Should "Proof" and "Truth" be Targeted First? Evidence for Addressing Some Nature of Science Concepts and Misconceptions Earlier than Others

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Introduction

The phrase "nature of science" (NOS) is typically used in referring to issues such as what science is, how science works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society itself both influences and reacts to scientific endeavors. Understanding the NOS is key to science literacy (AAAS, 1989; Matthews, 1994; McComas & Olson, 1998; NRC, 1996) and to enticing students to further their science education. McComas *et al.* (1998) argue that knowledge of scientists and how science works will enhance students' understanding of science as a human endeavor; increase interest in science and science classes; improve student learning of science content; and promote better social decision-making. Morris Shamos (1995) claims that understanding the NOS is the most important component of scientific literacy because that knowledge, accurate or not, is what citizens use when assessing public issues involving science and technology. The intelligent design public education controversy and common perceptions of what counts for credible evidence regarding global warming (Rudolph, 2007) and are just two examples of how misconceptions regarding the NOS impact public decision-making.

The centrality of the NOS for science literacy is also illustrated in the way it impacts students' attitudes toward science and science classes, and their understanding of science content. In *They're Not Dumb, They're Different*, Sheila Tobias (1990) reported that many bright post-secondary students (those she refers to as the "second tier") opt out of science as soon as possible, in part, because of mistaken notions about the NOS. The following student's frustration illustrates how misunderstandings regarding the NOS may affect interest in and understanding of science content.

> What is this game that scientists play? They tell me that if I give something a push it will just keep on going forever or until something pushes it back to me. Anybody can see that isn't true. If you don't keep pushing, things stop. Then they say it would be true if the world were without friction, but it isn't, and if there weren't any friction how could I push it in the first place? It seems like they just change the rules all the time. (Rowe and Holland, 1990, p. 87)

The counterintuitive nature of many science ideas (Wolpert, 1992; Cromer, 1993; Matthews, 1994) along with students' misunderstanding of the NOS account for many students' poor attitude toward and understanding of science. Matthews (1994) illustrates how understanding pendulum motion, and science more generally, requires understanding the role of idealization in science methodology. Rudolph and Stewart (1998) make clear how conceptually understanding biological evolution requires:

> students to become familiar with the metaphysical assumptions and methodological process that Darwin laid out. Theoretical context and scientific practice, in this view, are not just interdependent, but really two views of a single entity. (p. 1085)

Unfortunately, studies regarding students' and the general public's understanding of the NOS have been consistently disappointing (Clough, 1995; Durant *et al.*, 1989; Millar & Wynne, 1988; Miller, 1983 & 1987; NAEP, 1979; National Science Board, 2002; Ryan & Aikenhead, 1992; Ziman, 1991). This is not surprising given how science textbooks, cookbook science laboratory activities, and most audiovisual materials downplay human influences in research, sanitize the processes that eventually result in knowledge, and portray science as a rhetoric of conclusions (Jacoby and Spargo, 1989; Leite, 2002; Munby, 1976; 1989; Rudge, 2000). DeBoer (1991), in his review of the history of science education, argues that the positivist view of the philosophy of science from the last century still informs much classroom practice and pervades most available curriculum materials. Thomas Kuhn (1970) wrote that "[m]ore than any other single aspect of science, [the textbook] has determined our image of the nature of science and of the role of discovery and invention in its advance" (p. 143).

Accurately and effectively conveying the NOS plays an important role in making post-secondary introductory science courses more intelligible and meaningful for all students. This is particularly important in an era when the "science professoriate (has) a comfortable 'elsewhere' focus; for advocating K-12 reforms rather than coming to grips with the hemorrhaging of the student pipeline that occurs during the college years" (Schaefer, 1990). Seymour and Hewitt (1997), in an extensive study of why undergraduates leave the sciences, wrote that, "One serious cause of loss of interest was disappointment with the perceived narrowness of their [science, math and engineering] majors as an educational experience…" (p. 180). Tobias (1990) reported that a number of talented students in her study reported becoming disenchanted with science classes and chose different majors, in part, because science courses ignored the historical, philosophical, and sociological foundations of science. She writes:

> They hungered — all of them — for information about *how* the various methods they were learning had come to be, *why* physicists and chemists understand nature the way they do, and *what* were the *connections* between what they were learning and the larger world. (p. 81)

Recently, Eccles (2005), summarizing several previous studies, noted that we do a very bad job of accurately conveying to students what scientists do

Past attempts to accurately portray the NOS in curricular materials have been problematic for two reasons. First, publishers resist modifying traditional science textbooks in fear of losing market share. Second, post-secondary science faculty often balk when such instruction detracts significantly from science content instruction. One solution to this tension is the development of materials that teach both science content and the nature of science, and that post-secondary science faculty can use when and where they deem suitable. To this end, with NSF funding, we have developed several historical short stories that trace the development of specific science ideas and highlight key concepts regarding the NOS.

