Investigating College Biology Majors' Struggles to Understand the Nature of Science from Historically Accurate Short Stories.

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Abstract

This research sets out to more thoroughly understand student struggles and misconceptions regarding the nature of science. The participants were undergraduates at a large Midwestern university enrolled in an introductory biology course (N=168). The participants read historically accurate short stories that highlighted the nature of science through embedded bullet points and questions. Responses to the embedded questions were collected. Qualitative research methods were employed to identify, organize and make meaning of student misconceptions and conceptual hurdles. Results include descriptions of misconceptions and noting the supportive nature of students' misconceptions. That is, some misconceptions seem to be supporting other misconceptions and possibly preventing conceptual change.

Introduction

Importance of nature of science

Science literacy is an important goal for an educated society. Unfortunately, definitions of science literacy in practice are often relegated to lists of facts to be memorized rather than understanding how science works. Yet, reform efforts have continuously worked against simple, factual knowledge as the end of science education (AAAS, 1989; NRC, 1996). Shamos (1995) argues that helping students understand how science works and how scientists do their work is a more attainable goal than having students come to know science in the formal academic sense. While reform efforts do acknowledge the need for students to understand science subject matter, reform efforts explicitly discuss the need for inclusion of the nature of science for science education as summarized below.

> Scientific literacy also includes understanding the nature of science, the scientific enterprise, and the role of science in society and personal life. The *Standards* recognize that many individuals have contributed to the traditions of science and

> that, in historical perspective, science has been practiced in many different cultures. Science is a way of knowing that is characterized by empirical criteria, logical argument, and skeptical review. Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture (National Research Council, 1996, p. 21)

More specifically the *Standards* note that "students need to understand that science reflects its history and is an ongoing, changing enterprise" (NRC, 1996, p. 107). The history of science can clarify and deepen students understanding of NOS concepts (Clough, 2006)

Teaching the nature of science

Misconceptions regarding the nature of science are prevalent among both students and teachers (Lederman, 1992; Abd-El-Khalick & Lederman, 2000a). Common misconceptions include: theories become laws, scientific laws are absolute, an ahistorical universal scientific method exists, science is not creative, science can answer all questions, scientists are objective, all science is experimental, science is a solitary endeavor, science and technology are the same, and many more (McComas, 1998). These misconceptions are not surprising given the way science is often taught in both secondary and post-secondary education. Cookbook labs, instructor language, and textbooks implicitly and explicitly portray science from a positivist philosophy that dominated the early 20th century (DeBoer, 1991).

While the nature of science is often relegated to a serious of "tenets", educators must use caution when reducing the nature of science to a list of tenets (Clough, 2005). The nature of science, like most all science content, is more than a list to be memorized. Students must wrestle with the complexities and ambiguities of NOS ideas and how they are useful for understanding how scientists work. Teachers must consider how students assimilate new ideas into mental structures. Simply telling students how science works or having them read about science is not enough (Rowe & Holland, 1990; Saunders, 1992).

Teachers must find out what their students are thinking and design activities that lead students to more accurate understanding (Clough, Clark & Berg, 2000). Students cannot be indoctrinated into understanding the nature of science. Even in model classrooms, long-term conceptual change can prove difficult (Clough, 1995).

Activities to help teachers accurately address the nature of science have typically included "black-box" type activities (Lederman & Abd-El-Khalick, 1998). Such decontextualized activities are not designed to teach students about science content, yet work well to engage students with NOS discussion. Additionally, inquiry-based science content instruction has been promoted as a moderately contextualized approach to teach students about the nature of science. Yet, Abd-El-Khalick & Lederman (2000a) have noted the need to explicitly draw students' attention to the nature of science and have students reflect on NOS concepts. Simply having students read about or even perform activities that accurately portray the nature of science are not enough to counter the years of inaccurate portrayals that students have experienced.

Clough (2006) has added to the explicit/reflective suggestions for effective nature of science instruction by noting the importance of scaffolding between decontextualized, moderately contextualized, and highly contextualized NOS activities. While using decontextualized and moderately contextualized activities are important, neither provide students with the rich context that historical episodes of real science can provide.

While discussing decontextualized and moderately contextualized activities Clough (2006) notes:

> First, such experiences may easily be seen by students and teachers as not reflecting their perceptions of authentic science – how science, as practiced by scientists, is done. … While playing an important role in conceptual change, decontextualized and moderately contextualized NOS experiences create a very limited context in which students must reexamine their existing ideas. (p. 473)

Clough goes on to note that teachers often see decontextualized activities as an 'add-on' - detracting from science content instruction. In contrast, highly contextualized NOS instruction requires integration of historical or contemporary science episodes that can illuminate the complexities, challenges, metaphysical assumptions, theoretical context, cultural influences and leaps of logic inherent to scientific inquiry and the development of fundamental science ideas.

