Seamlessly Teaching Science Content and the Nature of Science:
Impact of Historical Short Stories on Post-Secondary Biology Students

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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. 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.

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 high school 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)

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.

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 teachers 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 thirty 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).

Project Website

The project website, *The Story Behind the Science*, (http://www.storybehindthescience.org) is nearing completion. Twenty-two of the thirty stories and support materials for effectively implementing the stories are already freely available for downloading in pdf format. Clough (2009) provides a detailed description of the project, story development, and project website.

3. Significance of Project

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.

The project historical stories are designed to 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 are intended to be 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. This project seeks to promote improved understanding of the NOS, while simultaneously helping future science teachers learn how to address these issues with their students.

4. Impact of Historical Short Stories on Post-Secondary Biology Students

During the fall 2009 semester, we conducted a study to determine the impact of five historical stories on students in a large introductory post-secondary majors biology course at a research-extensive university in the upper Midwest.

Research Questions

1. What effect, if any, do five historical short stories implemented in a post-secondary majors biology class have on students' understanding of the nature of science?
2. What are the perceptions of post-secondary biology students toward:
   a) historical science stories containing embedded NOS questions and comments?
   b) the goal of understanding the nature of science?

Research Context and Methodology

The introductory biology course in which this study took place met Tuesday's and Thursday's from 12:40 to 2:00. The course was primarily taught via lecture using extensive presentation software. However, approximately halfway through each class the instructor would implement more interactive pedagogy (e.g. discussion, group work, think-pair-share, etch.) for five to ten minutes. While the course is the first biology course for biology majors, others students take the course to fulfill requirements for general studies and for other majors such as chemistry, or pre-med. Topics covered in the course include: diversity of life, classification, genetics and evolution. For this study, five stories were implemented in the following order:

1. Understanding Earth's Age: Early Efforts by Naturalists and Chronologists (September)
2. A Very Deep Question: Just How Old is Earth (September)
3. Creativity and Discovery: The Work of Gregor Mendel (October)
4. Charles Darwin: A Gentle Revolutionary (October)
5. Adversity and perseverance: Alfred Russel Wallace (October)

Students' pre and post NOS understanding was assessed using the Student Understanding of Science and Scientific Inquiry (SUSSI) Questionnaire (Liang et al., 2008) and four additional SUSSI-like items (items 7-10) created by the researchers(Appendix A.). The pre-test (N = 134) was completed in class during the first week of the course in late August, and the post-test was completed in class in the middle of December the week prior to final exams (N = 133). Utilizing quantitative and qualitative measures, the instrument measures the following NOS constructs:

Item 1 – Observations and Inferences
Item 2 – Scientific Theories
Item 3 – Scientific Laws Compared to Theories
Item 4 – Social and Cultural Influences on Science
Item 5 – Imagination and Creativity in Scientific investigations
Item 6 – Methodology of Scientific Investigations
Item 7 – Social Interaction among Scientific Researchers
Item 8 – Science and Religion
Item 9 – Development and Acceptance of Science Ideas
Item 10 – Discovery and Invention.

These NOS issues are quantitatively evaluated through four Likert sub-scale items that include the most common naïve and informed NOS views for each component. Each component is accompanied with a qualitative prompt that requests students to further explain their NOS understanding. For the purposes of this study, only the quantitative aspects of the modified SUSSI will be reported.

Components 1-6 were derived from the Student Understanding of Science and Scientific Inquiry (SUSSI) questionnaire developed by Liang *et al.* (2008) for use with undergraduate students. During development, the SUSSI was extensively tested and retested to ensure validity and reliability and has a high degree of efficacy due to the various ways to check for authenticity of the data. Components 7-10 were developed, structured, and evaluated by six science education researchers in order to ensure they achieved congruency with the original SUSSI components.

Students (N = 85) completed a questionnaire (Appendix B) outside of class in the middle of December the week prior to final exams. Students were asked to report how much time they spent reading each story, their perceptions of the stories', and their view of how important is the science education goal of learning about how science and scientists work and how science ideas are generated and become accepted.