However, even when historical materials are implemented, students' prior ideas regarding science content and the nature of science play a large role in their efforts to make sense of those experiences. Because most students' prior notions of the nature of science are filled with misconceptions, they will likely attend to aspects of NOS instruction that fit their prior ideas, unknowingly modify other aspects to fit their prior ideas, and ignore other aspects that do not fit their prior understandings (Abd-El-Khalick & Lederman, 2000; Tao, 2003). Even when context-rich stories are used, students often interpret them in idiosyncratic ways, and focus on aspects of stories that fit their misconceptions (Tao, 2003). Aware of this propensity among learners, our short stories include bulleted points within the text that explicitly draw students' attention to key NOS concepts illustrated in the stories. In addition, four questions are inserted at relevant places in the short stories to encourage students to reflect on the NOS.

Use of these historical short stories in post-secondary geology and biology classes has resulted in improved student understanding of particular NOS ideas when compared to a control group. Students in the biology treatment group also scored higher on particular unit-ending science content questions (Clough *et al*., 2007). However, an analysis of students' responses to questions in the short stories revealed that a substantial percentage of students expressed significant NOS misconceptions such as: (1)

good scientific knowledge is proven true; (2) good science is that which follows the "scientific method"; (3) technology as the purview of young people providing an objective view of reality and enabling the discovery of truth; and (4) the view that the textbook is the most current authority rather than the scientists conducting research. Interestingly, these NOS misconceptions that students expressed were in responses to questions that did not seek nor require such information. In other words, a number of students raised NOS issues not directly targeted at the question.

This analysis raises important questions regarding how students interpret historically based NOS instructional materials, and how they learn NOS more generally. The number of students who expressed an ontological idea that scientific knowledge is "proven" or "true" was surprisingly large, particularly since none of the four short stories they completed addressed the status of scientific knowledge or sought this view from students.

Research Questions and Purpose of Study

This study examined the short story responses of 278 students in a post-secondary introductory geology course who completed four geology historical short stories. This analysis was done to determine:

1. How prevalent in this sample are student comments expressing an ontological view of scientific knowledge as true?
2. For students who express this view, how frequently does it appear in their responses to short story questions?
3. How do post short story quiz scores of students expressing an ontological view of scientific knowledge as true compare to post short story quiz scores of students not expressing such an ontological view of scientific knowledge?

The extent that students express positions regarding the ontological status of scientific knowledge, even though the four historical short stories did not explicitly address this issue, may reflect a fundamental NOS misconception that accounts for prior research indicating that learners often interpret history of science materials in unanticipated and incorrect ways.

Conceptual Framework and Methodology

This study used the qualitative framework of grounded theory to guide the development of research questions and the collection and analysis of data. The questions appearing in the historical short stories and quizzes were all open-ended. We wanted students' responses to be in their own words as this may reveal much about how they interpret the short stories and questions. During a pilot study conducted in 2005, 40 students were randomly selected and interviewed to determine how well their verbal responses matched their written responses. Agreement was sufficiently high (>96%) for us to conclude that student written responses accurately reflect their thinking.

All scoring of short story questions involved three researchers. Rather than determining beforehand how responses would be coded, we used a constant comparative method and grouped student responses and rank ordered those groups. Eventually, categories of student responses were collapsed into the following five groups: 5) accurate and detailed response, 4) accurate, but vague response, 3) mixed response with some inaccuracies, 2) inaccurate response, 1) unclassifiable response. Quizzes were scored in the same manner.

Data collection occurred during the spring 2007 semester. Subjects were students in two sections of an introductory geology course taught at a large public research university in the Midwestern United States. The instructor of the course had implemented historical short stories in this course the two semesters prior to the spring 2007 semester. Students in the course are primarily freshmen, represent a variety of non-science majors, and register for the course to fulfill part of their general education requirement. Each section enrolls about 200 students, and 278 of these students completed the short story assignment on WebCT. Only the WebCT responses were analyzed for this study.

The two continental drift historical short stories were assigned to students during the third and fourth week of the course. Students were provided two weeks to read the two historical short stories, complete the four questions embedded in each short story (8 total questions), and submit their work via WebCT or paper copy. Two additional historical short stories addressing the age of the earth were assigned in the same manner near the midpoint of the course. Subjects' WebCT responses were downloaded and compiled into a single file for coding. Three researchers met and read responses and discussed possible scoring schemes. Following this meeting, each researcher independently coded student responses to the questions embedded in the historical short stories. Intercoder agreement exceeded 85% for all but one question. In that one instance, the three researchers met again and, after discussion, the coding scheme was modified. Student responses to that question were then recoded and the 85% criterion was exceeded. The following questions were included in the text and answered by students in this study.

