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The Story Behind the Science: Bringing Science and Scientists to Life in Post-Secondary Science Education

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Abstract With funding from the United States National Science Foundation, 30 historical short stories designed to teach science content and draw students' attention to the nature of science (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 stories at the project website are presented.

1 Introduction

The phrase "nature of science" (NOS) has been used for some time, particularly in the science education community, in referring to what science is, how science works, the epistemological and ontological foundations underlying science, the culture of science, and how society both influences and reacts to scientific activities (Clough 2006). Accurately understanding the NOS is crucial for science literacy (AAAS 1989; Matthews 1994; McComas and Olson 1998; NRC 1996) and can perhaps play an important role in enticing students to further their science education. Matthews (1994), McComas et al. (1998) and others have argued 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) claimed 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 opt out of science, in part, because of mistaken notions

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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 a portion of 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 (2007) argues that some business and political groups exploit the public's misunderstanding about how science is done in order to create doubt about global warming, a tactic also used by opponents of biological evolution. 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 and Wynne 1988; Miller 1983, 1987; NAEP 1989; National Science Board 2002; Ryan and Aikenhead 1992; Ziman 1991). This is not surprising given how science textbooks, cookbook science laboratory activities, and most audiovisual materials ignore or 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; Duschl 1990; Rudge 2000). Almost two decades ago, DeBoer (1991) reviewed the history of science education and noted that an outdated view of the philosophy of science continued to impact classroom practice and permeate popular science curriculum materials—a situation that persists today. 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)

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 and Cooley 1963; Matthews 1994; Hagen et al. 1996; Clough 1997, 2004, 2006; Abd-El-Khalick 1999; Irwin 2000; Stinner et al. 2003: Metz et al. 2007 and many others) that faithfully reflects the work of scientists illustrates the humanity of science, the enjoyment and frustrations in conducting research, and the complexities and challenges individual scientists and the scientific community experience in developing and justifying science ideas. In addition to potentially enhancing understanding of science content, these examples can 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. Moreover, effective NOS instruction demands that the context of scientific work be considered (Driver et al. 1996; Ryder et al. 1999; Brickhouse et al. 2000: Rudolph 2000; Clough 2006).

However, 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) argued 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 creation of historical short stories that illustrate the development and acceptance of fundamental science ideas, important NOS ideas (Metz et al. 2007), and that post-secondary science faculty can infuse when and where they deem suitable.

2 Historical Science Stories

Metz et al. (2007) argued that well constructed historical narratives, by their very nature, humanize a subject by raising "personal, ethical, sociological, philosophical and political concerns which tend to increase interest and motivation in students" (p. 315). A story is just one type of narrative and refers to "a sequence of events which involves *characters*" (Jahn 2005, N1.2), presents events chronologically, and contains a plot that intentionally relates events in the story (Prince 1973; Egan 1978). Stories may be used in a variety of ways and with several purposes in mind, but efforts to help readers make sense of the story are crucial (Metz et al. 2007). This is particularly the case when the intent of historical stories is to improve understanding of the NOS. Making sense of information is significantly impacted by a learner's prior knowledge. Because misconceptions regarding the NOS are so prevalent and often deeply held, students easily draw mistaken conclusions from stories even if they are historically accurate. This is because students' prevailing misconceptions unknowingly cause them to miss or ignore important NOS messages in a story, and at other times transform accurate NOS portrayals to fit their misconceptions (Abd-El-Khalick & Lederman 2000a; Tao 2003). Students' personal and peculiar interpretation of science stories was noted in a study by Tao (2003):

> Since most students drew on the science stories for justifications of their views, the way they interpreted the science stories was crucial. Students' peer interactions showed that most of them were not fully aware of the overall theme of the stories; instead they attended to certain aspects that appealed to them and appeared to confirm and reinforce their inadequate views. (p. 167)

Clough (2006), drawing from how people learn, argued that historical science stories play a crucial role in effective NOS instruction. However, he cautioned that their efficacy to teachers and students for achieving effective NOS teaching and learning demands attention to the following:

1. Science stories should focus on important science ideas already ubiquitous in science courses. This will make more likely their use in science classrooms. Many teachers are reluctant to use history and nature of science curriculum materials that take significant amount of time away from teaching science content.
2. Science stories should be written so that they may be flexibly used by science teachers (e.g. choice should exist regarding which stories to use, the number of stories to implement, and where in the curriculum stories are used, etc.). Such stories are more likely to make their way into science classrooms.
3. Science stories should be created that address both the past and the present so that teachers and students will not dismiss accurate NOS ideas as those of a bygone era.
4. Science stories should incorporate where appropriate the words of scientists to accentuate the human side of science and to add authenticity to the NOS ideas being illustrated.
5. Science stories should incorporate comments that explicitly draw students' attention to key NOS ideas and include questions that have students reflect on the NOS.
6. Science stories should be connected to other science content in and outside the classroom.

2.1 Narrative Elements and NOS Myth-Conceptions

While including historical science stories has much potential to improve students' understanding of the NOS and enhance attitudes toward science education and science careers, Allchin (2003) makes the important point that "the concern should be what *type* of history is used" (p. 329). That is, too often science stories portray scientists and science as larger than life, thus conveying misconceptions about both. Allchin acknowledges that any account of science is inherently selective and limited, but notes that "selectivity does not inherently yield *myths*" (p. 330). The important issue he raises is that even when an author sincerely intends to accurately convey the history and nature of science, common narrative elements often transform stories into myths that distort scientists and the NOS. Allchin lists the following narrative elements that interfere in accurately portraying the NOS:

- Monumentality: portraying scientists as valiant, virtuous, solitary geniuses—nearly superhuman. This results from ignoring: (a) any character flaws of scientists; (b) errors and misinterpretations made by scientists; (c) the contributions of other scientists, and (d) the extensive time required for knowledge to be developed and established by the scientific community of which a scientist is a member.
- Idealization: portraying research designs as faultless and the meaning of data as straightforward—a form of naïve empiricism. This results from emphasizing particular features of a story, downplaying other instances, and ignoring certain events in order to simplify the story. While the intent may be to ease comprehension of the story, the outcome distorts the NOS by making the research process and advancement of knowledge appear linear and uncomplicated.
- Affective Drama: portraying scientists and science as prevailing, but often after some noteworthy struggle. This results from using rhetorical devices such as: using eureka events; highlighting the exoneration of a person or an idea; (c) ascribing surprising outcomes solely to chance.
- Explanatory and Justificatory Narrative: portraying that accurate scientific knowledge follows logically from proper scientific methodologies. This results from reporting historical events in a manner implying that correct methods lead to correct knowledge while incorrect methods lead to incorrect knowledge.

These tendencies are rooted in general cognitive biases, as documented by cognitive scientists. That is, we typically tell stories to inform, motivate, and entertain. That leads to "sharpening" the essence of the intended message and "leveling" or unintentionally concealing details thought to be less important. However, if we are aware of our motives, then we are better able to regulate our behaviors (Gilovich 1991, pp. 90–94) and thus produce stories that more accurately reflect the history and nature of science.

3 The Story Behind the Science: Project Description

The remainder of this paper describes the rationale for and efforts of a United States National Science Foundation (NSF) funded project to create and disseminate science short stories that: (a) accurately reflect the history and nature of science; (b) mentally engage students in drawing intended NOS ideas; and (c) are written in a manner so they will be used by post-secondary science faculty in introductory science courses. The project title, *The Story Behind the Science: Bringing Science and Scientists to Life*, reflects the intent of the stories to humanize science, accurately and effectively teach important NOS ideas, improve science literacy and entice more individuals to consider science careers.