Using the history of science to teach nature of science

The inclusion of historical and contemporary science examples in science education has long been promoted (Conant, 1957; Klopfer & Cooley, 1963; Matthews, 1994; Clough, 1997, 2004; Abd-El-Khalick, 1999; Lonesbury & Ellis, 2002). The AAAS (1990) claims, "Generalizations about how the scientific enterprise operates would be empty without concrete examples" (p. 145). Lonesbury & Ellis (2002) note the utility of the history of science for providing these concrete examples. Matthews (1994) asserts that history is necessary to understand the nature of science. All of the efforts cited above fit into the highly contextualized end of the previously mentioned continuum, although not all have noted the need for explicit/reflective instruction (Abd-El-Khalick and Lederman, 2000).

Clough (2006) adds to the importance of using explicit/reflective highly contextualized NOS instruction for students:

> The crux of this matter is that as NOS instruction moves from explicit/reflective decontextualized to explicit/reflective highly contextualized, the ease in which students can dismiss a teaching scenario as misrepresenting how authentic science works decreases. This means that students will be less likely to exit from instruction while holding an approximate fit of a NOS encounter to their preexisting ideas. (p. 475)

Clough continues, noting the importance of explicit/reflective highly contextualized NOS instruction for science teachers:

> Second, in moving along the continuum toward highly contextualized explicit/reflective NOS instruction, the ease in which science teachers may dismiss NOS education as detracting from science content diminishes. Rather than an 'add-in' activity, NOS instruction is ubiquitous with teaching science content. (p. 475)

While empirical studies concerning the use of historical materials to teach NOS have had some success (Klopfer & Cooley, 1963; Lonesbury & Ellis, 2002), problems with historical materials have been noted (Tao, 2003). More extensive work is needed in developing historical materials that address NOS concepts, understanding how students' NOS conceptions are affected by historical materials, and how instruction might be best carried out concerning the use of historical materials to teach NOS.

This work is one portion of a larger National Science Foundation funded project intended to develop and study the effect of explicit NOS instruction through the use of historical short stories (Clough et al., 2006). Faculty members from science education, history of science, geology and biology, as well as graduate students from science education and history of science worked to develop curricular materials related to the study. Creating the short stories comprised of 1) researching and writing short stories (4-6 pages in length) that exemplify elements of the nature of science through historically accurate descriptions of scientific work in the fields of geology and biology that relate to content of the course studied including: age of the Earth, Darwin, Wallace, and Mendel; 2) writing statements and questions designed to draw students' attention to both content and NOS concepts – particularly evidence use, the variety of processes involved in the construction of knowledge, the need for creative interpretation of data, science is but one way of knowing relying heavily on methodological naturalism, the effect of experience, culture and society on science, subjectivity, and the tentative, yet durable, nature of scientific knowledge; and 3) researching and writing assessment items that align with the NOS and content understanding promoted by the stories.

Purpose of Study

This study investigates the use of historical short stories designed for use in introductory college-level science courses. The development of these materials and this study have been supported, in part, by a grant from the National Science Foundation (Clough, Olson, Stanley, Colbert & Cervato, 2006). The primary purpose of this study is to understand interpretations and struggles of introductory biology students when reflecting on the nature of science through the use of specifically designed historical short stories. Specifically this study intends to answer the following research questions.

A. What misconceptions persist in light of HSS's?
B. What hurdles do students encounter when trying to gain NOS understanding from historical short stories?
C. What interrelations exist among demonstrated misconceptions/struggles?

Development of Materials Used in the Study

Short stories and embedded questions

Development of the historical short stories was informed by the extensive literature concerning NOS instruction and incorporation of historical materials for teaching science. To draw students' explicit attention and provide opportunities for reflection on NOS ideas (Abd-El-Khalick and Lederman, 2000) questions and bullet points were inserted within each of the stories. Furthermore, the stories represent authentic science episodes and are rich in science content to provide rich context for the NOS ideas being promoted (Clough, 2006). Heilbron (2002) notes the need for more than history when he notes: "Whenever possible the case studies should carry epistemological or methodological lessons and dangle ties to humanistic subject matter. But never should the primary purpose of the cases be the teaching of history" (p. 330). Heilbron's work further informed the development of the short stories through his suggestions of 1) creating case studies that can be easily inserted into science courses; 2) creating case studies that convey useful scientific information; and 3) case studies ought to be written by teams of historians, philosophers, scientists and teachers.

