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Abstract

The nature of science (NOS) is a foundational framework for understanding scientific ideas and concepts. This framework includes scientific methodology, the process of revising and interpreting data, and the ways in which science is a social endeavor. Nature of science literature treats science as a way of knowing that is based on observable phenomenon. While discipline-specific coursework teaches the factual information of science, it may fall short on teaching scientific literacy, a key component of which is understanding NOS. We have designed an English course that features nonfiction narratives describing the early days of epidemiology, hygiene awareness, and the current controversy surrounding vaccination. Using a validated assessment of student understanding of NOS, the Student Understanding of Science and Scientific Inquiry (SUSI), we have determined that this science-themed English composition course was effective in teaching NOS. Student understanding of NOS increased between the beginning and the end of the course in eight of the nine parameters of NOS measured, with the greatest gains in understanding the role of revision and of creativity in science. Our data imply that the course helped students develop a slightly less naïve understanding of the nature of science and its importance in the development and dissemination of scientific ideas and concepts.

Disciplines

Curriculum and Instruction | Educational Methods | Language and Literacy Education | Science and Mathematics Education

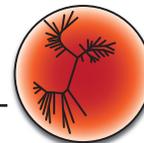
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Using Nonfiction Narratives in an English Course to Teach the Nature of Science and Its Importance to Communicating About Science[†]

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The nature of science (NOS) is a foundational framework for understanding scientific ideas and concepts. This framework includes scientific methodology, the process of revising and interpreting data, and the ways in which science is a social endeavor. Nature of science literature treats science as a way of knowing that is based on observable phenomenon. While discipline-specific coursework teaches the factual information of science, it may fall short on teaching scientific literacy, a key component of which is understanding NOS. We have designed an English course that features nonfiction narratives describing the early days of epidemiology, hygiene awareness, and the current controversy surrounding vaccination. Using a validated assessment of student understanding of NOS, the Student Understanding of Science and Scientific Inquiry (SUSSI), we have determined that this science-themed English composition course was effective in teaching NOS. Student understanding of NOS increased between the beginning and the end of the course in eight of the nine parameters of NOS measured, with the greatest gains in understanding the role of revision and of creativity in science. Our data imply that the course helped students develop a slightly less naïve understanding of the nature of science and its importance in the development and dissemination of scientific ideas and concepts.

INTRODUCTION

One goal in the *Vision and Change* report published by the American Association for the Advancement of Science in 2011 was to help students make sense of data within a framework, such as the *process* of science and scientific thinking. Science communication is an important aspect of this framework and should convey how a science idea meets the needs of the scientific community and increases public understanding of “scientific awareness, understanding, literacy, and culture” (1). Yet a variety of factors, including an audience’s lack of understanding of the nature of science, makes clear communication on science issues difficult.

The term “nature of science,” or NOS, refers to the values and assumptions made about scientists, the scientific method, and the nature of scientific knowledge (2). Briefly, scientific knowledge is subject to change, based on observations and inferences that are both subjective and objective. Science is creative, is subject to societal influence, and does

not follow a single method. Mature scientists accept the nature of science (NOS) and they are trained to be precise and accurate with their communications, yet the general public may not be aware of NOS, much less the complexity of scientific issues.

While understanding NOS is a crucial component of science literacy, it is not often explicitly taught in science classes (3). When undergraduate students are assessed, science majors and nonmajors are indistinguishable from one another in their views on NOS. Both groups have a mix of naïve, transitional, and informed views before and after taking a science course (4). Indirect interventions have had modest to no effects on increasing student understanding of the nature of science (5).

Science educators realize that communicating science is difficult and have incorporated multiple methods into their courses to teach effective communication skills. Writing-to-Learn (6, 7) is a decades-old system employed by high school science teachers to add English elements to science writing. However, these assignments were often superficial, with students crafting poems about invertebrates as a way to memorize details of a clam’s anatomy, for instance (6). Later versions of this pedagogy used more complex exercises, such as journal entries where students would describe their findings with metacognitive prompts (8). While these teaching methods facilitate deeper learning (9, 10), they use writing as a tool to teach science *content*, not to teach

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students NOS or how an audience's understanding of NOS affects communication. At the same time science educators are struggling to teach NOS in a sea of discipline-based content, English faculty teaching first-year composition courses struggle to engage students. English composition classes are often viewed by students as an irrelevant barrier to overcome rather than the skill-building experiences they are designed to be (11).

