Humanizing Science to Improve Post-Secondary Science Education

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ABSTRACT: With funding from the National Science Foundation, 30 historical short stories designed to teach science content and draw students' attention to the NOS have been created for post-secondary introductory astronomy, biology, chemistry, geology and physics courses. The project rationale, story development and structure, and freely available project website are presented.

1. 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. While some characteristics regarding the NOS are, to an acceptable degree, uncontroversial and have clear implications for science teaching and learning (Smith *et al.*, 1997; McComas *et al*., 1998; Eflin *et al.*, 1999), many are contextual and make sense only in light of science practice.

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 centrality of the NOS for science literacy is 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 may 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). Postman (1995) characterizes that image as follows:

> …textbooks are concerned with presenting the facts of the case (whatever the case may be) as if there can be no disputing them, as if they are fixed and immutable. And still worse, there is usually no clue given as to who claimed these are the facts of the case, or how "it" discovered these facts (there being no he or she, or I or we). There is no sense of the frailty or ambiguity of human judgment, no hint of the possibilities of error. Knowledge is presented as a commodity to be acquired, never as a human struggle to understand, to overcome falsity, to stumble toward the truth.
>
> Textbooks, it seems to me, are enemies of education, instruments for promoting dogmatism and trivial learning. They may save the teacher some trouble, but the trouble they inflict on the minds of students is a blight and a curse. (p. 116)

Accurately and effectively conveying the NOS can play 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). Encouraging second tier students to continue their science education and consider science careers is crucial. After interviewing a number of these students, Tobias (1990) reported that they became 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. Students imagine scientists as "eccentric old men" who work alone. In order to increase the number of women in science, she argues that we need to increase their interest in these fields "and that means making them aware that science is a social endeavor that involves working with and helping people." Because women tend to value working with people, "we need to show them that scientists work in teams, solving problems collaboratively."

Misconceptions regarding what science is, how science works, and the life and characteristics of scientists are damaging to general scientific literacy and result in an unacceptable loss of highly creative and frequently underrepresented individuals who opt out of science in favor of other pursuits they perceive as more humane and creative (Eccles, 2005; Tobias, 1990). Thus, accurately and effectively conveying the NOS in post-secondary introductory science courses is essential, not a luxury to be addressed if time permits.

Over 100 years ago William James (1907) noted “You can give humanistic value to almost anything by teaching it historically.” In advocating an historical approach to teaching all subjects, Postman (1995, p. 124) wrote, “I can think of no better way to demonstrate that knowledge is not a fixed thing but a continuous struggle to overcome prejudice, authoritarianism, and even ‘common sense’.” An historical approach (e.g. Conant 1957; Klopfer & Cooley 1963; Matthews 1994; Hagen et al. 1996; Clough 1997, 2004; Abd-El-Khalick 1999; Irwin 2000; Stinner et al. 2003 and many others) illustrates the complexities and challenges individual scientists and the scientific community experience in constructing ideas and determining their fit with empirical evidence. In addition to enhancing understanding of science content, these examples exemplify important epistemological and ontological lessons that are bound up in that content and central to understanding the NOS, and place the science content in a human context. The importance of explicitly contextualizing NOS instruction is also reflected in the research of Driver et al. (1996), Ryder et al. (1999), and Brickhouse et al. (2000) showing that students’ perspectives on the NOS are, at least in part, dependent on the science content that frames the discussion. This is also reflected in Abd-El-Khalick’s (2001) noting that the results of his empirical work with preservice elementary teachers indicated that ‘‘the context and content in which preservice teachers learned about NOS influence their ability to apply their understandings to novel contexts and content’’ (p. 229).

Past attempts at accurately portraying the NOS in science textbooks, or developing primary source materials that concentrate on the history and nature of science have been problematic for two reasons. First, publishers resist modifying traditional science textbooks in fear of losing market share. Second, post-secondary science faculty balk when such instruction detracts significantly from science content instruction. For instance, past efforts such as *Harvard Case Histories in Experimental Science* (Conant, 1957) and *History Of Science Cases* (Klopfer and Cooley, 1963), despite their well-considered nature, are now out of print. Both emphasized the history of science to such an extent that many science faculty perceived the science content as secondary. In promoting the history of science in science education Heilbron (2002) argues that it ought not be in such depth that it detracts from the science content. He writes:

> Finally, wherever 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)

A key solution to this tension is the development of materials that teach both science content and the NOS, and that post-secondary science faculty can infuse when and where they deem suitable.

