, providing "gene theory" and "Mendel's Laws of Genetics" as examples, and appropriately explaining the distinction and function of the two.

Multiple Scientific Methods

Table 8 displays results for views about multiple scientific methods. Initial views fell toward the left, naïve, side of the continuum, claiming that "the scientific method" is a requirement for valid science. Participants commented that they had been taught "the scientific method" in school, and that is the way they thought science needed to be done.

> Naïve range: [#5, Yes, scientists must follow the scientific method] "I believe the scientific method is layed [sic] out perfectly to judge something as an experiment. When following this method you make sure to cover all the steps and you don't have to worry about missing something. The method gives you guidelines."
>
> [re science and art] "Both allow experimenting to create an end product. They are different by the fact that experiments, to be successful, need to be completed in one certain way."

By the end of the course, 23 participants demonstrated a more inclusive view of scientific inquiry. A view that accepts observational and correlational investigations as valid means of producing scientific knowledge.

> + range: [#4] "This is more of an observation than an experiment….They made observations and used facts from these observations to draws a conclusion."
>
> [#5] [No there are many scientific methods] "They differ because different situations warrant different methods of collecting and analyzing data. I think the most important thing is the way information is looked at."
>
> More informed range: [#4] [This investigation is scientific because] "all of these are ways of dealing with science…There's no 1 right way to go about dealing with science. Example: Franklin versus Crick/Watson."

Experiment

Table 9 presents results describing views of scientific experiment. The intention here was to elicit the preservice teachers' definitions and uses of this common word in science. Results demonstrate that there are various meanings, some of which changed over the course of the semester. Most notable is the increase in description of experiment as a controlled investigation, utilizing variables and controls to determine cause/effect relationships. During the course, class discussion explored similarities and differences in scientific methods, explicitly identifying those procedures that classify as controlled experiments. Views concerning the requirement of experiments for production of scientific knowledge shifted (12 pre/2 post). These results are consistent with those found for multiple scientific methods. Finally, there was a positive shift in students' views of hypotheses as requirements for scientific investigations. Various lessons attended to this issue by asking students if they had formally made a hypothesis at the beginning of their investigation. Nonetheless, three students are holding fast to their preconceptions of hypothesis requirements.

Scientific Models

Table 10 displays results of participants' descriptions of scientific models, including examples of models they provided to support their views. There are slight changes from pre to post in descriptions. Overall, most ideas about models concerned their explanatory and representation qualities. Only a few in the posttest considered models in terms of their use in investigations through enabling predictions and tests. A more complete view of models includes both their value as products of investigations as well as their use within investigations (tool of inquiry) (Schwartz, 2004). The most notable change is the use of examples. Students were better able to describe models through examples from the biology course. They were also able to include a several additional examples not from the course.

Justification

Table 11 presents results describing how participants thought scientific knowledge was justified. One of the survey items, #6, asks respondents to consider how scientists know when they are ready to make their results public. Responses to this item and #7b were the primary source of data for Table 11. Participants used phrases such as "proof of _______" more frequently in the pretest than the posttest (17 and 6, respectively), providing evidence of a positive shift in conception of the nature of evidence in justifying claims. There is also a reduction in number of participants insisting that all of the data be evidence for the conclusion ("No contrary data"). Under "other" for the posttest, we see that one participant explicitly recognized that some data may not "fit" and that scientists should try to explain anomalies. The posttest results also include statements about considering alternative explanations.

An additional piece of information emerges from the responses regarding participant views of how the public should respond when scientists puts out claims associated with unseen phenomena. Several students stated that the public could accept such claims, provided there is supporting evidence, but also realizing that these claims may change in the future. For example, one participant stated for item #7b, "We should accept [conclusions about unseen phenomena] knowing that their explanations and descriptions are inferences and new evidence/data may be found that alters or falsifies these ideas in the future." This statement suggests the student sees the value in understanding the tentative, yet evidence-based, NOS for the general citizenry.

Use of Examples

Table 12 displays all the types of examples provided within post test responses. Examples pertaining to course content were more frequent than those not related to the course. The course-related examples were from all units of the course, including introductory NOS lessons. Furthermore, examples specifically from the context of the VNOS and VOSI surveys were sited less frequently than other types of examples. The implications of their use of examples are discussed below.

Discussion and Implications

The purpose here was to describe and measure the efficacy of embedding NOS thematically within an undergraduate biology course, where the biological context was something other than evolution. The results demonstrate the success of the instructional approach on advancing these preservice elementary teachers' NOS views as well as views of some aspects of NOSI. Given the fact that the instruction was based on research-tested pedagogy for effective NOS teaching, the results are not surprising. The measured gains are substantial and directly correlate with instructional attention. These results are consistent with the growing body of literature demonstrating the effectiveness of explicit/reflective NOS instruction (Lederman, 2007).