With these suggestions in mind, a team of science educators, historians of science, geologists, and biologists set about creating historically accurate short stories containing carefully worded questions and bullet points to highlight and guide student thinking about the nature of science and the science content. For the biology course studied, five short stories were used – two stories on the age of the Earth, and a story each on Mendel, Darwin, and Wallace.

The geology stories were selected to help students understand the tremendous age of Earth. Students' understanding of deep time is a prerequisite for understanding the great amount of time needed for biological evolution to result in the great diversity of species now inhabiting the Earth. Yet, Trend (2001) notes that people's cognitive frameworks of deep time "differ greatly from the scientific consensus" (p. 192). Half of one sample population (10-11 & 14-15 year olds) believed that the Earth and life originated at about the same time (Marques and Thompson, 1997b). If students do not have an accurate notion of how long the Earth has existed or how long life has been around, there is little wonder why they dismiss evolution *a priori.* Two short stories were used near the beginning of the course to address some of these misconceptions about how scientists have come to understand the age of the Earth as well as introduce students to some fundamental NOS ideas, including: data must be interpreted, science is socially and culturally embedded, science is but one way of knowing, subjectivity and the theory-laden nature of research, and the role of creativity in science.

Another short story used concerned the work of Gregor Mendel. As part of the introductory biology curriculum, students were expected to be introduced to basic genetic principles. Because students were learning about Mendel's Laws, the short story that had been developed about his work was appropriate for the content. Additionally, the Mendel story helped to further illustrate NOS ideas promoted by the geology short stories and added key ideas such as: the lack of a "scientific method", the role of consensus building, as well as the revolutionary character of science progress.

Southerland and Sinatra (2003), when studying how students' learning disposition correlate to their acceptance of biological evolution, note the possible link between student NOS understanding and acceptance of biological evolution and Johnson and Peeples (1987) claimed college biology students' understanding of evolution through natural selection was dependent on their understanding of the nature of science. To highlight the nature of science within the context of this controversial topic, short stories were assigned to students on both Darwin and Wallace. These short stories draw attention to the two most prominent individuals associated with the development of evolution and encourage students to see evolutionary theory as more than the work of a single man. The Wallace and Darwin stories reaffirm many of the NOS ideas promoted by the other three stories and also explicitly address additional NOS concepts, including: rationales for methodological naturalism, the immense time for ideas to be developed and accepted, the tentative nature of ideas, the difference between scientific laws and theories, and the difference between observational and experimental science.

Research Participants and Study Context

The research participants in this project were students enrolled in a one-semester, undergraduate, introductory biology course at a large, public, Midwestern U.S. university (N = 168). First year students who intend to major in biology or other related science disciplines typically take the introductory biology course. The course studies a variety of biological concepts including, but not limited to: diversity of life, classification, genetics, biological evolution, and ecology. The primary method of instruction included lecture based on instructor-designed PowerPoint presentations that were available to students online. However, the instructor also had students discuss in small groups, share ideas with small groups, and ask questions in class as well as using an online platform.

Data Collection & Analysis

Participants were asked to read a total of five short stories and complete the embedded questions as homework. To answer the research question, the homework was collected in hardcopy, typed format.

Because the short stories used in this study account for Abd-El-Khalick and Lederman's (2000) need for explicit/reflective NOS instruction as well as Clough's (2006) call for highly contextualized instruction, the student responses to the short stories ought to be fertile ground for identification (and categorization) of persistent NOS misconceptions and elements which hinder students NOS learning. Because this research was directed toward identification/categorization of elements and exploration of their connections, a grounded theory approach was implemented in answering the research question (Tesch, 1990). Student answers to embedded short stories were analyzed to gain greater understanding of how students interpret and make meaning of the NOS ideas promoted by the short stories. Constant comparative methods were used to create and confirm categories and coding schemes (Glaser and Strauss, 1967).

For this study, four embedded questions were analyzed spanning two of the five short stories. The first short story used in this paper, "Naturalists and Chronologists" (NC), concerned the quest to understand the age of the Earth highlighting the role of the many players and varied philosophical assumptions they adopted. The other story, "Charles Darwin: A Gentle Revolutionary" (D), targeted Darwin's progression toward developing natural selection theory.

Three questions from the "Naturalists and Chronologists"(NC) story were analyzed. Their text and abbreviation appear below:

> (NC, Q1)
> Those who are investigating the natural world at this time have either the personal financial resources or the financial support from others to conduct their work. The word "scholar" comes from the Latin word "scholee" which means "leisure time". Today we hardly think of conducting scholarly work as "leisure". Why do you suppose that in the past, leisure time was associated with doing science and other forms of scholarship?

> (NC, Q2)

Consider how scientist's many associations likely influence and nurture their thinking. Many people dislike the thought of a science career, seeing it as a solitary undertaking. How does this story illustrate that science is a social endeavor?