3.1 Project Rationale

Despite ongoing calls stressing understanding the NOS as a critical component of scientific literacy (AAAS 1989, 1993; ASE 1981; Collette and Chiappetta 1984; Lederman 1992; Matthews 1989, 1994; NSTA 1982, 2000; Shahn 1988), few science teachers, particularly at the post-secondary level, devote instructional time to accurately conveying the NOS. The time such instruction is perceived to take away from traditional science content instruction likely deters many science teachers from purposely and accurately addressing the NOS in their courses (Abd-El-Khalick et al. 1998; Olson and Clough 2001). And yet, understanding the NOS is fundamental to scientific literacy because the conceptions of scientists, the scientific enterprise, and the processes of science are what citizens use when assessing public issues and controversies involving science and technology. Social decision-making, interest in science, and understanding science content are all linked to understanding how science and scientists work (McComas et al. 1998).

For a variety of reasons, many talented individuals perform well in introductory science classes, but choose not to pursue further education in science (Seymour and Hewitt 1997; Tobias 1990). 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 2 years of college science, students change directions" (p. 4). 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, and encouraging students to continue their science education and consider science as a career. 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). 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)

Encouraging capable but disillusioned students to continue their science education is important for improving science literacy and for attracting individuals into science careers.

3.2 Project Goals and Objectives

The long-term goal of *The Story Behind the Science* project is to encourage science teachers at all levels to accurately and effectively convey the NOS to improve science literacy and the attitudes of students toward science, scientists and science education. The more immediate goal of the project described here is to develop historical and contemporary short stories that accurately and effectively promote understanding the NOS and that science faculty will use in post-secondary introductory astronomy, biology, chemistry, geology and physics courses. This project makes possible the widespread justification and implementation of materials that accurately and effectively convey the NOS in post-secondary introductory science courses. *The Story Behind the Science* project objectives are as follows:

1. Create 30 short stories for use in post-secondary astronomy, biology, chemistry, geology and physics courses (6 short stories in each of these five disciplines). These short stories are linked to important science ideas commonly taught in these courses, and they draw students' attention to important NOS issues entangled in the development of those ideas.
2. Develop accompanying support materials that help faculty seamlessly implement these historical and contemporary short stories alongside the fundamental science ideas taught in these subjects.
3. Implement the short stories in introductory science courses and collect formative assessment data that informs revisions to improve the stories.
4. Evaluate the educational outcomes of the project in post-secondary introductory science courses.

3.3 Development of Short Stories and Supporting Materials

Thirty historical stories have been created (six each for astronomy, biology, chemistry, geology and physics) that are targeted at key science ideas taught in post-secondary introductory science course. They 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.

The project stories also incorporate mediation strategies (Metz et al. 2007)—specifically, comments and questions are inserted at appropriate points in each story to encourage reflection and help students draw intended NOS ideas. Reflecting how people learn (Bransford et al. 2000), the short stories developed in this project explicitly engage students in questioning commonly held NOS misconceptions. 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 and Lederman 2000b). 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, and the role of history of science alongside explicit and reflective NOS instruction is supported by the work of Abd-El-Khalick and Lederman (2000a) and Howe (2003). Importantly, 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 the stories was a several step process. Because stories are published on-line, we are able to make further modifications based on feedback and continuing project research.

Step 1 Post-secondary science faculty in astronomy, biology, chemistry, geology and physics identified important science ideas that are commonly taught in those introductory courses. Science faculty, the project historian of science, and the project director (a science educator) together selected six ideas in each discipline for stories to be created. The final decision was determined based on the following criteria: (a) the primary science idea addressed in the story must be commonly taught in the particular introductory post-secondary science course; (b) the topic must be one that the historical development and acceptance of the idea could be addressed in a four to seven page story understandable to the target audience; and (c) the topic must be such that important NOS issues embedded in the story can be readily drawn and grasped by most students in the targeted audience.

Step 2 The project historian of science and doctoral students in the history of science: (a) accessed historical and contemporary resources that addressed the development of the identified science ideas; (b) wrote extensive summaries using those sources particularly emphasizing the characters involved and the complexities individual scientists and the scientific community experienced in constructing and validating those ideas, and (c) submitted those materials to the project director.