So what do we learn from this study? First, NOS can effectively be embedded within biology contexts other than evolution. This paper provides examples of how NOS can be embedded in multiple contexts of a biology course, and how this instruction positively impacts student learning. Learners demonstrated abilities to support their NOS views with examples spanning several biological content areas. Second, the results of this study suggest a thematic approach has greater impact than a single-unit approach, even when both approaches are content-embedded. Consistency and exposure across the curriculum are recommended. Third, despite repeated opportunities to consider and write about NOS connections, there remains variability in learning outcomes. Each of these findings is discussed below.

The Significance of Examples

The students in the course were able to find connections between all targeted aspects and all targeted content areas. Table 12 shows these connections. A most interesting finding is that the context examples appear in unequal frequencies related to aspects. Under the aspect "Tentative NOS," students used examples from all broad contexts (the NOS introduction, genetics lessons, molecular lessons, and the sickle cell unit). Likewise, "Theory and Law" examples are drawn from all contexts. For "experiments," the primary context is the third unit that is an historical investigation of sickle cell anemia. Only one example is drawn from another course area (Griffith's experimental work with bacterial strains). However, students were able to draw from their own experiences in other contexts to discuss "experiments." Regarding "Models," it appears that the molecular unit provided the most examples accepted (or understood) by the students, although the introduction and sickle cell unit each had one example represented. We may glean from these results that some contexts may be "better" than others for enabling NOS connections to biological contexts that students accept. We may also glean from these results that using a variety of contexts may facilitate learners' overall understanding of NOS and abilities to explicate their views with multiple examples. We must keep in mind, however, that the majority of examples were those most familiar to the students, as originating from the course. Thus, teaching NOS in all science contexts, that being *beyond evolution,* during undergraduate science courses is highly recommended to situate future teachers for success in seeing NOS as integral to the domain of science and success in embedding NOS within their future science curriculum.

There is some evidence to suggest the students were somewhat able to transfer their conceptions from the learning context to a different context. Consider the results for observation and inference, one of the aspects showing the most gains. The context examples come from the NOS introduction and the molecular unit only. Yet, students were able to use two of the survey-related contexts and one earth science context to demonstrate their understanding of observation and inference. Because these examples were not a focus of any instruction, these results may suggest the transference of views from the learning context to a different context. We find a similar possibility with examples for Creativity. Students related creativity to the work of James Watson and Francis Crick, while also including creativity as a common characteristic of science and art. While discussions surrounding the story of Watson and Crick included the role of creativity, the students were not asked to discuss commonalties between science and art. Further study is warranted to explore the extent to which learners are able to translate NOS knowledge from the learning context to novel contexts, the conditions under which transfer is facilitated, and if there are some NOS aspects that are more easily connected than others.

Thematic vs. Single context

Howe and Rudge (2005) studied the effectiveness of using the historical events to understand sickle cell anemia as a context for explicit/reflective NOS instruction. They reported that explicit examples and reflective prompts in the investigation of historical data over a period of eight classes were successful in advancing preservice elementary teachers' views of several NOS aspects. This unit is one of the three taught in the present course. Therefore, I can compare the extent of growth demonstrated through thematic instruction to prior reports of change from just the one unit. The results here suggest that the thematic approach is likely more effective in reaching more students. It is difficult to directly compare outcomes, but percent gains and use of examples suggest the thematic approach has broader impact on the same type of learner population. Furthermore, the students were able to make multiple connections between NOS aspects and various biology topics, as evidenced not just through their survey responses, but also through their journal writings and exam answers. They identified appropriate examples from content throughout the semester to support their views. Results indicate the importance and potential impact of *consistency* in message about NOS across the curriculum, as opposed to a one-shot NOS introduction or embedding within one unit (Clough, 1997; Clough & Olson, 2004; Lederman, 2007; Lederman & Lederman, 2004). The success of the thematic approach may be due to repetition and/or variable contexts. From day one to the final exam, NOS is an overt objective of the course. Learners benefit from multiple examples and applications of concepts. Presenting NOS across the curriculum may provide optimal learning opportunities for learners. If they do not see connections in one context, such as genetics, they may see connections in another, such as molecular biology.

Misconceptions Maintained: Why do some learners experience conceptual change but not others?

The finding that five participants maintained more absolutist NOS views is intriguing (Table 2). Despite repeated examples, peer conversations, whole class discussion, and reflective writings these students were unable to alter their initial conceptions. They continued to use terminology such as "proof" and "true" to explicate their positions. These learners have an apparent reluctance to accept notions of ambiguity in science. Perhaps these undergraduates are not prepared to productively grapple with contentious notions of tentativeness and robustness in science (Hofer & Pintrich, 1997; Perry, 1970). Similar implications are drawn from a closer examination of the apparent gains regarding views of Subjective NOS. Many of the preservice teachers shifted from their initial "seeing is knowing" view to an "anything goes" view. Others have reported similar shifts from realist to multiplist perspectives (Abd-El-Khalick, 2001; Hofer & Pintrick, 1997).