2. The Story Behind the Science: Project Description

Project Rationale

Schaefer (1990) writes, “A migration reversal must take place at several junctions at which the sciences lose potential practitioners: the transition between high school and college; the freshman year; and the mid-major, mid-decision points where, having completed as many as two years of college science, students change directions” (p. 4). With United States National Science Foundation (NSF) Course, Curriculum, and Laboratory Improvement (CCLI) funding, we have created thirty historical stories (six each for astronomy, biology, chemistry, geology and physics) targeted at key science ideas taught in post-secondary introductory science course. The stories we have created tell the story behind the science ideas, and are structured so that post-secondary science faculty can infuse them when and where they deem suitable. This project makes possible the widespread justification and implementation of materials that accurately and effectively convey the NOS in post-secondary introductory science courses.

Empirical evidence supports the view that NOS instruction is more effective when it has both an explicit and reflective character (Abd-El-Khalick *et al*. 1998; Abd-El-Khalick & Lederman, 2000a). Reflecting how people learn (Bransford *et al*., 2000), the short stories developed in this project explicitly engage students in questioning commonly held NOS misconceptions. The historical stories in this project address the development of fundamental science ideas (using the words of scientists) with embedded comments and questions that explicitly draw students' attention to key NOS ideas. Clough (2006) argued that this feature is crucial for deeply understanding the NOS. The value of history of science with explicit/reflective NOS instruction can be inferred in work by Abd-El-Khalick and Lederman (2000b), and is supported more directly in a study by Howe (2003). These historical and contemporary short stories fit seamlessly in post-secondary introductory science courses because they are linked to fundamental ideas taught in those courses. Faculty can implement these stories when and where they wish to enhance students' understanding of science content and the NOS.

Development of Short Stories and Supporting Materials

Step 1: Science faculty (project co-PIs, Dr. Jim Colbert and Dr. Cinzia Cervato, and senior personnel Dr. Tom Greenbowe, Dr. Charles Kerton and Dr. Craig Ogilvie) identified fundamental science ideas taught in respective post-secondary introductory biology, geology, chemistry, astronomy, and physics courses. Six ideas in each discipline were selected for stories to be created.
Step 2: Historian of science (project co-PI Dr. Matthew Stanley) and a graduate student in the history of science: a) accessed relevant historical and contemporary resources related to development of the identified fundamental science ideas and b) wrote summaries illustrating the complexities individual scientists and the scientific community experience in constructing and validating those ideas.
Step 3: Science educator (project PI Dr. Michael Clough) edited the historical material to create a 3-7 page story. Key NOS issues inherent in the stories were identified and comments and questions were inserted to explicitly draw readers' attention to those issues.
Step 4: A reading specialist reviewed each short story and recommend changes to ensure the reading level is appropriately matched to the abilities of freshman and sophomore college students.
Step 5: The project historian of science and project science faculty reviewed the short stories to ensure they accurately portrayed the history of science and science content.
Step 6: The project PI, Dr. Michael Clough, is preparing supporting materials that include: a) how the historical short stories may be integrated alongside the teaching of science content so that both fundamental science ideas and the NOS are better understood; and b) accessible additional resources.
Step 7: Field-testing has occurred in geology, biology and astronomy courses. Additional field-testing is planned for the 2009-2010 academic year.

Project Website

The project website, *The Story Behind the Science*, (http://www.storybehindthescience.org) is under development. The bolded links below appear on the homepage. Twenty stories are freely available for downloading in pdf format, and additional stories and supporting materials will soon be available.

Astronomy Stories

- Detection of Black Holes: The Power of Robust Theory and Mathematics
- Data Makes Sense Only in Light of Theory: The Story of Cosmic Microwave Background
- Imagination and Invention: The Story of Dark Matter
- Personalities and Pride: Understanding the Origins of Elements
- The Great Debate: Just How Big is the Universe?
- Accounting for Anomaly: The Discovery of Neptune

Biology Stories

- Charles Darwin: A Gentle Revolutionary
- Adversity and Perseverance: Alfred Russel Wallace
- Creativity and Discovery: The Work of Gregor Mendel
- Model Building: Piecing Together the Structure of DNA
- A Distinctly Human Quest: The Demise of Vitalism and the Search for Life's Origins
- The Realization of Global Warming

Geology Stories

- Continents: A Jigsaw Puzzle with no Mechanism
- Data Don't Speak: The Development of a Mechanism for Continental Drift
- Understanding Earth's Age: Early Efforts by naturalists and Chronologists
- A Very Deep Question: Just How Old is Earth?
- Ice Ages: An Alien Idea
- Determining How Volcanic Activity Fit into the Greater System of the Earth