To address these parallel yet distinct needs, we designed an English course with written, oral, visual, and electronic (WOVE) communication outcomes that simultaneously taught students about NOS and its importance to communication. The readings, discussions, and assignments were all designed to address WOVE communication objectives as well as instruct students on NOS and its importance to communication. The course was designed as a science-themed communications course to help students reach a more informed view about the nature of science and its relevance to effective communication of scientific ideas and concepts.

Intended audience, learning time, and prerequisite student knowledge

The NOS-themed course was designed as a first-year English course at a large research-focused (RI) university. English 250 is the second in a two-term series of communication courses required for all majors at Iowa State University. It requires students to analyze, compose, and reflect on "written, oral, visual, and electronic (WOVE) discourse within academic, civic, and cultural contexts" (<https://www.engl.iastate.edu/isucomm/about-isucomm/>).

During fall 2010, spring 2012, fall 2012, and spring 2013, 229 students enrolled in NOS-themed sections of English 250. There were 178 first-year students, 42 second-year students, 4 juniors, and 5 seniors in our student population. Of the students taking the course, 164 students were female and 65 students were male. Approximately 83% of these students were taking English 250 in a learning community (LC), meaning they took this and several other courses as a cohort with their peers. There were also 78 first-generation students in this group.

Learning objectives

As seen in Table 1, the course learning objectives encompass five major themes. The first four themes (Written, Oral, Visual, and Electronic) were common to all sections of English 250. The last theme was focused on teaching students the nature of science and is the focus of this paper.

PROCEDURE

Materials

This course was taught using science-themed books and an essay describing the nature of science. The three

books used were *The Ghost Map* (12), *The Doctors' Plague* (13), and *Autism's False Prophets* (14). The course schedule describing how and when these books were used is provided in Appendix 1.

Student instructions

Students read each text and came to class each day ready to discuss their reading assignment in the context of the overall course objectives. The alignment of the books and assignments to specific aspects of NOS is shown in Appendix 2. In addition to participating in class discussions (Appendix 3), students were required to write formal assignments in response to the course material. The most substantial assignment was the documented report with annotated bibliography. The assignment and its rubric are included as Appendices 4 and 5.

Course design and implementation

The core principle of English 250, the rhetorical situation, dictates that effective communication reaches the audience in terms of attitudes, knowledge, needs, and values; has a specific purpose or goal; and considers the larger situational context. In short, any message needs to be constructed according to the audience, purpose of communication, and context surrounding the message. The English content of the course included the rhetorical situation (audience, purpose, and context), lines of argument (pathos, ethos, logos, kairos), and information literacy (analyzing, using, and documenting sources) in written, oral, visual, and electronic communication. The learning outcomes and assessments are listed in Table 1.

The foundation of the NOS-themed course was the nature of science's immediate and direct relevance to the rhetorical situation. We discussed the characteristics and nature of science as foundational assumptions that scientists use to guide their research, thought processes, and communications. We also discussed that a lay audience may not be aware of, understand, or accept, these characteristics. We then addressed how communication on scientific topics and concepts may appear to audiences that do not understand the nature of science. Table 2 summarizes student thoughts on the understanding and misunderstandings of NOS. The class discussed the fact that communication does not occur in a vacuum; that the intended audience's previous experiences will affect their attitude toward the communication and the communicator; and that the current economic, social, cultural, political, and geographical reality will influence the message.

The course was designed to use specific discovery narratives to illustrate the characteristics of scientific thinking, so students could use concrete details to explain abstract concepts. For two weeks of the course, we considered John Snow's inquiry into the cause of cholera (12). Readings and classroom discussions analyzed how

TABLE I.
Course learning outcomes and assessments related to each of these outcomes.

Course Learning Outcome (LO) Students will be able to:	Course Assessment
Written	
Analyze professional writing to assess its purpose, audience, and rhetorical strategies	Annotated bibliography
Construct argument that integrate logos, ethos, pathos, and kairos	Response to “anti-vaccination” letter
Write source papers analyzing a rhetorical situation and identifying and accurately documenting appropriate source material	Research paper on a vaccine-preventable disease, including annotated bibliography
Oral	
Engage as active team member in small and large groups as contributor, listener, and presenter	In-class discussions where students are graded on the quality of their participation
Visual	
Rhetorically analyze visual communication	Discussion of <i>The Ghost Map</i>
Create visual argument	Visual argument during <i>Autism’s False Prophets</i> discussion
Electronic	
Rhetorically analyze electronic communication	Analysis of the “anti-vaccination” letter from social media
Create electronic argument (ePortfolio)	End-of-term reflection on portfolio
NOS	
Reach more-informed view about the nature of science	SUSSI administered before and after class
Predict effects of (mis)understanding the nature of science on communication	In-class discussion, final paper

SUSSI = student understanding of science and scientific inquiry.

the characteristics of science informed Snow’s research, his collaborations with others, and his communications about his new idea that contradicted all contemporary knowledge. Our discussions also addressed the lines of argument available to John Snow, and how he was able to convince the local administrators to act, despite the lack of physical evidence of contagion in the water, and even though his explanations did not adhere to contemporary scientific concepts of disease transmission. Discussion questions are included in Appendix 3.