There was only one participant who maintained an objective view of scientific knowledge (- on Table 5). Her initial ideas were that with enough data, scientists would agree. Her final ideas were perhaps even more strongly stated:

> [#8] [scientists disagree about dinosaur extinction] "The information is not specific enough. [It] can be subjective and tentative because of the lack of evidence."
> [The controversy can be resolved] "eventually if we found more evidence to support a theory or prove theories wrong, but we may never find enough information."

This is quite curious because she moved within the + range for all other aspects. Even her views of tentativeness fell close to acceptable range, as she explained that both theories and laws are subject to change. She is able to explain the roles of observation and inference, and the distinction between theories and laws. Her language regarding justification of knowledge, data, and evidence remained "absolutist" or "realist" through her consistent use of "proof" and related iterations. Despite explicit discussion in class about problems associated with absolutist terminology (proof, true, right/wrong), she held to her initial representations. Why is this student able to modify views of some NOS aspects, including tentativeness, but not subjectivity? Deanna Kuhn and colleagues report that acceptance of subjectivity with respect to "truth judgments" is more difficult for learners than acceptance of subjectivity with respect to personal taste or aesthetic judgments (Kuhn, Cheney, & Weinstock, 2000). Abd-El-Khalick (2001) suggests that "learning about specific NOS aspects might interact with learners' broader epistemic views in ways that might hinder such learning" (pg. 230).

Finally, regarding conceptions of theory and law, how deeply held is the hierarchical perspective! Even though the preservice teachers may accept that all scientific knowledge is subject to revision, many still cling to the conception that there is a hierarchical progression in developing laws from theories. The examples presented in this course were still insufficient for about half of the students to accept.

Is there a relationship between success in NOS learning and success in learning of the other biology content?

This is not a formal research question for the present study, but the results beg the question. The data have not been formally examined for correlations between success in learning of other biology content and success in learning NOS. These data are available and the analysis is pending.

I can speculate, however, based on the individuals who maintained naïve views of some of the aspects. These participants were not always the ones who earned the lowest grades in the course. For example, the following response is from a posttest survey. This student earned the grade of "BA" in the course, yet she maintained misconceptions about theory/law and scientific methods. This student has a conception of "scientific" as requiring the establishment of cause/effect relationships. This view was placed on the naïve side of the continuum. She did not demonstrate a change from her pretest profile with respect to scientific methods.

> [#4] [This investigation is not scientific] "because he didn't try to determine the cause of tooth shape. Science aims to explain things without any room for interpretation. The cause of tooth shape could have very well been caused by something besides food, such as chewing bones, trees, etc."

This student also fell toward the left of the continuum with respect to tentativeness, observation/inference, and empirical NOS. This same student scored high on classroom assessments that targeted the biological content. So, why didn't she accept the NOS concepts as well?

Regarding all these issues, an important "next step" is to explore what is happening cognitively and affectively with the learners who do not advance. What are their cognitive hurdles to conceptual change regarding some NOS aspects but not others? Perhaps an exploration of knowledge structures to probe relationships among NOS and NOSI conceptions, as well as among these concepts and other epistemological domains (e.g. as described in Hofer & Pintrich, 1997; Kuhn et al., 2000) would provide some insights.

Explicit teaching about NOS within the context of science content courses has been recommended for helping future teachers (1) learn the content of NOS and (2) experience the pedagogy of teaching NOS within science contexts. This approach employed in this study fulfills these criteria. But what effect will such learning experiences have on the future planning and classroom instruction for the elementary teachers? Hubbard and Abell (2005) examined the impact of learning physics in an inquiry environment on performance in science methods. A similar investigation regarding impact of content-embedded NOS learning on future success in the classroom is warranted. Are these future teachers able to find NOS connections across their curriculum?

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Appendix A

VNOS/VOSI-270

Name: ___________________________________

Date: __________________________________

Previous science courses:
Bios 1 Life Science for Elementary Educators 1 _____
Phys 1 Physical science for Elementary Educators 1 _____
Geog 1 Earth Science for Elementary Educators 1 _____
Bios 2 Life Science for Elementary Educators 2 __current___
Sci 2 Physical Science for Elementary Educators 2 _____
Geos 2 Earth Science for Elementary Educators 2 _____
Other college level science courses? Please list:

You have had some experience with learning science and have certain views about the type of things you learn in science class and where the science information comes from. There are no right or wrong answers. I am interested in your ideas about science and how science is done. Please answer each of the questions. You can use all the space provided to answer a question.

1. What, in your view, is science? How can you determine when something **is** science (such as biology or physics) and when something is **not** science (such as religion or philosophy)?

2. How are science and art similar? How are they different?

3. A lot of science relies on terminology.
   (a) What do you think a scientific experiment is? Give an example to support your answer
   (b)What does the word "data" mean in science?
   (c) Is "data" the same or different from "evidence" ? Explain.