Data Analysis

SUSSI instrument items 1-6 were analyzed separately from SUSSI-like items 7-10 that were created by the researchers. Responses to Likert items were given numerical values with 5 being the most informed and 1 being the least informed view of the NOS. These were summed to give a score ranging from 4 to 20 for each NOS component. Component scores for the separate portions of the instrument were analyzed using separate MANOVAs. The first MANOVA tested the null hypothesis that there are no differences between pre and post SUSSI component scores as a whole. The second tested the null hypothesis that there are no differences between pre and post scores of the researcher-derived SUSSI-like items 7-10 as a whole. Subsequent ANOVA analyses were then conducted on individual NOS component scores for the two portions of the instrument to determine significance of pre and post differences (Tabachnick. & Fiddell 2007). To adjust for multiple testing in subsequent ANOVA analyses, p-values were appropriately adjusted using Bonferroni corrections. This resulted in Bonferroni adjustments of p-values to 0.008 and 0.0125 for ANOVA analyses on the SUSSI and added NOS components respectively.

5. Results and Analysis

Evidence of Implementation

We observed the instructor assigning the short stories and embedded questions, and also observed the instructor and students as they discussed the assigned questions during class. Students received a small amount of credit for completing the assigned questions, and most all students received full credit. In addition, the end of study survey asked students to self-report the amount of time they devoted to reading the stories. Table 1 summarizes this self-report data and indicates that for each story, well over half the students reported spending 30 or more minutes reading the story. Our classroom observations, the responses to short story questions submitted by students, and their self-report data all indicate that the five stories were implemented to a significant extent.

Table 1: Students Self-Report Data Regarding Time Spent Reading the Stories

Time (Minutes)	**Earth's Age 1 Story**	**Earth's Age 2 Story**	**Mendel Story**	**Darwin Story**	**Wallace Story**
>60	12.9	10.6	7.1	9.4	8.2
30-60	52.9	49.4	54.1	48.2	51.8
15-30	27.1	34.1	29.4	29.4	34.1
15	7.1	5.9	9.4	10.6	5.9
Didn't read	0	0	0	2.4	0

Results given in percent

Students' Understanding of the Nature of Science

Initial analyses included calculating pre and post reliability indices on the two portions of the instrument. Cronbach's alpha values ranged from 0.73 (pre) to 0.71 (post) on the SUSSI as a whole; and from .43 (pre) to .61 (post) for SUSSI-like items 7-10 as a whole. Cronbach's alpha values ranged from 0.22 to 0.79 (pre) and .13 to .73 (post) on individual SUSSI NOS components; and from 0.09 to 0.76 (pre) and 0.46 to 0.67 (post) on individual SUSSI-like items 7-10 (Table 2). According to conventional concepts of reliability and validity, these values are not ideal. However, Liang et al. (2008) noted that Cronbach's alphas for SUSSI componentsmay be lower due to their having a small number of sub-items. In addition, due to the empirical nature of the components used to develop the SUSSI, conventional validity and reliability measures may not apply well to this instrument (Aikenhead and Ryan 1992; Rubba et al. 1996; Liang et. al 2008).

MANOVA analyses show that, viewed collectively, significant differences exist in pre and post component scores on the SUSSI portion of the questionnaire (F (6, 260) = 38.85, $p < 0.0005$, Wilks' Lambda = 0.527, eta squared= 0.47). This was also the case for scores of the added NOS components (F (4, 256) = 20.09, $p < 0.0005$, Wilks' Lambda= 0.761, eta squared= 0.24).

Complete ANOVA results appear in Table 2. ANOVA analyses on the SUSSI portion of the instrument indicate that post scores are significantly higher than pre scores for the components of imagination and creativity in scientific investigations ($p < 0.0005$); scientific laws compared to theories ($p < 0.0005$); and methodology of scientific investigations ($p < 0.0005$). Means for post scores of these components were approximately 20 to 30 percent higher than their respective pre-scores (Table 1.). Notably, without conservative Bonferroni adjustments differences between pre and post component scores for social and cultural influences on science and science observations would have also been significant (p= 0.026 and 0.027, respectively). No significant differences existed between pre and post component scores for nature of scientific theories ($p = 0.165$)

Subsequent ANOVA analyses (Table 3) researcher developed SUSSI-like items 7-10 yielded significant differences between pre and post component scores for social interaction among scientific researchers ($p < 0.0005$) and science and religion ($p < 0.0005$). Means for post-scores of these components were approximately 10 to 17 percent higher than their respective pre-scores (Table 1.). No significant differences existed between pre and post component scores for development and acceptance of science ideas ($p = 0.185$) and discovery versus invention of science ideas ($p = 0.876$).