Short Story 1 - Continents: A Jigsaw Puzzle With No Mechanism

1. Note how several of these explanations use catastrophes appearing in religious texts to explain natural events. How does this illustrate the influence of the wider culture and prevailing ideas on people investigating the natural world?
2. Note that each idea proposed thus far has some explanatory power, but also has significant problems. How does the time required to develop science ideas as described in this story compare to what is often conveyed in science textbooks?
3. Note that Wegener and other scientists are creating ideas to *account for* what they observe. That is, nature and extracted data does NOT *tell* scientists what to think. Data doesn't speak—it must be noticed, valued, and interpreted. What does this imply about the way in which scientists construct new ideas?
4. Currently accepted scientific knowledge influences scientists' interpretation of data. Oftentimes someone who is young in age or new to a field of study begins revolutions in scientific thinking. Why might this be the case?

Short Story 2 - Data Doesn't Speak: Development of a Mechanism for Continental Drift

1. The scientist's perspective above raises one of the most interesting aspects of doing science. Note that while some scientists have discarded Wegener's theory, others support the idea or some variation of it. Decisions regarding the acceptance or rejection of scientific ideas are a very complex process. How does this example illustrate the importance of consensus building in the scientific community versus the views of individual scientists?

2. Note the different interpretations depending on the framework and ideas one uses to make sense of the same data. People often think that good scientists are objective. What does this story imply about the possibility of scientists being objective?

3. Given that data must be interpreted, how do statements like "The data shows . . ." inaccurately convey how scientific ideas are developed?

4. The first rule of wing walking (walking on the wing of a biplane) is that you never let go of one wing wire until have hold of another. Using this analogy, why do scientists hold onto a dominant theory (even if it doesn't work as well as desired) unless a very plausible alternative theory exists?

Short Story 3 - Early Efforts to Understand the Earth's Age: Naturalists and Chronologists

1. 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?
2. Consider how scientists' 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?
3. 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?
4. How does this story illustrate that science versus religion is not an accurate description of efforts to understand the age of the earth?

Short Story 4 - A Very Deep Question: Just How Old is the Earth?

1. John Phillips, in 1860, used the idea of sedimentation to estimate the earth's age. Based on the rate of sedimentation he observed occurring today, he assumed that approximately one foot of land eroded into the ocean every 1,330 years. He speculated that geologic columns would have a maximum height of 72,000 feet. Using his approach and numbers, calculate the approximate age of the earth he came to. [Note: This is a science content question and was not coded in the NOS misconceptions analysis.]
2. Note that how scientific research is conducted (the *processes* of science) is intertwined with prevailing ideas about natural phenomena. This, in turn, affects new thinking about the natural world. Use information from this short story to explain how scientific knowledge and scientific process are intertwined.

3. Many students today choose not to pursue science careers, thinking that science is a dull and unimaginative process. Using this historical episode, explain how *both* the methods scientists use and the sense they make of data illustrate that science is a creative endeavor.

4. Scientists are rarely pleased with ideas that do not cohere. Why do you think that scientists want their ideas to fit together, even if those ideas come from different science disciplines?

To determine the extent to which students express ontological views of science as proven or true, the researchers conducted a word search on the electronic file containing students' short story responses. Searches were conducted on the words: prove, truth, objective, accurate, discovery, right, fact, and valid. Student responses were then read in context and only students who expressed a response that clearly indicated a view that science knowledge is ontologically true were analyzed for this study. A second group was created that included students whose responses potentially indicate an ontological view, but we were less certain of how strongly students held to that view. A third group included the remaining students whose responses did not include a view that science knowledge is absolute truth.

Findings

Prevalence of Ontological Views of Science Knowledge as Proven Truth

Across the study sample, 91 of 278 students (32.7%) expressed an ontological view of science as proven truth. 89 students (32.0%) were in the second "potentially holding this view" group, and the remaining 98 students (35.3%) did not express this view. This finding does not mean that all students used the words "proven" or "true." The following responses from students illustrate responses that contributed to a student being placed in the "proven truth" category.

> I think religion is used as a cop out. There just wasn't enough technology available back then to make sure their assumptions were correct. Yes, the continents looked like they all fit back together. There was no way of them proving it scientifically so they use religion, which can not be proved. (J.R. SS1Q1)
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> For anything to go into a scientific textbook it must be without a doubt true. Those textbooks are what will teach our future scientists. (K.V. SS1Q2)
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> Scientists use their knowledge to come up with theories, they then use the process of science to help prove their theory wrong or disprove their theory so then they go back and form a new hypothesis and true to prove that one until they come up with a theory that is proven correct by scientific process. (K.M. SS2Q2)
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> In the scientific community, it is important to take into consideration what your fellow colleagues have to say in regards to certain issues. It is helpful to build a consensus with other scientists because there is strength in numbers and typically when more people agree upon an issue, there is a likelier chance that their belief is correct. Although an individual may discover the truth, generally when people with different ideas and theories can come to the same conclusion, it would appear that their consensus is correct. (K.B. SS2Q1)
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> I think that scientists want their ideas to fit together because then they are for sure true. It is like second opinion is always better. It could also mean that they are on the right track to finding something helpful to mankind. (J.D. SS4Q4)
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> During this story one of the common themes was science versus religion, releigion can't prove anything about the age of the earth. THey have no way to show any actuall observation of how old they actually beleive, while scientists have been able to prove every claim about the age of the earth and show those with observations and evidence to back all of their claims. (P.O. SS3Q4)
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> Often times, religion will interfere with the information a scientist discovers. So, instead of taking the information as facts, they will interpret it incorrectly. (J.G. SS3Q4)

Prevalence of "proven truth" views across questions

To address the second research question, we wished to determine how prevalent these "proven truth" perspectives are throughout an individual student's responses. For example, how many questions are answered by students in this manner, and what are those questions? Do some questions elicit this view more than others?