(NC, Q3)
Many textbooks and teachers will talk about what data *shows* or what data *tells* us. How does Hutton's and other scientists' need to convince others of the meaning of observations illustrate that data doesn't *show* or *tell* scientists what to think?

Only one question was analyzed from the Darwin story for this research.

(D, Q3)
Nobel prize winning scientist Percy Bridgeman once stated that science is "doing one's damndest with one's mind, no holds barred." He was expressing that doing science research demands creativity and that scientists will use most any method that will help them understand the natural world. Many people wrongly think that scientists follow a rigid step-by-step scientific method when doing research. This misconception wrongly leads to another misconception that the value of a scientific claim can only be made through a controlled experiment. Many of the most well established scientific ideas defy investigation by means of a controlled experiment. a) How might you account for the prevalence of these two significant misconceptions regarding how science research is done? b) How might the public's adherence to these misconceptions cause them to reject biological evolution?

These questions represent a wide spectrum of NOS ideas the short stories target and their analyses are here presented as a documentation of emergent themes that may prove useful to those planning instruction, embarking on research, or designing curricular materials.

Each student response for a single embedded question was read and searched for misconceptions or language indicating unclear understanding of NOS ideas. In addition to misconceptions regarding the NOS, alternative interpretations of the short-story questions or text were noted. During the initial reading and open coding, descriptive words and phrases were used to identify chunks of student writing. After initial open coding, axial coding reduced the descriptive words and phrases into common categories or themes.

Once initial themes were developed student responses to the embedded question were reread and chunks of student responses were highlighted using color codes to designate the theme in which that chunk could be grouped. Once student writing for each question was grouped by themes, each theme data set was read again and more specific codes were developed to gain deeper insight.

After each question was analyzed and subsequent themes developed, questions identifying related NOS concepts were compared for similarities or contradictions in themes. Finally, all themes developed for each question were compared to understand the pervasiveness of student misconceptions and struggles as well as identify additional or interrelated themes to help explain student struggles to conceptual change.

Limitations of Study

The interpretive nature of our data analysis creates concerns for the constructs of validity and reliability. Of course our interpretation of the students' words is affected by our own perceptions. All research is limited by the assumptions researchers make. In an effort to improve the interpretation of the results here reported, some assumptions and limitations of the researchers/research are discussed.

1. The most reliable way to understand students thinking is through interviews (Aikenhead, 1992; Lederman, 2002). Because of such a high N, interviewing all participants was not feasible. During a pilot study, forty students were interviewed to ascertain accuracy of participant

interpretation of the questions as well as researcher interpretation of written responses.

2. Results and conclusions apply to high levels of short story implementation. The instructor placed great significance on the short stories: discussing them in class, and using test items based on the short stories. Similar results would not be expected in other courses without similar levels of short story implementation.

Results/Discussion

While the students held many widely varied misconceptions, the discussion below focuses on more commonly expressed misconceptions or idiosyncratic interpretations. We must note that most students did not express the misconceptions below. Many students demonstrated very accurate NOS conceptions that they could support using examples from the stories. However, this research intends to better understand student struggles and persistent misconceptions that are expressed when reflecting on the short stories via the embedded questions. All student quotes include codes to identify the short story questions from which the quote came.

The themes discussed below were created to organize related student misconceptions or struggles. The themes included several sub-themes that will be discussed to provide a more robust understanding of possible problematic thinking.

While numbers of students expressing each themes is noted in parenthesis next two each theme, this work is not concerned with quantifying student views. Instead, we intend to explore the inaccuracies of student thinking by documenting problematic language and working to understand how these themes relate to one another and to student struggles to understand the NOS. We hope these descriptions/discussions of student misconceptions/struggles will provide insight for teachers, curriculum designers, and researchers working to improve the teaching and learning of NOS at all levels of education.

Misconceptions related to ontology/epistemology of science.

(63 students)

Many students expressed misconceptions related to either the ontology or epistemology of science. Oftentimes these misconceptions were intricately tied to one another. This amalgamation is not surprising considering the manner in which students believe scientific knowledge is generated, its limitations and strengths, will affect their views concerning the truth nature of the knowledge generated.

While none of the questions or bullet points within the short stories explicitly addressed the ontological status of science ideas, many students demonstrated they believe science to result in absolute knowledge. This ontological view may impact students' later understanding of the tentative nature of science or the differences between science and religion. The view that science results in absolutely true knowledge is not surprising considering the way science is portrayed in popular media, textbooks and courses. While students rarely made explicit their view that science is absolutely true, their writing provides clear indication of their views.