4. A person interested in animals looked at hundreds of different types of animals who eat either meat or plants. He noticed that those animals who eat similar types of food tend to have similar teeth structures. For example, he noticed that meat eaters, such as lions and coyotes, tend to have teeth that are sharp and jagged. They have large canines and large, sharp molars. He also noticed that plant eaters, such as deer and horses, have smaller or no canines and broad, lumpy molars. He concluded that there is a relationship between teeth structure and food source in the animals.
   Do you consider this person's investigation to be an **experiment**? Please explain why or why not.
   Do you consider this person's investigation to be **scientific**? Please explain why or why not by describing what it means to do something "scientifically."
   This investigation **is** / **is not** (circle one) scientific because….

5. The "scientific method" is often described as involving the steps of making a hypothesis, identifying variables (dependent/independent), designing an experiment, collecting data,

reporting results. Do you agree that to do good science, scientists must follow the scientific method?

_______YES, scientists must follow the scientific method
_______NO, there are many scientific methods

- If YES (you think all scientific investigations must follow a standard set of steps or method), describe why scientists must follow this method.
- If NO (you think there are multiple scientific methods), explain how the methods differ and how they can still be considered scientific.
-

6. How do scientists know when they are ready to make their research results public? What kind of information do they need in order to convince others of their claim?

7. Models are widely used in science. What is a scientific model? Describe and give an example.
A scientific model is…..

8. Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists still disagree about what caused this extinction.
(a) Why do you think they disagree even though they all have the same information?
(b) Do you think this controversy could be resolved? If so, how? If not, why not?

9. There are many types of phenomena (past, present, and future) that scientists study, but cannot see. For example, scientists have never seen “dark matter”, the center of the earth, or into the nucleus of an atom. Yet many scientists use their understanding of these phenomena to do research.
(a) If they have never seen these things, what kind of information is this knowledge based on? [how do they know what they know about these things?]
(b) Should we, as a public, accept scientists’ explanations or descriptions of things they have not seen? Why or why not?

10. Scientists try to find answers to their questions by doing investigations. Do you think that scientists use their imagination & creativity in their investigations?
(a) If you think “no”, explain why imagination & creativity are not part of science.
(b) If you think “yes”, explain why and in what part of their investigations (planning, analysis of data, interpretation, etc.) you think they use their imagination & creativity?

11. (a) What do you think is the difference between a scientific theory and a scientific law?
(b) Give an example of a scientific theory and an example of a scientific law.
(c) Do you think scientific theories we have today will change in the future? Why or why not?
(d) Do you think scientific laws we have today will change in the future? Why or why not?

Appendix B
Examples of Introducing NOS

Reading: Students were assigned two readings during the first two weeks of the course.

- Nature of science description in the course pack.
- McComas, W. (1996). Ten Myths of science: Reexamining what we think we know about the nature of science. *School Science and Mathematics Journal, 96*(1), 10-16.

Poster/Presentation:
Groups of 2-3 were assigned a myth. They constructed a poster that describes the myth and why it is considered a myth. Groups presented their posters to the class. Class discussion followed each presentation for questions, examples, and relevance. Sample questions to generate discussion: Did any of you ever see a "scientific method" poster in any of your science classrooms? [most hands go up] What is the scientific method, as depicted on those posters or in textbooks? [students offer "steps"] Based on what we have been talking about and what you've read so far, do you think all scientists follow these same steps? [usually get some confused looks; students offer comments of yes and no. I probe further by asking for examples and explanations of "why." Eventually, we get around to applying other aspects of NOS to see if they are represented in the "scientific method." Because this is just the beginning, I don't push the issue too far. I encourage students to keep thinking about the discussion and readings. I let them know we will keep asking the question about the methods of scientific investigation as we explore biological topics. We will have lots of examples that will help us better understand why "the scientific method" is considered a myth.]

Sample activity and explicit NOS instruction

Activity	Aspects targeted	Example of Explicit Approach
The Tube (included constructing their own models) (Lederman & Abd-Ek-Khalick, 1998)	Observation/ inference	Students often make inferences rather than observations. When this happens, I ask if they are making an observation or inference, or if they can observe what they are saying. Example: S: The ropes are somehow tied together in the tube. T: What makes you say that? S: Because when you pull one, the others move. So they must be connected. T: Ok. Then what do you observe? S: The ropes moving. T: What then did you infer from that observation? S: That they must be connected. T: Ok. So is there a difference then between what is observed and what is inferred? S: Observed is what you see. Inferred is what you can't see but what you think is going on to make what you can see happen. T: Ok, that pretty well explains the difference. Your inference that the four observed ends of rope are somehow connected inside the tube. This inference is based on your observation of the movement of the ropes on the outside of the tube. You did not directly observe that they were connected, did you? But you can support your inference that they are connected based on what you are able to observe. We need to keep the distinction between what is observable and what is inference. [I often make two columns on the board as students make observations and inferences. We discuss differences. We discuss the need for inferences to have supporting observations. This introduces the concept of "evidence."
	Subjectivity	Students propose reasons for why the tube behaves the way it does. We verbally share ideas as a class. If someone does not make the proposal, I ask if they think a little man may be in the tube, pulling and pushing the strings as I manipulate the outside? This usually gets a laugh, but that is the point. T: Why do you laugh at the idea of a little man inside here? S: Because he couldn't breathe. T: Oh, sure he could. There is enough space at the holes for air to get in. Or maybe he has on a little oxygen tank. S: There is no such thing as someone that small.