For the next two weeks, we considered Ignác Semmelweis’s work on preventing puerperal fever (13). Again, readings and classroom discussions allowed students to analyze how the characteristics of science informed Semmelweis’s research. This time, however, we discussed how Semmelweis was ineffective in communicating his ideas. We compared and contrasted the two scientists and the results of their research: Snow prevented another epidemic but Semmelweis’s discovery was dismissed.

With the examples of two scientists as communicators, one effective and one ineffective, the class turned to evidence-resistant ideas about vaccinations (14). For five weeks, we read and discussed the rise and fall of several arguments against vaccination, and how misunderstanding of the characteristics of science affected the discourse. We addressed assumptions about science and scientists,

competing worldviews, various methods used to communicate with those who accept evidence-resistant ideas, and whether or not scientists should be the people to communicate with the general public. Throughout these discussions, we referred back to Snow and Semmelweis.

During the course of the semester, students completed several written projects in connection with the readings. Each student chose one vaccine-preventable disease to research during the semester. Students developed an annotated bibliography with ten quality source materials—one to two reference sources, one to two book chapters, one to two websites, four to five peer-reviewed articles. They then wrote a documented report about the disease. They also analyzed the rhetorical style of an anti-vaccination argument and wrote a response to the argument. In order to complete these projects, students utilized their knowledge of the rhetorical situation, lines of argument, and NOS together in a responsible manner that would engage the general public. The details and rubric for this assignment are provided in Appendices 4 and 5.

Prior to their teaching this class the first time, four graduate teaching assistants met with the lead instructor twice to learn about the different aspects of the books as they relate to both WOVE curricular guidelines and the nature of science. This instructor team communicated throughout the term as questions arose.

Assessment of student understanding of NOS.

The assessment for this paper is focused solely on the NOS learning objectives, in deference to the audience and purpose of this communication. During the first and last week of the class, students were given a modified Student Understanding of Science and Scientific Inquiry (SUSSI) survey, with added questions about the timing of the development of scientific ideas and the relationship between science and religion (15). Students earned full points for completing the survey, and surveys were not examined until after final grades had been submitted. Because the SUSSI was administered at different times (before and after taking the course) and in sections taught by different instructors, we used a repeated measures multivariate analysis of variance (MANOVA) to determine the relative contribution of the course materials and the course instructor on student responses in each of the nine areas surveyed (16).

Informed consent and data handling. All participant data were collected and analyzed with protocols approved by Iowa State's Institutional Review Board. The coursework was deemed exempt (IRB # 11-414). Personal data—year, major, sex, learning community participation—was provided by the Registrar's Office and protected by using separate, non-identifiable codes.

Evidence of student learning

Students could identify the importance of understanding NOS early in the course. During the second week of class, immediately following the administration of the pretest, the modified SUSSI, the students read an essay called "Characteristics of Science" (17). This essay was the basis of a lengthy discussion of both the characteristics of science and the negative consequences on communication if the audience did not clearly understand the nature of science. The ideas presented in Table 2 were the basis of discussion throughout the rest of the term as students discussed each of the three books used in this class.

Taking the NOS-themed English course increased students' understanding of NOS. The summary data from the modified SUSSI showed differences in student understanding of NOS after completing this course (Table 3). In each of the nine areas surveyed, the changes were small, a shift from "uncertain" (3) toward "agree more than disagree" (4) or from "disagree more than agree" (2) to "uncertain" (3). There was less of a change in the students' understanding of the role of social interaction between scientists. The two largest differences between pre and post involved the students' understanding of revision in the

TABLE 2.
Characteristics of science and potential misunderstandings.