> …data doesn't show or tell scientists what to think, due to the fact that much of the data being thrown out to the scientists doesn't always seem to be proven true (RM, NC3)

> Once you get some followers who truly believe in what you have discovered, it's much easier to prove. (MM, NC3)

> Today, the meaning of data is to show or tell us about something and to prove a fact or a theory. (CM, NC2)

> …and people were so unsure of what they were finding that nobody ever knew if they were right or wrong. These days there are so many scientific ways to prove what is found to be true or untrue…(SB, NC1)

Clearly, these students have other misconceptions beyond believing science results in "proven truth". These issues will be discussed in later themes.

Some students take the stories' attention to the need for interpretation of data as meaning science ideas have little value. These students, as many often do, have likely shifted from one extreme (science is 100% true) to the other (science does not result in reliable knowledge).

> What [the data in this question] tells us is what Hutton chose to interpret it as saying, however educated, this was still just a guess. (TD, NC3)

Other students believe that science knowledge results from strict adherence to the scientific method. This belief could easily lead to students seeing science as not creative.

> The prevalence of these ideas may come from the fact that most scientists use the method of forming a hypothesis then confirming that idea by using an experiment. (JY, D3)

> When I think of scientific experiments, I think of following a step by step process that involves a lot of time and data. You must use logic and reasoning to be able to make your data correlate to your hypothesis. Very rarely do I think of using intuition and new thinking to prove a hypothesis.(LG, D3)

Some students claimed that the uniformity of methods is why science is reliable, while not using the scientific method results in untrustworthy knowledge.

> …[society] fail to realize how the scientist came up with this crazy idea while using the same method that every other scientist does. (RT, D3)

> Scientists don’t always follow a step-by-step scientific method, which means there is no efficient supporting evidence. (SG, D3)

As with the “proven truth” ontology misconception, some students seem to have adopted the opposite extreme concerning the scientific method. Rather then a specific scientific method, the students seem to think most science proceeds randomly. These students seem to have adopted an extreme view of the role of serendipity.

> Scientific experiments and observations are random which in turn lead to some of the greatest discoveries. (SV, D3)

Related to the scientific method, many students wrongly believe science requires controlled experiments despite the short stories’ explicit noting that believing science requires controlled experiments is a misconception.

> Because there is no set way or experiment that can be done to truly prove the theory of biological evolution, there is no way of really knowing that it is correct. (AG, D3)

> Scientists create theories that sometimes may be proved right by controlled experiments, but at other times, different outcomes denying the theory may be the case. (EG, D3)

The students’ belief that science requires controlled experiments is tied up with their views concerning the ontological status of science as well as their acceptance of biological evolution. As noted previously, this relationship is not surprising, but must be considered when helping students learn any of these concepts.

Many students’ inaccurate ontological beliefs manifest as misunderstanding the role of theory in science.

> We might see a need for a right or wrong answer in evolution, but the fact is, science is a lot of theory and proving one thing is impossible. (SV, D3).

> The public may reject scientific theories because there really is not right or wrong answer. (EG, D3)

The final excerpt below illustrates how these ontological and epistemological issues are difficult to separate. This student exhibits misconceptions regarding theories, experiments, scientific method and more generally ontology.

> This idea of following ridged, controlled experiments to prove scientific theories is fairly established. People assume that if theories are not proven down to the genetic/microscopic level with proven facts, then they cannot be true in any form. I say that is a fair evaluation because for so long theories were made based on too much cultural influence and thus was not true. People take the extreme against such declarations in order to avoid such situations.
>
> Because of such measures taken today to prove scientific theories, many people reject theories of biological evolution. This is due to the reason that most of the theories are just theories; they don't have rigid experiments that prove them absolutely true.(HA, D3)

This response illustrates how students use various related misconceptions as support for each other. When this entangled, deconstructing misconceptions and helping students understand any one concept likely becomes more difficult. Yet, addressing all of these misconceptions simultaneously can be difficult and confusing for learners.

Data does not require interpretation

(66 students)

The notion that data does not tell scientists what to think and that scientists must creatively make meaning or interpret data is explicitly addressed by the short stories. Yet, many students ignore the explicit messages and still over exaggerate the role of data. These students seem to be holding on to an extreme empiricist view regarding science.

> Today, the meaning of data is to show or tell us about something and to prove a fact or a theory. (CM, NC2)

> Data does show and tell scientists an observation, an explanation or an idea about their research, but each scientist can take what they've obtained and believe or do whatever they want pertaining to their research. (DA, NC3)

These views could be tied to students' views regarding the epistemology and ontology of science. If students believe scientific data is self-explaining, they will see little reason to believe science is not "proven truth". Furthermore, these students will likely struggle to understand the full creativity inherent in the scientific endeavor.