		T: Oh, so my idea isn't a good idea because we have never seen a little man? Wouldn't it work though? S: Yes, but it isn't a good explanation because it doesn't make sense. T: There you go. It doesn't make sense with how we understand and accept the world to be. My idea would work, sure. But it is not a valid explanation of the mechanism of the tube because it does not fit within our theoretical framework of what is possible. Therefore, not all claims are equally valid. Some fit "better" than others. We have expectations and perspectives that influence how we explain the world. Do scientists have expectations and perspectives that influence how they explain the world? S: Of course. T: Of course. This is what we mean by subjectivity in science. Scientists come to investigations with perspectives that align with current knowledge. That doesn't mean they all have the same perspective. That just means whatever perspective they have influences what and how they do science. Just like the cubes. Remember? If you did not have knowledge of the English language, those symbols on the cubes would have taken on a completely different meaning. The patterns identified and predictions made would have been completely different. Would they have been wrong?
	Tent ative ness	After students have tested their models against the "real thing" (my tube), I ask a series of questions: T: Are all the "working" models equally valid? This generates discussion about what constitutes a valid claim in science. T: Since we have some models that seem to be valid, do we know what is in the "real thing" (my tube)? S: not necessarily T: Why not? S: Because there are different possibilities. T: Well, do you think we will ever know for sure? S: Yes, if you open up your tube. T: I can't do that. Just like at this time, we can't see into an atom. For the tube, you made observations, inferences, constructed and tested your models. If it works, does it matter if it matches the inside of mine or not? S: no. not really. T: Why not? S: Because it works. T: Again, what do we mean by "it works"? S: It does what yours does and we can make predictions that come true. T: Ok. But the model may not be exactly like the real thing. If we can't ever open up the tube, will we never know if we have it "right?" S: No. T: Does it matter? S: It might. If something else happens to make it not work anymore, then you know it is wrong. T: Ok. What do you think happens in that case? If there comes a time when the model no longer fits the observations? S: You have to find a new one that fits the new information. T: Ok, then we may never know if we have it "right" and that doesn't matter as long as the model is working for us. When additional information is available, or when perhaps we look at the data again in a different way, the model may have to be changed. Do you think that happens in real science? S: Sure. Scientists get new information. T: Ok. Then do you think science ever has or knows it has the absolute final "truth" ? Think about if we can never open the tube, but we must rely on the collected data and creative inferences. S: Maybe. T: Well, you just said new observations may make it necessary to change the model. Right? Will we ever be able to make every possible observation for all of time? S: no. T: Then is there a chance the model, or any scientific knowledge, may have to change in the future? Is anything known for absolute certainty? S: no T: Ok. This is not to imply that scientific knowledge is flimsy. Don't forget we have a lot of observations and knowledge that went into the construction of the tube models. You just didn't make them up based on nothing. Science has basis in what we call empirical observations. That means data are gathered, examined, and used to support scientific claims. That is part of the nature of science.

Appendix C

Example of embedded NOS instruction

<u>Sample activities and explicit/reflective prompts from the Molecular unit</u>

- Students view the *Race for the double helix* movie
- Worksheet: describe and compare NOS views from the film (Watson, Crick, Franklin, Wilkins)
- In-class study of the work of Griffith, Avery/McCleod/McCarty, Hershey/Chase, Chargaff.
  - Written exercise: Students asked to compared the approaches of each; how the work was accepted (or not); examined how subjectivity, creativity, and tentativeness are represented in the various works; Class discussion provides opportunity to scaffold appropriate connections (as needed)
- Explicit connections to earlier activities: Written exercises and group discussion
  - How was the work of developing a model of DNA similar to what you did with the tube? *[Focus is on observation/inference; creativity; subjectivity; empirical; tentative; models; prediction; justifiable claims]*
  - Recall the overhead of the dog. Once you saw the dog, you were unable to NOT see the dog. Once it was in your mind that a dog is what you were looking for, a dog is what you saw.
  - Can we relate "the dog" to the development of DNA model? Where did we see an influence of perspectives and expectations to the work of Watson & Crick? Rosalind Franklin?
  - How did their expectations play a role in what data were sought and how data were interpreted?
  - Do you think they were doing bad science because they had preconceived notions? Why? What do you think would have happened if they had no expectations about DNA structure?
  - What role does prior knowledge and expectations play in science?
  - Can we ever totally avoid them?
  - Do we want to?
- Discussion questions:
  - Nobody could directly see DNA, so why were some models more acceptable than others? How were they critiqued? What elements of NOS and SI do you think that demonstrates? *[observation/inference; subjective; empirical; justification]*
  - What do you think Rosalind Franklin views are about subjectivity in science? What about the movie makes you think that? How does this view compare with what we have been discussing about the theory-laden NOS?
  - What were the roles of observation and inference in the development of a DNA model?
  - What type of evidence did these scientists use to support their claims? Why do they need evidence?
  - Compare the type of science done by Watson and Crick, Franklin, and Griffith.
  - How are they similar?
  - How are they different?
  - Are they all science? Why? What makes something scientific?
- Topic: The Central Dogma
  - Activities: Models and modeling of the processes
  - Targeted aspects: Predictions, Subjectivity, tentativeness, creativity