Table 2. *Descriptive statististics and Cronbach's alpha values for pre and post NOS component scores.*

SUSSI Item	Pre				Post			
	N	*M*	*S.D.*	*α*	*N*	*M*	*S.D.*	*α*
Item 1: Scientific Observations	134	16.57	2.30	0.63	133	15.91	2.51	0.70
Item 2:Scientific Theories	134	16.51	1.82	0.35	133	16.15	2.33	0.59
Item 3: Scientific Laws Compared to Theories	134	9.90	2.09	0.22	133	12.05	2.23	0.13
Item 4: Social and Cultural Influences on Science	134	15.63	2.20	0.50	133	14.94	2.80	0.72
Item 5: Imagination and Creativity in Science	134	12.45	3.52	0.79	133	16.26	2.76	0.73
Item 6: Methodology of Scientific Investigations	134	11.16	2.39	0.44	133	13.87	2.13	0.35
Item 7:Social Interaction Among Scientific Researchers	131	14.69	1.90	0.42	130	16.13	1.92	0.64
Item 8: Science and Religion	131	12.29	1.89	0.09	130	14.37	2.27	0.46
Item 9: Development and Acceptance of Science Ideas	131	16.24	2.47	0.76	130	16.63	2.22	0.67
Item 10: Discovery Versus Invention of Science Ideas	131	10.49	2.36	0.49	130	10.44	2.81	0.67

Items 1-6 are SUSSI items (Liang et. al 2008)
Items 7-10 are researcher developed SUSSI-like items

Table 3. *Results from ANOVA analyses testing for differences in pre and post component scores.*

Component	*F*	*DF*	*p*	n_p^2
Item 1: Scientific Observations	4.98	1/265	0.027	0.018
Item 2: Scientific Theories	1.94	1/265	0.165	0.007
Item 3: Scientific Laws Compared to Theories	65.90	1/265	<0.0005*****	0.199
Item 4: Social and Cultural Influences on Science	4.99	1/265	0.026	0.018
Item 5: Imagination and Creativity in Science	96.84	1/265	<0.0005*****	0.268
Item 6: Methodology of Scientific Investigations	96.01	1/265	<0.0005*****	0.266
Item 7: Social Interaction Among Scientific Researchers	36.74	1/259	<0.0005*****	0.124
Item 8: Science and Religion	64.81	1/259	<0.0005*****	0.200
Item 9: Development and Acceptance of Science Ideas	1.77	1/259	0.185	0.007
Item 10: Discovery Versus Invention of Science Ideas	0.024	1/259	0.867	0.000

* Denotes significance
Items 1-6 are SUSSI items (Liang et. al 2008)
Items 7-10 are researcher developed SUSSI-like items

Perceptions of Post-Secondary Biology Students

The results reported in tables 4 through 10 are quite positive. Students overwhelmingly report that the stories portray science research as more interesting than they previously thought (Table 4). Over 42% report that the stories increased their interest in science as a career while only approximately 1% indicated a reduced interest in science as a career (Table 5). All students reported that the stories positively impacted their interest in the science content targeted in the stories, and nearly 50% indicated a robust response toward the content in the stories (Table 6). Students overwhelmingly indicated the stories improved their understanding of the science content (Table 7). Given these very favorable perceptions of the stories, that over 96% of students would like to see at least 1-2 of these kinds of stories replace traditional textbook reading is not surprising. Almost 25% of students would like to have five or more of these kinds of stories as part of their class. Students in this study overwhelmingly support understanding the nature of science as a science education goal with 87% reporting it is important or very important (Table 9). All students reported that the short stories had at least some value for helping them achieve this goal, and over 60% indicated the stories were much help or very much help in achieving an understanding of the nature of science (Table 10).