The number of students who expressed an ontological "proven truth" view for each question is shown in Table 1. Percents are provided and indicate the percent of students in the "proven truth" group who expressed this view, followed by the percent of students in the entire sample.

Table 1: Number of students expressing "proven truth" views per question

Short Story Question	NOS concept targeted	N	% w/in group	% of whole sample*
SS1Q1	Wider culture and prevailing ideas influence explanations scientists develop	7	9.6	2.5
SS1Q2	Science textbooks downplay or ignore extensive time required to develop ideas	45	61.6	16.4
SS1Q3	To construct a new idea, a scientist must be creative—including noticing what to look for, what is important, and how data is to be interpreted	27	37.0	9.8
SS1Q4	Being entrenched in currently accepted science ideas may prevent a scientist from perceiving things through a different framework	7	9.6	2.5
SS2Q1	Individual scientists may hold a variety of personal views, but building consensus in the scientific community is crucial for an idea to be accepted	29	38.7	11.1
SS2Q2	Scientists may interpret data differently and thus cannot be completely objective	36	48.0	13.6
SS2Q3	Scientific ideas are developed through creativity and interpretation. Data does not tell scientists what to think.	26	34.7	9.9
SS2Q4	Scientists will often hold onto problematic ideas unless plausible alternative ideas exist	34	45.3	13.1
SS3Q1	Science requires a society in which basic subsistence needs are met. Enough wealth must exist to enable certain individuals to pursue scientific endeavors.	4	5.6	1.5
SS3Q2	Scientists have extensive interaction with others in the process of doing science.	8	11.1	2.9
SS3Q3	Scientists must work to convince others of their ideas. Other scientists are not necessarily going to make the same meaning of the same data.	21	29.2	7.7
SS3Q4	Both scientists and religious leaders have held young and old Earth views. "Science vs. religion" is an inaccurate description of this field of study.	16	22.2	5.9
SS4Q2	Scientific knowledge and process are intertwined—each advances the other	23	31.9	8.6
SS4Q3	Science requires creativity in developing methods as well as interpretation of data	25	34.7	9.1
SS4Q4	Scientists seek coherence of ideas within and beyond their science discipline. Ideas that do not cohere are suspected to be problematic.	41	56.9	14.7

*The total number of students who submitted at least one short story is 278. Not all students answered every question, however. For calculations in this column, only the actual number of short story responses received for that question was used. In order, those numbers are: 278, 274, 276, 277, 262, 264, 262, 260, 274, 272, 272, 272, 266, 275, and 279.

Some questions (and some short stories) were more likely to elicit "proven truth" views from students. In particular, short story 1 (continental drift), questions 2 and 3 had a relatively large number of students who answered the question using "proven truth" views. In short story 2, all questions had a high number of students responding by using these views. Short story 3 was the exception, with only questions 3 and 4 eliciting "proven truth" views by more than 20% of students in this group. Finally, short story 4 had a relatively high number of students in this group responding with "proven truth" views.

Short Story 1 Question 2 was the question with the most student responses that expressed a "proven truth" view. The question asked students to consider how long it takes science ideas to develop and to compare that with what is often conveyed in textbooks. Several students in this group tended to interpret the question to mean they should compare how long it takes to develop a science idea with how long it takes to develop a textbook. This view is illustrated in the following students' responses.

> The time it takes to develop scientific ideas in this story and in textbooks is relatively the same. It take a long time for a scientific idea to be tested and researched to one day become a scientific theory. It must be proven, tested and produce results. It may take years for it to finally develop and it may take many people. This is the case in both the story and in textbooks. (D.G. SS1Q2)

> In the 1800s scientists mearly guessed at how the Earth was formed or how it was acting at the time. To go along with a hypothesis that has no factual reasoning is rediculous. The Earth has been around for 4.57 billion years and I find it hard to believe that a scientist knows exactly why everything happens without a factual backing. Science textbooks today give the complete overview of the Earth's formation with factual proof of the 4.57 billion years Earth has been around. (R.M. SS1Q2)

> The time to develop a scientific idea as described in the story can take a matter of minutes because the ideas are based on thought and not scientific proof. Such as Edward Suess who proposed the idea for the creation of mountains and ocean basins from the lava cooling like a sinking apple. He didn't take time to try to prove if his idea was true...he just formed his idea to fit what he/society believed could have happened. However, the time to develop the scientific ideas that our in science textbooks took/take years and years because they have to be proven to be true. (N.S. SS1Q2)

> It takes some time to test a certain hypothesis to see if it is in fact true. Suess didn't really test his hypothesis, rather just looked around at clues and gave a answer to the problem. (Z.E. SS1Q2)

Some students hold the view that what is in the textbook is correct, proven, or absolute. They may express the idea that scientists learn from the textbook, rather than from their investigations and work within the community. Therefore, what is in the textbook is absolutely correct (or should be). Students may use a "scientific method" epistemological view to support their argument.