<u>Sample assessment item from the molecular unit:</u>

Source: Quiz

- None of the scientists who were working on the structure of DNA ever directly saw a DNA molecule. Yet, they developed and critiqued models. Recall that Watson and Crick criticized Pauling's model. Franklin criticized Watson and Crick's early model.
  - If nobody had ever seen what DNA looked like, where do DNA models come from?
  - If nobody had ever seen what DNA looked like, how could any of the models be criticized as "wrong"?
  - If nobody had ever seen what DNA looked like, why was the eventual model of Watson and Crick accepted?
  - What do these types of events tell us about the nature of science?

Figure 1. NOS Views Continuum

Table 1. Biology course overview

Week	Topics	Activities for explicit NOS connections	NOS Assessments
1-2	NOS and Scientific Inquiry	All aspects introduced: The cubes The tube Twirlies Fossils Reading: "10 myths" (McComas, 1996) Poster presentations	VNOS/VOSI pretest 10 myths poster presentation NOS concept map
3	Cells/ cell theory	Cell models; theory	
4	Cell reproduction: mitosis	Modeling mitosis: observation/inference, models	
5	Reproduction: meiosis	Modeling meiosis: Observation/inference	Quiz 1: NOS aspects, 10 myths revisited
5	Mendelian Genetics: Simple dominance patterns	Modeling crosses Observation/inference Creativity: making sense of data Theory/Law distinction	
6	X-linkage Pedigree analysis Relevance to decision making	Pedigree analysis: subjectivity; observation/inference; tentativeness; creativity	
7	Exam 1		2 NOS Items
7	Historical look at "the genetic material"	Examine procedures and findings of Griffith; Avery, McCleod, McCarty; Hershey & Chase Discuss differences in procedures (experimental approaches); justification of claims; subjectivity (protein vs. nucleic acid)	
8	View movie "Race for the double helix"	Worksheet, group discussions, class discussions about NOS as depicted in the film; subjectivity, creativity, tentativeness, observation/inference, empirical NOS, multiple scientific methods; justification of claims	Class discussions Worksheet
9-10	The central dogma: DNA replication RNA transcription Protein synthesis	Modeling processes Predictions: subjectivity Practical application of creativity in making sense of information	Quiz: NOS connections from the historical view and video
11	Exam 2		3 NOS items
11	Biotechnology applications PCR, DNA fingerprinting, cloning, stem cells	Examining data: Observation and inference	
12-14	Mystery disease (sickle cell anemia case study)	Series of studies of historical data to investigate a mystery disease; class discussions and guided journal writings with NOS connections (modeling; observation/inference; subjectivity; creativity; multiple methods; empirical NOS; theory/law; tentativeness	Daily journal reflections VNOS/VOSI posttest
finals	Exam 3		5 NOS items

Tables 2-8. Pre and Post Views of Nature of Science Aspects along the NOS Views Continuum