Table 4. *Stories portrayal that doing science research is more interesting than previously thought.*

- *To what extent did these stories portray that doing science research is more interesting than you previously thought?*

N	%	Description
1	1.2	Not at all
5	5.9	
26	30.6	Somewhat
40	47.1	
13	15.3	Very much

Table 5. *Impact of stories on students' interest in science as a career.*

- *To what extent did the short stories impact your interest in science as a career?*

N	%	Description
0	0	Reduced Interest
1	1.2	
48	56.5	No Impact
27	31.8	
9	10.6	Increased Interest

Table 6. *Impact of stories on students' interest in science content in the stories.*

- *To what extent did these stories increase your <u>interest in the science content</u> in the stories?*

N	%	Description
0	0	Not at all
4	4.7	
39	45.9	Somewhat
35	41.2	
7	8.2	Very much

Table 7. *Impact of stories on improving students' understanding of science content.*

- *To what extent did these stories improve your <u>understanding of the science content</u> related to the stories?*

N	%	Description
0	0	Not at all
3	3.5	
27	31.8	Somewhat
43	50.6	
12	14.1	Very much

Table 8. *How many short stories students would prefer in a course.*

- *If assigned short stories were to replace other homework readings, how many of these kinds of short stories would you like as part of your class?*

N	%	Description
3	3.6	No Stories
21	25.0	1-2 Stories
40	47.6	3-4 Stories
20	23.8	5+ Stories

Table 9. *Students' perception of the nature of science as a science education goal.*

- *Learning about how science and scientists' work, and how science ideas are generated and become accepted, is a goal for science education.*

  How important do you think this goal is?

N	%	Description
0	0	Not at all
1	1.2	
10	11.8	Somewhat important
32	37.6	
42	49.4	Very important

Table 10. *Impact of stories on helping students achieve NOS understanding*.

- *Learning about how science and scientists' work, and how science ideas are generated and become accepted, is a goal for science education.*

To what extent did these stories help you achieve this goal?

N	%	Description
0	0	Not at all
2	2.4	
30	35.3	Somewhat
40	47.1	
13	15.3	Very much

6. Discussion and Implications

The results of this study are very positive regarding the value of implementing historical short stories in this post-secondary introductory majors biology course. The short stories had meaningful positive impacts on students' understanding of the NOS, interest in science careers, and interest in science content.

Few post-secondary instructors appear willing to sacrifice science content instruction in order to improve students' understanding of the NOS and attitude toward science and science classes. Also, university science faculty are likely unfamiliar with the science education literature regarding the NOS and the need for explicit/reflective NOS instruction (Abd-El-Khalick & Lederman, 2000). Given the non-negotiable stance many post-secondary faculty members have toward covering large amounts of science content, science stories like those implemented in this study (http://www.storybehindthescience.org) may provide post-secondary science faculty an acceptable way to both improve students' understanding of the NOS and attitudes toward science and science education. Furthermore, the resulting increased interest in science as a career will likely be looked upon favorably by post-secondary science instructors who often view their role as training future scientists. While the kind of stories implemented in this study will unlikely, by themselves, change the landscape of post-secondary science education, they appear to be a viable way to improve university students' understanding of the NOS and slow the flight of talented students from science.

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The Story Behind the Science

Bring Science and Scientists to Life
http://www.storybehindthescience.org

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

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Appendix A: Views on Science and Scientific Inquiry

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate choice to the right of each statement.

SD = Strongly Disagree
D = Disagree More Than Agree
U = Uncertain or Not Sure
A = Agree More Than Disagree
SA = Strongly Agree

1. Scientific Observations

A.	Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	SD	D	U	A	SA
B.	Scientists' observations of the same event will be the same because scientists are unbiased.	SD	D	U	A	SA
C.	Scientists' observations of the same event will be the same because observations are facts.	SD	D	U	A	SA
D.	Scientists may make different interpretations based on the same observations.	SD	D	U	A	SA
Explain why you think scientists' observations and interpretations are the same OR different, and **provide examples to support your answer**.						