> It takes years to prove that science ideas are true. I think that the writers of the text book try to put information in that they know is true. It is very easy to do with things that they have already proven. I also think that they do put some information in that isn't quite proven yet, but are sure to tell the student that. (L.C. SS1Q2)

> For anything to go into a scientific textbook it must be without a doubt true. Those textbooks are what will teach our future scientists. (K.V. SS1Q2)

> In science textbooks they have more proof then these scientific ideas. I think the ideas have good reasoning behind them, but maybe don't have enough evidence behind them to be proven. (C.S. SS1Q2)

> The ideas that North America was created by volcanoes or connected by bridges that no longer exist are good ideas, but they have bad evidence to support themselves. Ideas like these have to be backed up in some way and the fact that they aren't is what makes these claims fairy tale instead of

> reality. Textbooks use research and tons of evidence to support all of the claims that they make. Reading information in textbooks makes me believe it is true because of the background and evidence. (P.O. SS1Q2)

> Like in all textbooks a theory or idea is always discussed, but the textbook always tells the reader what the problems with this theory or idea are. Not all ideas are always accepted. There are always question brought up about the theory. It takes time for a person to prove their theory because of all the doubt by other scientists. Scientists have to do years of research to prove their theory and answer the questions of the people who doubt them and try to prove them wrong. It is like the scientific method. (K.M. SS1Q2)

> The reasoning of ideas in the story are not factual or testable. It seems as if the explanations given are more opinion based than any type of reliable research or factual evidence. In the text books we are given a method is followed. First observations are made and then from observations and gathered data a hypothesis can be formed. From this hypothesis the idea is tested and proved reliable or falsified. Finally ideas are renewed and tested untill they can be proved true. (A.B. SS1Q2)

The following quotations are representative of “proven truth” perspectives for the remaining short story questions. Noteworthy is that all short story questions were answered by at least 4 students with a “proven truth” view. We have arranged student quotations by frequency of “proven truth” responses rather than their order within short stories.

SS4Q4 (n=41; 56.9% of group)

> I think that scientists want their ideas to fit together in order to prove that their ideas are correct and can be proven as theories. (K.N. SS4Q4)

> I think scientists would want their ideas to fit together because if their ideas don’t cohere, it may be hard for them to prove it or it just might be false all together. If their ideas fit together then the chance of that idea working or being true is more likely. Also, science is made up of numerous parts and disciplines, so acquiring information and facts from each part will also increase the likelihood of creating even better ideas. (K.S. SS4Q4)

SS2Q2 (n=36; 48.0% of group)

> As technology begins to improve scientists have become more objective so they can really find out why the continents separated. They started to discover the ocean floor, by being objective they figured out that the plates fit back together. (D.B. SS2Q2)

> This story is a good example because it shows that it is important for scientists to be objective because a scientist needs to be open before entering an experiment. If they already have preconceived notions about what they are experimenting, it might have an affect on the outcome. This could be a huge factor in creating theories, and harder for other scientists to agree with. (J.B. SS2Q2)

> From the data scientist observe, it s good for them to be objective. Like from above where scientist believe in two different ideas about the pole, it is good to be objective. Instead of all scientist believing in one idea, there are two (even more in other theories) ideas that scientist can study and research to find out the exact theory. As stated later in this story “Without hypotheses to test or disprove, exploration tends to be haphazard and ill-directed. Even completely incorrect hypotheses may be very useful in directing investigation toward critical details.” (R.S. SS2Q2)

I agree that good scientists are objective, this story proves it. They don't allow outside influences to change their opinions. They form their own theories and try to prove them. They don't go off of someone else's work. (J.M. SS2Q2)

SS2Q4 (n=34; 45.3% of group)

They do this because it is a good possibility that at least a part of their theory is correct. So if they keep going off the theory then they are closer to finding the truth to what has happened in the past or coming in the future. (J.A. SS2Q4)

4.I belive that they don't want to admit that they don't know the anwser. It seems better to them to told on to a theory that they know might be wrong, but arn't for sure and then discover the truth, than to admit that they don't know. Thats one idea. The other is that maybe they really do believe that they are right, its that they need to find more evidence to prove it. (L.C. SS2Q4)

SS2Q1 (n=29; 38.7% of group)

Well, basically it states that even though there are a few different views on continental drifts by a few scientists, if you have negative evidence regarding it then you shouldn't teach the hypotheses. By doing this your trying to keep "fact" or what could be fact away from what you've discovered to be most likely not true. You can't mix them. (R.J. SS2Q1)