Physics Stories

- Pendulum Motion: The Value of Idealization in Science
- The Role of Theory: Pendulum, Time Measurement, and the Shape of the Earth
- Conservation of Energy and Mass *(Coming Soon)*
- Magnetism *(Coming Soon)*
- Newton's First Law *(Coming Soon)*
- Potential Energy *(Coming Soon)*
- Universal Gravitation *(Coming Soon)*

Chemistry Stories

- Atomic Structure *(Coming Soon)*
- Calorimetry *(Coming Soon)*
- Entropy *(Coming Soon)*
- Heat *(Coming Soon)*
- Periodic Table *(Coming Soon)*
- Phlogiston *(Coming Soon)*

Accurately Portraying Science and Scientists

- Information addressing how to effectively use the project stories will soon be posted.

Project Research

- Conference papers, summaries of research, and references to publications

Project Team

- Currently the names and affiliations of Project PIs and Senior Personnel appear. Additional information will soon be available

3. Significance of Project

Many very talented students dislike science, wrongly perceiving it as a purely logical, cold and algorithmical process devoid of human influence. Highly creative individuals frequently pursue other fields of study due to these misconceptions (Tobias, 1990), a trend that must be reversed. This project primarily targets introductory science courses, a time when students make critical decisions about whether to pursue careers in science. The short stories are also very appropriate in science content courses for elementary and secondary education students, in nature of science courses, and in science methods courses that address the nature of science. This NSF funded project is:

1. *Focused on learner-centered teaching* – bringing humanity back into science to help students better understand how individuals do science, and how societal influences have affected the development of scientific knowledge and the participation of various groups in science endeavors.
2. *Interdisciplinary in its approach to scholarship* – bring together faculty from history, astronomy, biology, chemistry, geology, physics, science education and English education to create innovative historical and contemporary science short stories that will improve post-secondary science education, promote science literacy for all, and further the field of science education.
3. *Designed to enhance student learning* – through curriculum development and innovative science teaching, we aim to improve student learning of science concepts while also increasing students' interest in and understanding of the scientific enterprise. For instance, student understanding of biological evolution has been shown to be significantly influenced by their understanding of the NOS (Johnson & Peeples, 1987; Bishop & Anderson, 1990; Rudolph and Stewart, 1998; Rutledge & Warden, 2000; Trani, 2004), and secondary science teachers who understand the NOS are more likely to teach this fundamental theory (Scharmann and Harris, 1992).
4. *Targeted to promote interest in science and life-long learning* – those who understand the NOS find science and science classes more interesting. This increased interest may help stem the flight of talented post-secondary students from science. Understanding the NOS prepares *all* students to make more informed decisions, and better understand the role of science in society. Having a greater interest in science, they are more likely to remain informed beyond formal schooling.

Despite a wide variety of efforts aimed at encouraging teachers to devote explicit attention to NOS instruction, results have, for the most part, been disappointing. Teachers generally appear unconvinced of the need to emphasize the NOS as a cognitive objective (Abd-El-Khalick *et al.*, 1998; Lederman, 1998), and likely see NOS instruction as detracting from their primary mission of teaching science content. Lakin and Wellington (1994) point out that NOS instruction appears to be contrary to "expectations held of science and science teaching in schools, not only by teachers and pupils but also those perceived as being held by parents and society" (p. 186). Science teachers balk at extensive explicit decontextualized NOS activities, seeing them as taking time from science content instruction. For the same reason, they also resist extensive history of science case studies. Our project historical stories diminish the argument that NOS education must detract from science content instruction. Rather than an "add-in" activity, use of our historical short stories to accurately convey the NOS is ubiquitous with teaching science content. Both secondary and post-secondary science teachers have expressed interest in our short historical stories that teach science content while also drawing students' attention to important NOS ideas. Perhaps teachers are willing to consistently teach the NOS if it is entangled within the science content traditionally taught in science courses, thus not taking significant time away from that instruction.

The general public's abysmal understanding of science as a way of knowing is illustrated in a number of ways, but perhaps most clearly by the evolution public education controversy. This project promotes improved understanding of the NOS, while simultaneously helping future science teachers learn how to address these vital issues with their students. Research conducted on this project will provide important information about teaching strategies to promote increased understanding of the NOS.

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The Story Behind the Science

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Please visit the site and provide feedback to the project principal investigator at mclough@iastate.edu

If interested in implementing the project stories and taking part in research efforts, please contact the project principal investigator.

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