Table 2. Tentativeness

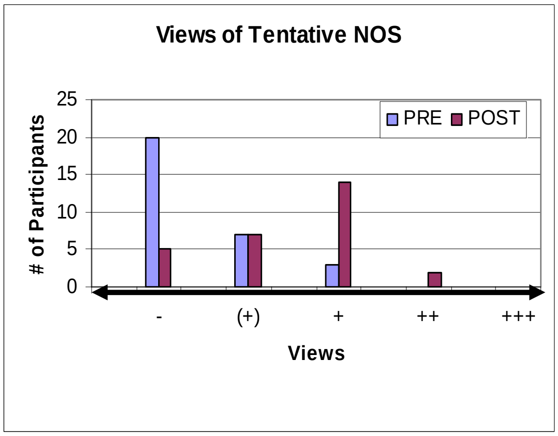

Table 3. Creativity

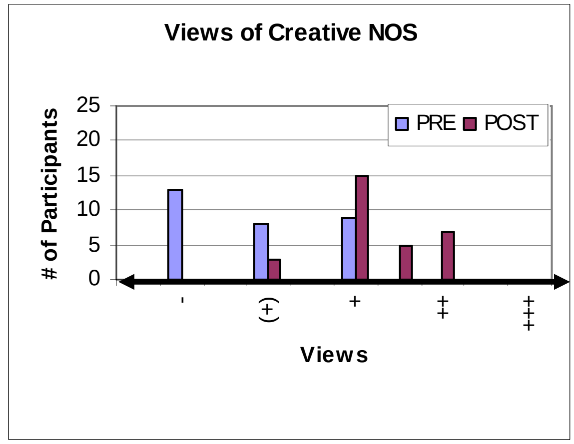

Table 4. Observation and Inference

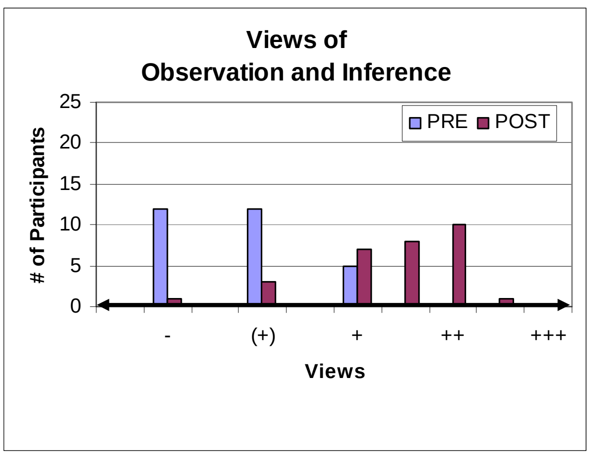

Table 5. Subjectivity

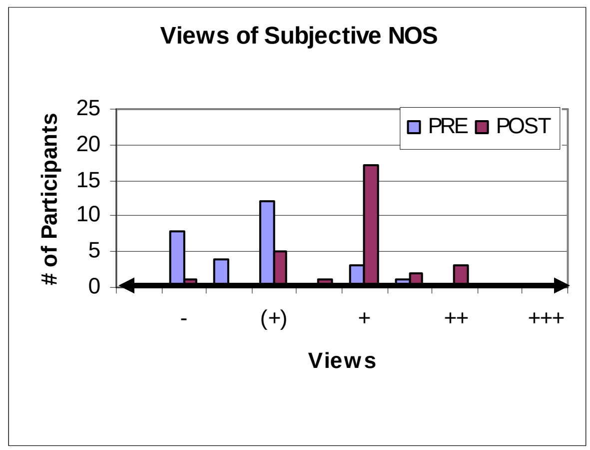

Table 6. Empirical NOS

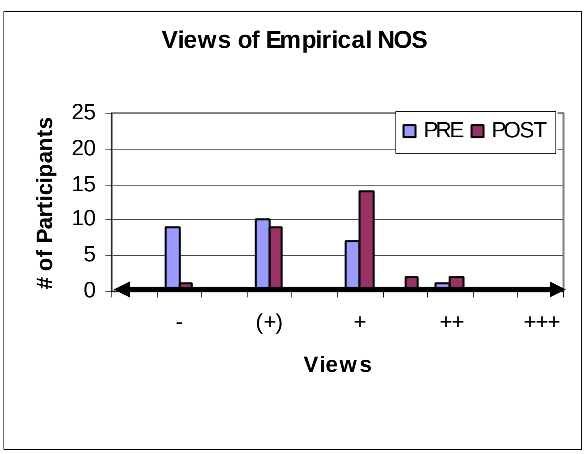

Table 7. Theory and Law

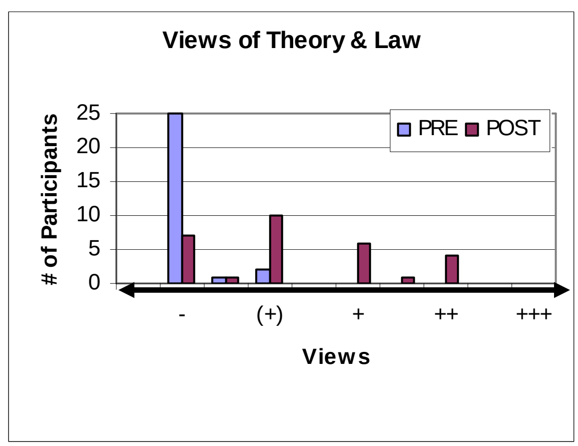

Table 8. Scientific Methods

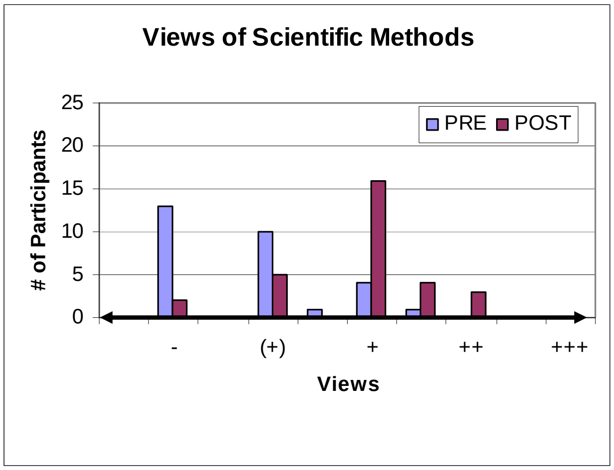

Table 9. Responses relating views of experiment

Experiment	**Pre**	**Post**
General	8	5
Controlled	17	23
Hypothesis	9	3
Required	12	2
Other:	Test hypothesis Solve a problem Prove a theory Prove or disprove something(2) Prove ideas right or wrong(2) Prove hypothesis Proves what scientists thinks Proves something(2) Explain something Test something you know Test an answer Test something to see if it is correct (2) Test of a theory	Tests Need a question Test to explain something To explain something Modeling Support or disprove something Prove or disprove something(2)
Examples	plant growth mix chemicals test motion or energy melting ice in sunlight	Griffith and pneumococcus Injecting different people with disease to see what the effect is Model of volcano used to test effect of changing a variable Test irregular shaped blood cells in a blood vessel model Anthony Allison’s work injecting people with malaria Comparison of mystery patient’s blood to normal blood pH test paper twirlie activity plant growth Electrical circuits put together differently

Table 10. Responses relating views of Models

Models	Pre	Post
Visual represent tation	15	13
Explanation	9	11
A Process	3	3
Exact replica	2	1
For Prediction	0	2
Use to Test	0	3
Other	Scale up or scale down (2) Used in teaching (2) Describes how something works (4) So others can repeat what you did An experiment (3)	Being creative Supports a claim (2) Display of what is happening (2) Manipulate to solve a problem (3) Simulates a phenomenon Based on observation and inference
Examples	DNA model (to see DNA) Atom Silver box (black box) Heart (2) Globe Solar system (4) Food chain on a computer Water cycle	Atom(3) The Tube (2) Volcano model to test effects DNA model (Watson&Crick) (7) DNA replication model Mystery patient: modeling RBC movement (2) Solar system Human body Molecular model Central dogma Model to understand dinosaur movement and behavior Pauling's DNA model DNA and RNA synthesis Protein synthesis