Step 3 Early in the project, the project director used the material provided by the historians of science to craft a four to seven page story for the particular topic. The project director then identified key NOS issues inherent in the story and inserted at appropriate places comments and questions to explicitly draw readers' attention to those issues. In time, those conducting the historical research for each science topic came to understand the structure and intent of the stories and took the primary role in writing the stories. The project director continued to edit the submitted stories, identify key NOS ideas in each, and insert comments and questions.

Step 4 A reading specialist reviewed the stories and recommend changes to ensure their reading level was appropriately matched to the abilities of typical freshman and sophomore college students. The project director implemented suggestions and then sent the story to the project historian and appropriate science faculty member.

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, respectively.

Step 6 Stories are implemented in the appropriate classes. Feedback from the instructor and students has been used in making needed changes to the stories to make them more intelligible, and to better mediate students' interpretation of the stories.

Step 7 Based on classroom observations of science faculty implementing the stories and student data, project staff have prepared support materials that include: (a) an overview of important NOS ideas for science education; (b) how to use the short stories; (c) Tips for creating effective class discussions; (d) additional tips for creating class discussion in large group settings; and (e) tips for structuring group work. Work is currently underway to develop assessment items aligned with key NOS ideas.

Step 8 Research regarding the efficacy of the short stories for improving students' understanding of the NOS, perceptions of the short stories and their impact on students' interest in science has been conducted in post-secondary introductory astronomy, biology and geology courses. Additional research is ongoing.

3.4 Framing Project Stories to Accurately Portray the Nature of Science

Accurately capturing the history of ideas in science and the contributors to those ideas in a four to seven page story that teachers will use in a post-secondary classroom is challenging.

In crafting the project historical stories, every effort was made to accurately portray the history of science and avoid or mitigate narrative elements that would distort the NOS. To the extent possible the project stories reflect Allchin's (2003) advice to:

> Suspect simplicity. Beware vignettes. Embrace complexity and controversy. Discard romanticized images. Do not inflate genius. Mix celebration with critique. Scrutinize retrospective science-made. Revive science-in-the-making. Explain error without excusing it. And above all respect historical context. (p. 347)

The following excerpts from *Creativity and Discovery: The Work of Gregor Mendel* (Williams et al. 2010) illustrate how one of the project stories presents the history of science and engages students in reflecting on the nature of science. The first excerpt below illustrates how many individuals over long periods of time contributed to the growth of knowledge regarding heredity, and how Mendel's thinking was impacted by that prior work.

> At the time Mendel began his scientific work, discussions regarding heredity had already been very active for a century. …Early investigations into heredity were done with animals. Plants were not used in hybridization experiments until the 1700s. In *Origins of Mendelism*, Olby maintains this was likely due to the difficulty natural scientists had in accepting that plants sexually reproduced. …
>
> What stimulated Mendel and others to begin investigating the mechanism of heredity was prior work regarding the fertility of hybrids. Almost 100 years earlier, around 1760, Joseph Koelreuter, a German, began mating hybrids with other hybrids. He filled all the space he could spare with potted plants acquired from all corners of the globe. He even wrote Linnaeus asking him for seeds of hybrids. Koelreuter made two important observations. The first was that not all hybrids could produce offspring, and the second was that when hybrids were mated, many offspring looked like the parents, but some appeared to be a new species. How could one set of parents create identical offspring and a new species all at once? Koelreuter provided the following interesting explanation: in nature, species remain fixed and like parents give birth to like offspring, but when humans interfere is when the 'unnatural' crosses appear.
> While Koelreuter's explanation is no longer accepted, his work was important for questioning one of the major ideas regarding heredity, called "preformation." Preformation stated that an exact miniature replica of the parent existed inside sperm cells or ovum cells. Therefore, exact blueprints were passed on in each generation, with slight changes depending on the influence of either the male sperm or female egg—not both. The idea of preformation had survived to Koelreuter's day even though the microscope had been invented almost one-hundred years earlier. Despite failure to see the miniature replicas of parents in the sex cells, the preformation idea lived on because it explained why so many species had more or less identical offspring. Taking his extensive examples, Koelreuter measured key points on his hybrid plants, and argued that his results could only occur if *both* the male and female were involved in heredity. Mendel had extensively read Koelreuter's work, and it influenced the way he thought about heredity. Franz Unger, a professor of plant physiology at Vienna, was yet another influence on Mendel's thinking. Unger rejected the idea that species were stable and, in contrast to Koelreuter, proposed that variations arise in natural populations.