2. Scientific Theories

A.	Scientific theories are subject to on-going testing and revision.	SD	D	U	A	SA
B.	Scientific theories may be completely replaced by new theories in light of new evidence.	SD	D	U	A	SA
C.	Scientific theories may be changed because scientists reinterpret existing observations.	SD	D	U	A	SA
D.	Scientific theories based on accurate experimentation will not be changed.	SD	D	U	A	SA
Explain why you think scientific theories change OR do not change over time, and **provide examples to support your answer**.						

3. Scientific Laws Compared to Theories

A.	Scientific theories exist in the natural world and are uncovered through scientific investigations.	SD	D	U	A	SA
B.	Unlike theories, scientific laws are not subject to change.	SD	D	U	A	SA
C.	Scientific laws are theories that have been proven.	SD	D	U	A	SA
D.	Scientific theories explain scientific laws.	SD	D	U	A	SA
Explain what scientific theories and laws are and how they are different, and **provide examples to support your answer**.						

4. Social and Cultural Influences on Science

A.	Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.	SD	D	U	A	SA
B.	Cultural values and expectations influence what science is conducted and accepted.	SD	D	U	A	SA
C.	Cultural values and expectations influence how science is conducted and accepted.	SD	D	U	A	SA
D.	All cultures conduct scientific research the same way because science is universal and independent of society and culture.	SD	D	U	A	SA
Explain how society and culture affect OR do not affect scientific research, and **provide examples to support your answer**.						

5. Imagination and Creativity in Scientific investigations

A.	Scientists use their imagination and creativity when they collect data.	SD	D	U	A	SA
B.	Scientists use their imagination and creativity when they analyze and interpret data.	SD	D	U	A	SA
C.	Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning.	SD	D	U	A	SA
D.	Scientists do **not** use their imagination and creativity because these can interfere with the need to be unbiased.	SD	D	U	A	SA
Explain why scientists use OR do not use imagination and creativity, and **provide examples to support your answer**.						

6. Methodology of Scientific Investigations

A.	Considering what scientists actually do, there really is no such thing as the scientific method.	SD	D	U	A	SA
B.	Scientists follow the same step-by-step scientific method.	SD	D	U	A	SA
C.	When scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
D.	Experiments are the only way scientists develop valid scientific knowledge when they investigate the natural world.	SD	D	U	A	SA
Explain whether scientists follow a single, universal scientific method OR use different types of methods, and **provide examples to support your answer**.						

7. Social Interaction among Scientific Researchers

A.	Scientists usually work collaboratively with other scientists when conducting research.	SD	D	U	A	SA
B.	Scientists usually work with other scientists, but only to share results.	SD	D	U	A	SA
C.	Scientists usually work alone when conducting research.	SD	D	U	A	SA
D.	Scientific knowledge usually emerges from discussions and social interactions among scientists.	SD	D	U	A	SA
Explain to what degree scientists work with other scientists when doing research, and **provide examples to support your answer**.						

8. Science and Religion

A.	Science and religion are usually in conflict with one another.	SD	D	U	A	SA
B.	Supernatural explanations are not useful for helping scientists understand the natural world.	SD	D	U	A	SA
C.	Science ideas that have religious implications usually set scientists who do believe in supernatural beings against those who do not believe in supernatural beings.	SD	D	U	A	SA
D.	Scientists who will not use supernatural explanations when doing science can still believe in a supernatural being.	SD	D	U	A	SA
Explain why supernatural explanations should OR should not be used in credible scientific ideas, and **provide examples to support your answer**.						

9. Development and Acceptance of Science Ideas

A.	Credible scientific ideas are usually generated in a matter of days, weeks or months.	SD	D	U	A	SA
B.	Scientific ideas usually come to be accepted by the scientific community in a matter of days, weeks or months.	SD	D	U	A	SA
C.	Credible scientific ideas are usually generated over a period of years to decades.	SD	D	U	A	SA
D.	Scientific ideas usually come to be accepted by the scientific community over a period of years to decades.	SD	D	U	A	SA
Explain how much time is usually required for credible scientific ideas to be generated, and then accepted by the scientific community, and **provide examples to support your answer**.						

10. Discovery and Invention

In responding to the four items below, assume that a gold miner "discovers" gold while an author "invents" a story.