Other students will acknowledge the stories' explicit attempts to note that data must be interpreted, but believe that observations are not a form of data. These students hold on to their misconception that data tells, but manifest the misconception by noting data doesn't tell, it is observations that tell scientists what to think.

> Data is just a table of information that doesn't necessarily mean anything to you personally, but it's when you see it for yourself does it take meaning. (NL, NC3).

> Data can show and tell only so much for a scientist. When a scientist observes an object it can show and tell more about the object than data could. Scientists can think what they want to even after they are shown data while an observation can help prove a point. (PK, NC3)

> When a scientist observes an object it can show and tell more about the object then data could. (BA, NC3)

Many of these students believe data only comes in the form of numbers, graphs, and charts. They do not see the interpretive nature of observation and believe that when scientists witness phenomena, meaning is inherent in the observation.

Other students believe that data tells scientists what to think, but the non-scientist must either witness the phenomenon first hand or must make up their own mind regarding the 'discovery'.

> Data can only show or tell scientists what to think. By experiencing it on your own, you can connect with the data and understand why by actually seeing the changes, similarities and the differences first hand. (LH, NC3)

> Data informs us of discoveries, but we choose whether or not to believe those discoveries. (AL, NC3)

Lastly, students believe that technological advances mean scientists no longer need to creatively interpret data. This misconception is heavily tied to their naïve views regarding technology, which will be discussed more thoroughly in the next theme.

> In the past, scientists did not have the instruments we have today to give them the data; they had to figure it out themselves. (GH, NC1)

Misconceptions related to technology

(34 students)

Students today have grown up in a digitally enhanced world. Advanced technology has certainly improved society in many ways. Yet, the ubiquity and unquestioned use of technology can lead people to believe technology solves all problems or that technology has no downside. In today's world, the view that technology will save us from our problems and frustrations can be seen nearly everywhere. The benefits of technology are explicit and the unexpected side effects are most always ignored.

When students were asked why science was originally connected to leisure activities, the question hinted at the role social status and wealth had in determining who did science. Yet, a large portion of students immediately noted the "lack of advanced technology back then" and felt science was something used to "pass the time" before video games and television.

> Hundreds of years ago there were no televisions, no technological devices that people use during their leisure time so studying, observing, and making scientific discoveries was just part of their hobbies. (RM, NC1)

> …the reason people don't do "scholarly" work anymore is because there are so many other opportunities in today's world. Such as: taking your children to soccer practice, watching television, emailing your friend who lives far away, going to a sporting event, going to a movie and the list goes on and on. Back 100 years ago all of these opportunities were not even dreamed of. (NL, NC1)

Other students exhibited the view that any problems with past science have been solved with technological advances.

> In the past, they did not have the technology that we have today to help them with their discovery. (LH, NC1)

> In the past, scientists did not have the instruments we have today to give them the data; they had to figure it out themselves. (GH, NC1)

> Also, without modern technology, it took a considerable amount of effort to procure the sources and then to find the specific information they were looking for. (KN, NC1)

> Also, with new technologies, equipment costs money. To have the best results, there are needs for the best equipments. (CS, NC1)

> Back in the time of Hutton and others there weren't the advanced tools and equipment we have today to interpret data for us. (NH, NC3)

> Because of the lack of technology, there were no computers to solve complex problems. (JF, NC1)

While there is truth in saying technology has impacted and assisted science, these students naïve belief in the salvation powers of technology is troubling. These students could easily see scientists as those who run the computers with little creative input of their own. More problematic is that these students could wrongly believe that if the science is done on a computer, it must be right – leading to support of naïve ontological and epistemological views.

Many students fail to understand the demarcation between science and technology. While the line is blurry, if students do not come to understand important differences, they will likely not see the value in basic research. This misconception is demonstrated by the students' views that the purpose of science is of utility and progress, rather than for the purpose of gaining knowledge about the natural world.

> There has been many discoveries and everyone wants to find what will become useful. Science has become a race, a race to find the world breaking discoveries. (CS, NC1)

> Back in the early days of science, they were advancing technology by studying the earth and how it worked. In order for the world to develop progressively, they continually needed people to discover new ways of thinking and ideas. (SV, NC1)

> Science can be used to better mankind. (MD, NC2)

> I feel that society today does not place enough emphasis on the importance of scientists and the need to make new discoveries in order to improve the quality of life for the human race. (JF, NC1)

> Science is the thing that improves our life, so people should not take it lightly. (HS, NC2)

While I applaud the students for believing in the importance of science, their misconception of the purpose of science leads one to wonder about the future of basic science if the public only values technological advance.