Later in the same story, Mendel's F_2 published results are provided in a Table. The following excerpt from the story addresses data appearing in that Table, and illustrates that the meaning of data is not self-evident. Scientists must make sense of their data and this includes making decision on whether it is robust or anomalous, what it means, and what to report to help others make sense of the idea being put forward.

> Note that the numbers do not reflect a precise 3:1 ratio. While some crosses gave results that were almost exactly that ratio, other results were further from it. Moreover, Mendel's published paper made reference to additional crosses he performed, but whose numerical results were not reported. The results above were selected by Mendel for presentation, and were likely chosen because they best illustrate his proposed ideas regarding heredity. Varying levels of ambiguity is part of all scientific work, and those who do research must make judgments to make sense of that ambiguity. Mendel's crucial interaction with and interpretation of his data is apparent in: 1) his having to observe and judge which categories the outcomes of his crosses belonged, 2) his choice of which data to present publicly, and 3) the way he identifies and reacts to anomalous data.

And the following excerpt appears after another Table in the story that presents Mendel's published data regarding the ratio of hybrids to pure-breeding dominant individuals in the F2 generation.

> These results again illustrate that research findings must be interpreted. Fairbanks and Rytting write that when Mendel noted that one of his crosses yielded results he thought were not in line with the predicted ratio, "he repeated the experiment and obtained results that were more acceptable to him."

Comments are inserted at appropriate points in each story to help readers accurately interpret the meaning of particular events. For instance, the following comment appears in a box near the above excerpts.

> Mendel wasn't fudging his data. Scientists must make sense of data, and this entails interpretive judgments, because data doesn't tell scientists what to think. Over time, the wider scientific community will decide to what extent an individual scientist's decisions hold up to scrutiny, and this reduces, but does not eliminate subjectivity in science.

Questions are also inserted in each story to promote reflection on noteworthy NOS ideas. At the request of project scientists who field-tested the stories, the number of questions was set at four, reflecting the number of questions they were willing to assign students when reading any particular story. Two of the four questions, inserted at appropriate points, appearing in the Mendel story are:

- Explain how Mendel's thinking shows both a gradual progression from prior ideas regarding heredity and also a break from those prior ideas.
- How does Mendel's work illustrate that observation and data analysis is not objective (i.e. scientists "see" through the lens of their theoretical commitments)?

The above excerpts illustrate the kind of text found in the project stories that, as a whole, accurately portray the history and nature of science. Readers are urged to visit the project website to view additional stories and supporting materials.

3.5 Project Website

Project materials in pdf format are freely available at http://www.storybehindthescience.org. The bolded links below appear on the homepage.

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 Do Not 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 (*Forthcoming*)
- Magnetism (*Forthcoming*)
- Newton's First Law (*Forthcoming*)
- Potential Energy (*Forthcoming*)
- Universal Gravitation (*Forthcoming*)

Chemistry Stories

- A Puzzle with Many Pieces: Development of the Periodic Table
- Atomic Structure (*Forthcoming*)
- Calorimetry (*Forthcoming*)
- Entropy (*Forthcoming*)
- Heat (*Forthcoming*)
- Combustion (*Forthcoming*)

Support Materials

- Characteristics of Science: Understanding Scientists and Their Work
- How to Use the Short Stories
- Tips for Creating Effective Class Discussions
- Additional Tips for Creating Class Discussions
- Tips for Structuring Group Work

- Assessing the NOS (*Forthcoming*)

Project Research

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

Project Team

- Project PIs and Senior Personnel information, pictures and links to professional web sites.