I think now that there is a stronger consensus amoung scientists now then there was early in the 20th century. Science is derived from observations that are then formed into hypotheses. These hupotheses are tested and then determined if the hypothesis is false. Everyone has a different perspective of theories about plate tectonics yet when an idea is proven false it is the consensus of a group that will furthur the study on a topic instead of trying to change negative evidence into something unrealistic. (A.B. SS2Q1)

SS1Q3 (n=27; 37% of group)

Scientists are now making new hypothesize to they think are a possible explanation of what is causing the Earth's movement. They now follow through steps where they make a hypothesis and then do studies and research that hopefully will lead their hypothesis into a theory that can explain everything. (R.S. SS1Q3)

Scientists first construct new ideas through their own observations. They then use science to back up these ideas. What they often leave out though, is that if one would look at the problem from a different view, the theory could be proved incorrect. Scientists develop their own ideas from what they see and understand, and then prove them into theories when they have developed hard, scientific evidence. (J.B. SS1Q3)

Scientists have to look for clues and evidence. When they find some evidence, they then have to come up with a hypothesis, which may be true or false, and test it. Scientists have to proove what they find. (B.W. SS1Q3)

SS2Q3 (n=26; 34.7% of sample)

The data doesn't show, it helps prove a scientists' point. Scientific ideas are proven from facts and data scientists find. (H.K. SS2Q3)

To tell the truth, I don't understand what this question mean. I think the statement "The data shows…" convey how scientific idea are developed. So, if I must answer this question, I think most of scientific ideas are based on the hypothesis. This is not proved fact. Even though there are abundant data and evidence, we cannot say this is the fact. Thus, we can't just assume that this data shows this, accurately convey how scientific ideaa are developed. (E.L. SS2Q3)

They are possibly going off of other data that has not been proven by that scientist, so they might be giving information that is unproven. (D.M SS2Q3)

Because what some data shows doesn't mean that is the explanation, sometimes to prove something you have to put different data together to develop an idea. (L.S. SS2Q3)

SS4Q3 (n=25; 34.7% of group)

The science we learn about in school is the stuff that has already been researched and proven so it makes science seem more boring and not creative. We can't learn about the creative research that is done because it hasn't been done yet and you need to learn about the basics first to understand what is going on. (N.M. SS4Q3)

I think that really to understand that science is creative you have to be willing to take in account that a scientist has to dream up ways he thinks things happen. When gravity was first researched scientists had to be creative enough to determine that there must be something pulling that object downt o the earth. While scientists used creativity they also used the data they gather and then bring them together to make a conclusive truth. (B.M. SS4Q3)

SS4Q2 (n=23; 31.9% of group)

These two episodes show very different approaches to finding the same answers. These very different methods were the results of very imaginitive minds at work. Without thinking outside of the box on these different topics, one would never find any true answers, only open, answerless questions. (C.W. SS4Q3)

Scientist get to go out in the field and collect data which means traveling to exotic locations and seeing sometimes incredible natural events. This alone makes their job exiciting. There is also good in it when a new discover is made or something is proven to be right or wrong. (Z.N. SS4Q3)

SS3Q3 (n=21; 29.2% of group)

Somehow you have to back up the data to find the answer for experiment. The only way that someone will believe that the data is right is if you can prove it. (B.M. SS3Q3)

It doesn't? You could say Hutton simply taught himself to read, and then read to the illiterates. Perception doesn't create reality. That doesn't mean that science doesn't require imagination or induction to generate explanations of data. (C.B. SS3Q3)

Data doesn't show or tell us anything. Data can't just "tell" you how to interpret it. When you observe something you illuminate your own ideas and make theories regarding them. Scientists tell what they have discovered, which is proven true, is then considered "fact" or "data." The data didn't tell them what to think though, or even show them what to think, that was up to the scientists on how they chose to interpret what they've found. (R.J. SS3Q3)

SS3Q4 (n=16; 22.2% of group)

Scientific method has always been built around how one can go about a process and prove the idea. Religion is too abstract and cannot be proven, while science is built upon hard data and concrete objects and events we know happened. (P.S. SS3Q4)

It should never be science vs. religion. Instead, you can use science to “prove” Biblical facts. They work hand in hand. It shouldn’t be this is the right way – this is the wrong way kind of thing. You can use both and see how they contradict each other and how they are similar. The Bible could be a basis for thinking and seeing if scientific ideas match them in ways. (R.J. SS3Q4)

During this story one of the common themes was science versus religion, releigion can't prove anything about the age of the earth. THey have no way to show any actuall observation of how old they actually beleive, while scientists have been able to prove every claim about the age of the earth and show those with obsercations and evidence to back all of their claims. (P.O. SS3Q4)

SS3Q2 (n=8; 11.1% of group)

By looking at the story, all scientists need to work together. Hutton had many friends who were all scientists in different areas. All could contribute to help to gain an understanding of the true beginning of the earth. You need a group of people who have an intellectual understanding of what is going on and a creative mind to help come to a conclusion. (R.S. SS3Q2)