Science is not collaborative

(31 students)

When asked about the social nature of science, many students ignored the collaborative nature of science. Ignoring the role of collaboration may mean that students hold the view of scientists being a "lone genius". Most students who ignored collaboration in science focused on the communication of results or peer review as the only social activity within science. Some students even hinted at the notion that scientists must gain followers to validate their idea – perhaps indicating belief that science is democratic rather than empirical.

> Scientists try and convince people that their observations are meaningful and important by publishing their findings and telling everyone what they have learned in the hopes that someone else will believe what they say. Scientists must be very persuasive in order to get people to take their work seriously. (SB, NC3)

> Scientists share their discoveries with the outside world and inform everyone else of what they have been doing and what is being discovered. (CK, NC2)

> A science career is not a solitary undertaking because so much is relied upon others findings and approval. (SJ, NC2)

> The only way to expand in the scientific field is for scholars to be supportive and critical of other people's work, which is definitely a social thing. (TH, NC2)

The interaction of science and religion

(32 students)

Considering the controversial nature of evolution in the United States, student views regarding the interaction of science and religion are not surprising. Yet, the questions to which students responded for this study did not explicitly address religion. Clearly the interaction of science and religion is a powerful conceptual construct impacting students learning if it appears when not explicitly appearing in the questions.

Some students seemed to latch onto notions in the story that scientists are using naturalistic and religious ideas to explain phenomena. While this view may be accurate for the time period, the possible affect on student views regarding modern collaboration between science and religion is troubling.

> Many scientists wouldn't agree to [using biblical evidence for scientific questions] even though some might say that the bible is evidence. (RM, NC3)

> Early scientists used some natural observations to back up Christianity while ignoring the facts that disagreed. (AK, NC4)

> In text there is a reference to Christianity and how it explains that the earth was created and unlike most situations it was proven right. (HA, NC2)

> Science isn't trying to prove religion wrong rather its trying to see if it's right or not….science and religion is really more of a collaborative then anything else. (RA, NC4)

While these quotes can be supported from the short story, the views expressed could easily lead to acceptance of creation science as legitimate science. Rather than combining science and religion, encouraging students to understand the differences and utility of *both* science and religion as separate domains seems more fruitful.

More common was the view that science and religion are at odds. Students holding this view usually imply that scientists cannot be religious or vice versa. Rather than seeing two distinct types of knowledge that can coexist, the students see a choice to be made.

> If a scientist strongly believes in evolution, and you don't; the verbal battle between the two of you can get very bloody (MM, NC2)

> Therefore, science versus religion will always be in conflict to explain phenomenoa. (KG, NC4)

> Many scientists think outside the thinking of the community, and propose abstract ideas. This includes the idea of God being nonexistent. (AT, D3)

Several students indicated an elitist view of science. These students tend to see scientific knowledge as more useful or more accurate than religious views and tended to describe religious individuals as "close-minded". These views could be linked to views regarding the saving power of technology. These students do not seem to understand the limits of science and would likely claim science can answer all questions.

> Religion is something that you can't prove is true. You just believe what you personally think is the best for you and act upon that. Someone with a scientific mind will always want an answer to every question. This is why the two do not mix. (NL, NC4)

> Science is fact. Religion is belief. (MB, NC4)

> The public sticks with their belief because it seems easier to just believe the simpler explanation rather than take the time to think things through and put some thoughts into each of the explanations (AW, D3)

> Those who do not [accept evolution] are religious, and their rejection of biological evolution stems from their religious beliefs, not from their misconceptions of the scientific process. (MZ, D3)

Evolutionary evidence

(14 students)

Many of the misconceptions discussed thus far show up when students consider the evidence for evolution. Misunderstanding the nature of science can easily lead to dismissing the tremendous amount of evidence in support of evolution. Most of the students misconceptions related to evolutionary evidence included the errant belief that science requires experiments or misuse of the word theory. Some students simply didn't believe there was evidence in support of evolution, despite being in an introductory biology class that explicitly discussed the theory.

> Because there is no set way or experiment that can be done to truly prove the theory of biological evolution, there is no way of really knowing that it is correct. (AG, D3)

> Because there are no data available that can be seen with naked eyes, i.e. no controlled experiments to support the theory, it becomes very difficult for the scientists to believe the ideas and observations for a person. (SN, D3)

> The public could be caused to reject biological evolution because there isn't any concrete evidence that can be easily tested to prove that biological evolution is correct. (SN, D3)

> Since biological evolution couldn't be tested, or proved, they wouldn't believe it (RR, D3)

> The fact that something like evolution is too big to test is used as justification for rejecting it. (JK, D3)

Misunderstood language

(79 students)

In addition to explicit NOS misconceptions, many students interpreted the language of the stories or the embedded questions in unexpected ways. Some students interpreted questions about the scientific endeavor to be questions about science classes.