Table 11. Responses relating views of Justification

Justification	Pre	Post
Evidence	13	20
Proof	12	5
Data	9	4
Reproducible	19	11
Others repeat	5	1
No contrary data (no anomalies)	6	3
Proof it is true	3	1
Peer review	1	3
Other:	Confidence Have a proven theory (2) Proof without doubt	Recognize/explain anomalies Consistency/fit with accepted knowledge (2) Have evidence-based claims (5) Public is ready to hear claims Tried to prove wrong/ considered other alternatives (2)

Table 12. Use of examples to support NOS views: Post Instruction

Aspect	Supporting examples from the course	Supporting examples *not* from the course	Supporting examples reflecting VNOS or VOSI survey items
Tentative NOS	The cubes/ the tube Inheritance patterns of the mystery disease Invitro vs Invivo blood testing Development of DNA model (5) Views of scientific method(s)	Flat earth/round earth (3) Understanding of the ocean	Dinosaur extinction
Creative NOS	Watson & Crick interpreting Rosalind Franklin's data (2)		science vs art Dinosaur extinction
Observation/inference	DNA model The tube Rosalind Franklin's photo	Earth core	Teeth structure/food source Dinosaur movement/appearance
Subjective NOS	Watson & Crick's development of DNA model What is the genetic material (protein vs DNA)	Glass half full/half empty	Dinosaur extinction
Empirical NOS	Use of data to develop DNA models		Science vs. art
Theory and Law	Law of segregation Mendel's laws (4) Gene theory (2) Mystery disease theory (2) DNA replication The tube	Big Bang theory (3) Law of gravity (6) Theory of relativity Newton's laws Heat rises	Dinosaur extinction
Scientific methods	Rosalind Franklin compared to Watson & Crick	Study of earth's history (observational)	
Models	The Tube (2) Volcano model to test effects DNA model (Watson&Crick) (7) DNA replication model Mystery patient: modeling RBC movement (2) Central dogma Pauling's DNA model DNA and RNA synthesis Protein synthesis	Growth of plants Solar system Human body Molecular model Atom(3)	Model to understand dinosaur movement and behavior
Justification	DNA model: peer review		
Experiment	Test irregular shaped blood cells in a blood vessel model Anthony Allison's work injecting people with malaria(3) Comparison of mystery patient's blood to normal blood paper twirlie activity Test of blood flow Griffith's tests with bacterial strains	Testing Electrical circuits Plant growth Model of volcano used to test effect of changing a variable pH test	