Characteristic of Science	Student Ideas of Potential Misunderstandings
Scientists will employ whatever methods they find useful for understanding the natural world.	People might believe that the five-step scientific method is the only way to scientific discovery. They won't trust observation studies or epidemiological studies. They won't believe numbers in a risk analysis. They might only respect bench studies.
Doing science well requires imagination and creativity.	All scientists interpret data the same way. Not all scientists do things in the same way. Science is boring.
The generation and acceptance of scientific knowledge often takes much time.	Scientists have no idea what is going on. Scientists can't make up their minds about things. People will be impatient for answers. People can be victims of clickbait.
Science has a subjective aspect in methods used, data collected, and how data are interpreted.	People could take an absolutist perspective and perceive any difference in data or methods as invalidation.
Well-established science knowledge is durable, but always open to revision.	Scientists can't make up their minds. People don't perceive difference between scientific theory and vernacular theory.
Well-established science ideas are not easily abandoned.	Scientists are closed-minded and won't accept new ideas. People may see facts as mutable.
Doing science is a collaborative process.	Scientists work alone in their labs. Scientists can be perceived as the trope "mad scientists" or as white men in lab coats.

Students were asked to predict and discuss how misunderstanding the nature of science would affect public perception of science.

TABLE 3.
Summary of SUSSI responses before and after taking a science-themed English course.

Aspect of NOS	Pre-Course Average	Post-Course Average	Difference	SEM
Nature of scientific observations	4.15	4.33	0.18	0.045
Social and cultural influences on science	3.82	4.00	0.18	0.056
How science ideas are established	3.33	3.47	0.14	0.042
Role of imagination and creativity in science	3.09	3.76	0.67	0.080
Methodology in science	2.85	3.20	0.35	0.051
Social interactions among scientific researchers	3.38	3.40	0.02	0.035
Timing of development and acceptance of science ideas	4.19	4.44	0.25	0.052
Role of revision in scientific knowledge	3.50	4.13	0.63	0.047
Science and the supernatural	3.52	3.67	0.15	0.051

The Likert responses were coded numerically and averaged, with 1 = strongly disagree, 2 = disagree more than agree, 3 = uncertain, 4 = agree more than disagree, and 5 = strongly agree. The statements on the SUSSI included 2 questions in each set that were reversed and were therefore reverse-coded to calculate an average score for each aspect of the nature of science. SUSSI = student understanding of science and scientific inquiry.

building of scientific knowledge and the role of imagination and creativity in science. Based on these data, students had a deeper understanding of the nature of science as they left this English class than they did before the course.

There was instructor-to-instructor variability in some, but not all, of the areas addressed. Some sections were taught by teaching assistants, while most were taught by the course's designer, a full-time faculty member in the department of English. The repeated measures MANOVA revealed that the course, the instructor, and the interaction between the course and instructor all had significant effects on student responses (Table 4). However, the effect size, as measured by partial eta-squared (η^2), was greatest for the course itself, with the course instruction accounting for 43% of the changes in student responses. An η^2 over 0.4 or 40% is considered a large effect size in educational research (18). Six of the nine areas showed significant improvement in student understanding of the nature of science, with social interactions among scientists, how ideas are established in science, and the interaction between religion and science (science and the supernatural) showing insignificant changes when looking at the effect of the course alone. While there was some effect of instructor, this accounted for only 8% of the changes in student responses. The instructor effect was significant in three of the nine areas surveyed: creativity, development and acceptance of science ideas, and the role of revision in science. The interaction between instructor and course accounted for 11% of the variability in responses (Table 4).

DISCUSSION

The goal of our project was to determine whether a science-themed communications course would help

students reach a more-informed view of the nature of science and its relevance to effective communication of scientific ideas and concepts. It is interesting that the area of NOS with the lowest gains was social interactions, as others using the SUSSI to assess student understanding have seen similar results, with variability between aspects of NOS, instructors, and school setting, though with lower effect sizes (19). The data appear to support the conclusion that students developed a slightly less naïve understanding of NOS and came to appreciate why understanding the nature of science is important to them as future scientists who may be communicating with the public.

The concrete science narratives of Dr. Snow fighting cholera, Dr. Semmelweis battling puerperal fever, and modern physicians facing resistance from anti-vaccination groups seem to help students understand how the abstract characteristics of science affect the development and dissemination of scientific ideas and concepts. Students could see how misunderstanding the nature of science causes problems with people's ability to understand and accept scientific ideas, and why it is important to be aware of and address an audience's understanding of the characteristics of science when communicating scientific information.

Class discussions of cholera, puerperal fever, and vaccination yielded rich, if tense, conversations about how to talk with those individuals who refute scientific ideas. Instructors reported that students voluntarily brought social media conversations they were having with friends or family about vaccines, global warming, and GMOs to class, hoping that the instructors and classmates could give suggestions for responses. Students seemed to realize that they can advocate for and discuss science even though they are not professional scientists.