> Textbooks can only take you so far. Seeing is believing. When you see data occurring in front of your eyes it'll bring about all different varieties of knowledge not just what you had read in a textbook. (SG, NC3)

Other students misunderstood key words such as leisure and social. Many students believed the reference in NCQ1 to the word leisure to mean that science was done in "free time" rather than why science was associated with the word leisure. Students interpreted the word social to mean having friends, multidisciplinary, and competitive.

> The story illustrates that science is a social endeavor by showing how the scientists enjoyed it. They also had fellow scientists' friends, which I think would make a science career a little more interesting. (NK, NC2)

> Science is a social endeavor because when studying science, one cannot just study one specific type. All science is tied together in many ways. For instance, in biology when we want to determine the age of a fossil we use carbon dating. Carbon dating is more chemistry than biology. Scientists must be well versed in all types of science even to study one in particular. (GH, NC2)

> In this way, these many scientists seem to almost compete with one another to try to uncover facts and more quality research better than the other scientists. This is the reason science can be considered to be a social endeavor, in that competition through research is a way of motivation for many scientists. Therefore, science can in this way be compared to other social and competitive activities, such as athletics, which many consider a popular career choice. (JH, NC2)

When asked to explain how data doesn't "tell" scientists what to think, many students interpreted the question to mean that scientists don't tell others what to think when presenting their ideas. Rather than focusing on the data telling, the student focused on the scientist telling.

> Hutton and other scientists do not tell readers of their works what to believe; rather they simply inform them of their findings. This way the readers can make their own decisions based on the research, and are not shown or told what to believe by the scientists. (JH, NC3)

> Hutton and other scientists who do not have the support or evidence in the form of data need to convince others with hard physical and visual evidence and an explanation behind every aspect of their observation. (AG, NC3)

> Scientists try and convince people that their observations are meaningful and important by publishing their findings and telling everyone what they have learned in the hopes that someone else will believe what they say. Scientists must be very persuasive in order to get people to take their work seriously. (SB, NC3)

Lastly, when asked to reflect on the lack of a step-by-step scientific method, several students interpreted the question to be asking about the scientific concept (evolution) rather than the scientific process.

> There is no set "step-by-step" procedure that nature takes to create new species or a specific date for when adaptation occur. (KS, D3)

Conclusions and Recommendations

Helping students to understand the nature of science is a daunting task. The abstract nature of the ideas and the persistent misconceptions are not easy obstacles to overcome. This research notes the way in which the common misconceptions are not only resistant to change but are related in a way that students can use some misconceptions to support others. With these interrelated conceptual structures, students are not likely to change their views easily. Even with explicit instruction concerning one aspect of the nature of science, the students might articulate accurate conceptions while underlying conceptual frameworks support inaccuracies.

The misconceptions tied to the ontology and epistemology of science run rampant through most all aspects of the nature of science ideas addressed with the short stories in this research. Considering the fundamental nature of ontology and epistemology, perhaps more forceful and explicit attention must be paid to these concepts before addressing other NOS ideas. Before students can understand more specific NOS concepts such as the role of experiment or the lack of a scientific method, they may first need to understand the character of scientific knowledge. By working to restructure students' fundamental understanding of the philosophy of science, they may be more likely to deeply understand why the notion of a scientific method makes little sense or that technology cannot interpret data.

Importantly, this research demonstrates that curricular materials alone are not likely to change students' basic views toward science. Teachers must engage students with discussions that seek out not only their misconceptions, but also any related misconceptions that might present obstacles for student learning. Yet, curricular materials such as historical short stories can provide useful reflection activities or opportunities for instructors to probe student thinking.

The research further reminds us that language is of utmost importance. Not only is the language the teacher uses important (Zeidler & Lederman, 1989), the meaning the students make of that language must be ascertained. The historical short stories used in this study were carefully designed to accurately reflect the nature of science, yet students still interpreted the stories inaccurately, or ignored the accurate message being promoted.

Lastly, many students indicated that the nature of science in the story is different than the nature of science today. While the nature of science has and will continue to change, the story was trying to highlight NOS concepts that apply to today's science as well as the science within the historical episode. Having students reflect on how the historical science is like contemporary science may be necessary to prevent students from dismissing the historical nature of science as outdated.

Future work

This qualitative work is still underway and student misconceptions and their interrelations will continue to be examined. While aspects of the nature of science are clearly interrelated, we hope to more accurately describe how students use these different aspects to support one another. By better understanding how students make connections between varied NOS ideas, we will be better able to plan instruction, create curricular materials and prepare teachers for implementing NOS instruction.

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