4 Efficacy of the Project Short Stories

Several research studies have taken place and are continuing regarding the efficacy of the project short stories. During the spring 2007 semester, four geology short stories (Two addressing continental drift and plate tectonics and two addressing the age of Earth) were assigned in two large sections of introductory geology. The four stories and embedded questions were assigned as homework and then analyzed to determine how students interpreted the short stories and their ideas regarding the NOS. The use of historical short stories that contain NOS comments and questions resulted in significant gains in student understanding of targeted nature of science ideas (Olson and Clough 2007; Vanderlinden 2007). Specifically, (a) students better understood that invention and creativity are important processes in the development of science knowledge (as opposed to simplistic views that knowledge is simply discovered/uncovered/apparent from experimental work); (b) students better understand that data does not tell scientists what to think—that scientists creatively develop ideas to account for data (this is related to understanding how multiple interpretations of the same data are possible); and (c) that scientists and their work reflects the broader culture and society of the time, and this influences what is studied, what data is collected, how data is interpreted, and what explanations are considered. Therefore, science is not absolutely objective and separate from the broader world. An interesting finding from this study is how students' thinking about the NOS can be quite tangled. For example, 11.7% of the students in the study expressed the misconception that scientists must follow a rigid linear scientific method that leads to proven truth (a NOS misconception not targeted by the stories), and they could not reconcile this view with the notion that scientists create ideas to account for data, or that scientists may have different interpretations of the same data.

Kruse et al. (2009) presented a study they conducted of students' and their instructor's reactions to the use of five project short stories in a post-secondary introductory biology course. They report that the stories (Two addressing the age of Earth, one addressing Mendel, one addressing Darwin, and one addressing Wallace) positively impacted students' interest in science careers and that the instructor expressed his desire to continue explicitly addressing the NOS in his course. Many students noted surprise or encouragement when writing about their new insights on the NOS such as: science is collaborative, science is creative, and science does not have to be laboratory-based. The instructor has continued using the short stories in his course due to his perception that addressing the NOS decreases his students' resistance to biological evolution, and because the stories accomplish this while addressing science content that he teaches.

Recently, studies were conducted in large section post-secondary introductory astronomy, biology and geology courses to assess the impact of the project stories on students'

NOS understanding. Students in the post-secondary biology course showed improved understanding of several NOS ideas targeted in the implemented short stories. Specifically, students expressed a more accurate understanding of (a) scientific laws compared to theories; (b) the importance of imagination and creativity in doing science; (c) methodological pluralism (d) the significant collaboration that occurs among scientists; and (e) the crucial role of methodological naturalism in science. Perhaps just as importantly, students in the study indicated the stories increased their interest in science and science careers (Clough et al. 2010). Analysis of the geology and astronomy data is still underway, and future studies are planned for post-secondary introductory chemistry and physics courses.

5 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 for use 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 project is:

1. *Focused on learner-centered teaching*—addressing commonly identified NOS misconceptions held by students, the project stories bring humanity back into science to help students better understand how individual scientists and the scientific community 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*—bringing together faculty from history of science, 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, and further the field of NOS research.
3. *Designed to enhance student learning*—the project stories are designed 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 and Peeples 1987; Bishop and Anderson 1990; Rudolph and Stewart 1998; Rutledge and Warden 2000; Trani 2004), and secondary science teachers who understand the NOS are more likely to teach this fundamental biological concept (Scharmann and Harris 1992).
4. *Targeted to promote interest in science and life-long learning*—those who understand the NOS appear to 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.

Effectively encouraging science teachers to explicitly plan for and engage their students in accurate NOS instruction continues to be challenging. Clough (2006) writes:

> 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. Science 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. (p. 475)

The Story Behind the Science project stories diminish the argument that NOS education must detract from science content instruction. Rather than an "add-in" activity that science teachers perceive as detracting from the science content, use of the project historical short stories to accurately convey the NOS is ubiquitous with teaching science content. Post-secondary science faculty may very well be willing to plan for and accurately convey the NOS if it is entangled within the science content traditionally taught in their courses, thus not taking significant time away from that instruction. In previous presentations of the project stories, both post-secondary and secondary science teachers have expressed significant interest in our project stories. Work is already underway to create additional stories for post-secondary science courses and expand the project to create stories with the same kind of design for secondary science courses.

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