Science is a social endeavor because scientists must come together and communicate their ideas for them to become theories. To make the theory more reliable, they should tell other scientists as well and have them test the hypothesis to see if it's true. (C.L. SS3Q2)

SS1Q1 (n=7; 9.6% of group)

It seems to me that most of the countries that had scientists seemed to be Christian, or a religion close to that. Father Francis Placet made that statement that America did not exist before Noah's flood. Someone from a different religion wouldn't even know what that was, and they definitely wouldn't believe it. By being Christian it seemed to impact them, because they didn't have facts to go by, so they made up theories about things they knew about that might have a connection. (L.C. SS1Q1)

In the past, there was a lack of technology to help prove scientific hypotheses. People often used religion and theory to describe situations and why things occured. This helps explain why people used Noah's flood as a reason for the ocean dividing the continents. (H.P. SS1Q1)

I think religion is used as a cop out. There just wasn’t enough technology available back then to make sure their assumptions were correct. Yes, the continents looked like they all fit back together. There was no way of them proving it scientifically so they use religion, which can not be proved. (J.R. SS1Q1)

Many used the catastrophes that appeared in religious text to explain the natural events because back then, that is all they had. They don’t have the technology we have now to explain these natural events. For many people faith is a big part of their lives and therefore think that the reason these natural events occurred is because of what is printed in their religious text. In a way it also made people think that some higher power caused these events and had nothing to do with the way the plates were moving. Some scientists don’t believe that and therefore get more in depth and use science to prove what really happened. (K.M. SS1Q1)

SS1Q4 (n=7; 9.6% of group)

Many scientists are trying to prove the problems different with the other scientists who already solved the problems. By doing this, they want to be famous and want the following people believe that they proved that right things. (L.M. SS1Q4)

Many young scientists in the field most likely begin revolutions because they are looking for their way into fame. If a young scientist wants to become known as an equal with the other elder

> scientist he or she must come up with something completely new that makes the others proud of him or her. The other big reason for this could be because they have more time than the other elder scientist to actually prove there ideas. Many older scientists do not have as much time, being old and all, to successfully achieve something of such time. (E.O. SS1Q4)

SS3Q1 (n=4; 5.6% of group)

> I think at that times, they didn't have a correct concept of geology exactly, so going around to survey how old the earth is might have been concerned just like a hobby or a personal activity. Moreover, the trust of religions seemed to have influence on people regarding the age of the earth according to the records from the bible, something like that. Therefore, I guess they might consider investigating the natural world not serious things for them as science. (S.K. SS3Q1)

The short story responses for each question certainly provide information regarding the ways that students answer these questions and the extent to which "proven truth" ideas are used by students to answer the question. Also insightful is the percentage of responses that used a "proven truth" perspective by individuals in this study. A student who indicates scientific knowledge is "proven truth" on one question strikes us as potentially different than a student who uses this view to answer a large percentage of questions. Because not all students answered all short story questions, we determined the number of questions each student answered with a "proven truth" perspective, and divided this by the number of questions he or she completed. Of the 91 student in the "proven truth" group, 19 completed short stories 1 and 2 only, and 17 completed short stories 3 and 4 only. 55 students completed both short stories. Table 2 provides the results of this analysis.

Table 2. Percentage of individual students' responses that contain "proven truth" views

Percentage of Short Story Questions	Number of Students
<10%	0
10-19%	17
20-29%	29
30-39%	18
40-49%	16
50-59%	4
60-69%	5
70-79%	1

Twenty-nine students expressed a "proven truth" view in 20-29% of their responses. In raw numbers, the lowest number of "proven truth" responses given by a single student was 1, provided by only 7 students in the study, all of whom completed only 2 short stories. The highest number of "proven truth" responses was 10, provided by 2 students who answered all 15 questions. For these two students, two-thirds of the questions in the short stories were answered from the perspective of this misconception. This is of particular interest as none of the short stories explicitly sought this information nor was designed to teach the ontological status of scientific knowledge.

As illustrated in the table above, students who completed all four short stories answered at least 2 questions with a "proven truth" view. (If they had only one question coded "proven truth," this would represent only 6% of their total responses). The most common expression of this misconception was in one-fourth to one-half of all responses to short story questions. To illustrate how a single student uses this ontological view throughout his or her responses, one student's full short story submissions are provided below.

Student G.N.

Short Story 1 - Continents: A Jigsaw Puzzle With No Mechanism

1. Religion has shaped us and made it wrong to think that the world could have been shaped otherwise. It also is a good history book into what happened like the sinking of Atlantis to Noah's floods and other catastrophes that could have changed the land mass on the planet. Plus most of the scientist had to stay in the normal views in fear of being prosecuted by the very popular church.
2. With science books they are always changing no matter what the reason there is always new discoveries. Just like past scientists it takes time to get the real facts and for hypothesis to work out.
3. Scientists construct new and better ideas on way that they can more accurately account interrupt and input data that will fit their new theory or idea. New ways are always thought of to get better results and better explanations of the past.
4. I believe that someone new to a field is not set in any ways or ideas and is open to what the facts tell him. Scientists are human and like to fit their ideas but sometimes these ideas just don't so they must change. They sometimes won't or don't think that they should have to. New thinkers see the new facts and most of the time accurately interrupt them the best way they can.