A.	Scientific theories (for example, atomic theory, plate-tectonic theory, gene theory) are discovered.	SD	D	U	A	SA
B.	Scientific laws (for example, laws of planetary motion, gas laws, gravitational law, law of pendulum motion) are discovered.	SD	D	U	A	SA
C.	Scientific theories (for example, atomic theory, plate-tectonic theory, gene theory) are invented.	SD	D	U	A	SA
D.	Scientific laws (for example, laws of planetary motion, gas laws, gravitational law, law of pendulum motion) are invented.	SD	D	U	A	SA
Explain whether scientific laws and theories are invented OR discovered, and **provide examples to support your answer**.						

Appendix B: Survey Regarding Short Stories

This semester you read several short stories regarding scientists and how science ideas came to be accepted. Your honest feedback regarding these experiences would be very much appreciated. You may skip any question in this questionnaire that you do not feel comfortable answering.

1. How much time did you spend reading and answering questions for the **first** short story assignment titled "Understanding Earth's Age: Early Efforts by Naturalists and Chronologists" **(completed in September)**?

   A. greater than 60 minutes B. 30-60 minutes C. 15-30 minutes D. 15 minutes E. I didn't read the story

2. How much time did you spend reading and answering questions for the **second** short story assignment titled "A Very Deep Question: Just How Old is Earth?" **(completed in September)**?

   A. greater than 60 minutes B. 30-60 minutes C. 15-30 minutes D. 15 minutes E. I didn't read the story

3. How much time did you spend reading and answering questions for the **third** short story assignment titled "Creativity and Discovery: The Work of Gregor Mendel" **(completed in October)**?

   A. greater than 60 minutes B. 30-60 minutes C. 15-30 minutes D. 15 minutes E. I didn't read the story

4. How much time did you spend reading and answering questions for the **fourth** short story assignment titled "Charles Darwin: A Gentle Revolutionary" **(completed in October)**?

   A. greater than 60 minutes B. 30-60 minutes C. 15-30 minutes D. 15 minutes E. I didn't read the story

5. How much time did you spend reading and answering questions for the **fifth** short story assignment titled "Adversity and Perseverance: Alfred Russel Wallace" **(completed in October)**? Circle your response.

   A. greater than 60 minutes B. 30-60 minutes C. 15-30 minutes D. 15 minutes E. I didn't read the story

6. Please use the following scale to rank how interesting you found each story (If you did not read a particular story, simply leave the line empty)?

1	2	3	4	5
Very uninteresting		Neutral		Very interesting

   _____ Understanding Earth's Age: Early Efforts by Naturalists and Chronologists
   _____ A Very Deep Question: Just How Old is Earth?
   _____ Creativity and Discovery: The Work of Gregor Mendel
   _____ Charles Darwin: A Gentle Revolutionary
   _____ Adversity and Perseverance: Alfred Russel Wallace

7. To what extent did these stories portray that doing science research is more interesting than you previously thought?

1	2	3	4	5
Not at all		Somewhat		Very much

8. To what extent did the short stories impact your <u>interest in science as a career</u>?

1	2	3	4	5
Reduced interest		No impact		Increased interest

9. To what extent did these stories increase your <u>interest in the science content</u> in the stories?

1	2	3	4	5
Not at all		Somewhat		Very much

10. To what extent did these stories improve your <u>understanding of the science content</u> related to the stories?

1	2	3	4	5
Not at all		Somewhat		Very much

11. If assigned short stories were to replace other homework readings, how many of these kinds of short stories would you like as part of your class?

None _____ 1-2 _____ 3-4 _____ 5+ _____

12. Learning about how science and scientists' work, and how science ideas are generated and become accepted, is a goal for science education.

(a) How important do you think this goal is?

1	2	3	4	5
Not at all		Somewhat		Very much

(b) To what extent did these stories help you achieve this goal?

2	2	3	4	5
Not at all		Somewhat		Very much

We would very much appreciate your constructive comments about the stories. Please write your comments below. Thank you for your time and input into this National Science Foundation project!

Please provide the following information so that we may determine views regarding the stories held by different sets of individuals. <u>You may choose to skip any question you do not feel comfortable answering.</u>

Circle your academic standing → Freshman Sophomore Junior Senior Graduate

Gender: ________ Major: ______________________ Ethnicity: ___________________________