TABLE 4.
Summary of repeated measures MANOVA.

	<i>F</i>	<i>p</i>	η^2
Pre–Post Multivariate Effect	16.09	<0.001*	0.432
1 Nature of scientific observations	6.13	0.014*	0.030
2 Social and cultural influences on science	4.37	0.038*	0.022
3 How science ideas are established	3.20	0.075	0.016
4 Role of imagination and creativity in science	26.70	<0.001*	0.119
5 Methodology in science	13.01	<0.001*	0.062
6 Social interactions among scientific researchers	0.59	0.445	0.003
7 Timing of development and acceptance of science ideas	14.79	<0.001*	0.070
8 Role of revision in scientific knowledge	90.15	<0.001*	0.313
9 Science and the supernatural	0.98	0.323	0.005
Instructor Multivariate Effect	1.84	0.006*	0.080
1 Nature of scientific observations	1.94	0.125	0.029
2 Social and cultural influences on science	0.59	0.624	0.009
3 How science ideas are established	0.78	0.505	0.012
4 Role of imagination and creativity in science	6.43	<0.001*	0.089
5 Methodology in science	2.11	0.100	0.031
6 Social interactions among scientific researchers	0.71	0.550	0.011
7 Timing of development and acceptance of science ideas	3.21	0.024*	0.046
8 Role of revision in scientific knowledge	2.72	0.046*	0.040
9 Science and the supernatural	1.36	0.258	0.020
Instructor × Pre–Post Multivariate Effect	2.76	<0.001*	0.113
1 Nature of scientific observations	2.44	0.066	0.036
2 Social and cultural influences on science	2.95	0.034*	0.043
3 How science ideas are established	1.97	0.120	0.029
4 Role of imagination and creativity in science	6.84	<0.001*	0.094
5 Methodology in science	3.52	0.016*	0.051
6 Social interactions among scientific researchers	5.20	0.002*	0.073
7 Timing of development and acceptance of science ideas	0.91	0.436	0.014
8 Role of revision in scientific knowledge	1.99	0.117	0.029
9 Science and the supernatural	1.90	0.130	0.028

This test was used to examine the effect of course alone, instructor alone, and the interaction effect of the two combined. An asterisk (*) is used to indicate statistically significant effects. The overall multivariate effect size for the course was $\eta^2 = 0.43$, indicating that 43% of the changes in student responses in the SUSI survey were accounted for by the course itself. In comparison, the multivariate instructor effect accounted for 8% of the variance in student responses to the SUSI and the instructor–course interaction effect accounted for 11% of the variance. SUSI = student understanding of science and scientific inquiry.

Limitations, dissemination, and modifications

While an entire English course for science students is not always feasible, key features of such a course can be implemented on a smaller scale. It is important for science instructors to address NOS and how it informs their own course content, scientific inquiry, and communication. Science instructors can incorporate concrete connections to

NOS throughout their science courses. These connections need not be time-intensive; they can be made in a few sentences, two to three times per class. Students learning the characteristics of science can see them as abstract ideas and struggle to connect these characteristics to what scientists do and think. Using engaging science narratives that connect to the nature of science and science communication in each specific discipline helps students develop a better

understanding. Faculty could consider interweaving brief anecdotes or stories into lectures, or could provide students with nonfiction narratives to supplement their science textbook. Within these narratives and discussions, course instructors could focus discussions on how someone who doesn't understand an aspect of science may misunderstand science in general.

CONCLUSION

The nature of science provides a conceptual framework and, as such, may be a threshold concept (20). Once students pass over it, the doorway opens up a new way of thinking and processing, making the study and conduct of science easier and enabling a deeper level of understanding and making connections. Dunk *et al.* (21) found that, of education-related factors, instruction and understanding of NOS have the greatest impact on students' acceptance of evolution. It was the understanding of scientific thinking that seemed to change students' minds. We should consider placing more emphasis on teaching the epistemology of NOS so science information is put into an established framework rather than teaching scientific facts and information and thinking that students will figure out the NOS framework on their own.

SUPPLEMENTAL MATERIALS

- Appendix 1: Syllabus schedule for English 250: the language of science
- Appendix 2: Aspects of nature of science and discussion questions within each of the three books
- Appendix 3: Discussion prompts used for each of the three nonfiction books
- Appendix 4: Assignment overview: documented report with annotated bibliography
- Appendix 5: Rubric for documented report with annotated bibliography

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