Short Story 2 - Data Doesn't Speak: Development of a Mechanism for Continental Drift

1. If you don't believe in consensus building then why did it take so long for this idea to be widely recognized as the truth? There was no consensus so it took major time for the world to accept it since individuals and no collaboration of the world's leading scientists were done. The people who thought it up were thought to be wrong because they were outsiders.
2. Those scientists aren't as objective as first thought. That most scientists are set in their ways until proven otherwise. It has to be a proven fact and they don't like to buck their belief system.
3. Data can always be interpreted a different way by every person. So when it says the data shows it is just the author's interpretation not necessarily the accurate until it is tested by more scientists and proven to be factual.
4. They at least know that their first theory works and can explain their ideas. If they let go of their first theory to early to go with a new unproven theory that could be completely bogus it will leave them dead in the water. They must hold onto their first theory until it is proven otherwise and completely proven otherwise.

Short Story 3 - Early Efforts to Understand the Earth's Age: Naturalists and Chronologists

1. It could be that everybody had hard labor to do and the only time they could think would be when they have leisure time. Now it is as job with hard labor being a choice.
2. Almost every scientific invention was developed for it's time period and for that society so why then wouldn't be a social endeavor.
3. Data doesn't show every scientist like hutton says must interpret and develop data that will make their theory correct.
4. Relgion shaped science forever but it wasn't until people could truly prove things and society start to change that it moved away from religion verse society.

Short Story 4 - A Very Deep Question: Just How Old is the Earth?

1. 95,760,000 years old if my math is correct.
2. Scientific knowledge presents to us on how we must make scientific process work. One is dependent on another as evident in the short story that was read.
3. The whole process of deciding how old the earth is a very exciting idea. Both methods including testing and the guesstimating it make it very interesting you could be changing the world that idea is so awesome.
4. Scientists have ideas and theories and this theory must be tested and proved to be fact if they can't then they look to find the answers. Scientists don't care what scientist just as long as they can prove their theory correct.

The responses of G.N. are typical of students selected for inclusion in the "proven truth" group. Some responses are more accurate than others, but the "proven truth" view appears scattered throughout his responses.

Implications and Discussion

With NSF funding we are developing 30 historical and contemporary science stories for introductory post-secondary science courses, divided equally among the disciplines of astronomy, biology, chemistry, geology, and physics. These short stories target fundamental science ideas taught in these courses, and each story explicitly draws students' attention to important NOS issues entangled in the development of those ideas. Use of these historical short stories in post-secondary geology and biology classes has resulted in improved student understanding of particular NOS ideas when compared to a control group. Students in the biology treatment group also scored higher on particular unit-ending science content questions (Clough *et al*., 2007). However, an analysis of students' responses to questions in the short stories revealed that a substantial percentage of students (sometimes reaching 40% on a given question) expressed significant NOS misconceptions

For instance, the four historical short stories and questions embedded in the short stories did not explicitly address matters of scientific truth. Yet, many students responded to each of the short story questions by expressing some view about scientific knowledge being "proven truth". In many cases, this view was expressed to support an incorrect response to the question, while in other cases the intent of the question was missed entirely. For example, the short story titled "Data Doesn't Speak: Development of a Mechanism for Continental Drift" included a question about the possibility of scientists being objective. This short story clearly described how scientists grappled with the same data, yet interpreted it differently depending on the framework and prior ideas they used. However, 36 of 278 students (13.6%) who completed the short story question (representing 48% of the 91 students who expressed "proven truth" on any of the short story questions) expressed "proven truth" views on this particular question. Many of these 36 students used this view as a reason for supporting their position that scientists are (or should be) objective. Their misconception that scientific knowledge is "proven truth" appears to have hindered the students' ability to accurately interpret the short story. Wrongly seeing scientific knowledge as absolutely true, they appear unable to reconcile examples showing how personal and cultural biases influence scientific work. As a result, they ignore the example in the short story and use their personal view of the requirement for scientists to be objective in order to reach the truth.

Previous research (Tao, 2003) indicates that students' prior NOS ideas impact how they make sense of science stories. Students easily interpret stories in idiosyncratic ways, focus on aspects of the stories that fit their misconceptions, unknowingly modify other aspects to fit their prior ideas, and ignore other aspects that do not fit their prior understandings. Our work presented here raises the possibility that particular NOS misconceptions (i.e. scientific knowledge is proven truth, scientists follow a scientific method, and the perceived objective role of technology) are the root of students' difficulty in accurately interpreting historical materials.

What this means is that while some NOS concepts are, not surprisingly, linked to one another, particular ideas (i.e. the ontological truth status of scientific knowledge and epistemological issues of scientific methodology and the role of technology in doing science) may be more fundamental. If so, such issues need to be forcefully addressed early in NOS instruction.

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