Science As Storytelling for Teaching the Nature of Science and the Science-Religion Interface

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ABSTRACT

Here we describe a method for teaching the NOS called "Science as Storytelling, which was designed to directly confront naïve realist preconceptions about the NOS and replace them with more sophisticated ideas, while retaining a moderate realist perspective. It was also designed to foster a more sophisticated understanding of the science-religion interface, where occasional science-religion conflicts are seen as inevitable in cases where religious beliefs incorporate supernatural intervention in the natural world. We evaluated the program as implemented in a geology course for pre-service elementary teachers at Brigham Young University, and showed that it was successful at helping students understand the tentative and creative aspects of scientific thought, and fostering more positive attitudes toward science. Our evaluation also showed that the students adopted a more irenic stance toward science-religion conflict. These results directly contradict fears that emphasizing the creative and tentative aspects of the NOS, and admitting that science and religion sometimes conflict, will cause students to reject scientific claims to an even greater degree.

INTRODUCTION

Most science teachers would agree that their students and the general public badly need a better understanding of the nature of science (NOS) (AAAS, 1989; Abd-El-Khalick and Lederman, 2000; Moss et al., 2001; NAS, 1998; NRC, 1996; NRC, 1997; NSF, 1996). Many also complain that if people only understood the relationship between scientific and religious thought, they would not be so opposed to certain unpopular scientific theories, e.g., evolutionary theory and climate change (Antolin and Herbers, 2001; Farber, 2003; Miller, 2005; Rudolph and Stewart, 1998; Sprackland, 2005). Religious objections, in fact, can hamper many from even being able to rationally discuss such subjects (Antolin and Herbers, 2001).

In a commentary piece published in this volume of the Journal of Geoscience Education (Bickmore et al., this issue), we argue at length that science teachers often exacerbate these mutually reinforcing problems. This happens because we often harbor some naïve views about the NOS, and even if we don't, we may soft-pedal its tentative and creative aspects. Furthermore, scientists tend to be very naïve about conservative types of religious thought, and typically try to artificially minimize science-religion conflict by separating the two into mutually exclusive categories.

We then go on to argue that science educators should address these intertwining problems together, and in an exceptionally frank manner. We should make it very plain that we mean it when we say science is tentative and creative. And when we say scientific explanations do not appeal to supernatural causes, we should make it clear that this will inevitably cause some conflict with religious explanations that do appeal to supernatural causes.

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It has to be admitted from the outset, however, that this kind of approach might be risky. If we emphasize the tentative and creative NOS too strongly and admit that some scientific explanations are likely to contradict students' religious views, will this give students license to reject scientific views outright, without giving them a hearing?

In the study reported here we tested these two points of view as we piloted a program called "Science as Storytelling" for teaching the NOS and the science-religion interface. We designed the program to be administered during a single class period at the beginning of an introductory college science course. Nevertheless, our approach was so blunt that we were able to make significant gains in student understanding of the NOS and attitudes toward science. We did find that the fears mentioned above have some basis in fact, but to a much lesser extent than might be expected.

METHODS

Instructional Setting

We implemented the "Science as Storytelling" program in an Earth science class for elementary education majors (Physical Science 110B, hereafter PS 110B) at Brigham Young University (BYU—Provo, UT campus). The class typically has 120-140 students enrolled per semester. BYU is owned and operated by the Church of Jesus Christ of Latter-day Saints (i.e., "Mormons" or LDS,) and more than 98% of the student body is LDS.

We classify the LDS religion as "conservative," in the sense that adherents almost unanimously accept supernatural involvement with the world as a fact. In contrast, "liberal" religious beliefs would be more prone to discount the possibility of supernatural intervention in the world. We make this distinction because we feel this particular issue is the source of most science-religion conflicts for conservative religious believers, rather than any particular religious doctrines, which differ widely from group to group.

Since the LDS religion is conservative in this manner, it was inevitable that science religion conflicts would arise

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from time to time within the group. These conflicts have included the standard conflicts regarding evolution and the age of the Earth that have come up within most other Christian, Jewish, and Islamic groups (Jeffery, 1973; Numbers, 1992). While the LDS Church has officially remained neutral about these issues (Evenson, 1992), and the Mormons have a very strong tradition of producing far more scientists than average (Miller, 1992), many incoming students at BYU have been raised with essentially Young Earth Creationist beliefs.

Given the characteristics of the BYU student body, we considered our instructional setting to be a good laboratory in which to test whether our "Science as Storytelling" program could help change student perceptions of science, so they would be inclined to give scientific theories a more careful hearing. Both the student and faculty cultures at BYU are significantly more religious even than those at other research universities with similar religious heritages (Lyon et al., 2002), however, so it is possible that our results will not be as applicable to students from less religious backgrounds. We do report, however, the experience of a colleague at a state university in California who adapted our program with good results.

THE SCIENCE AS STORYTELLING PROGRAM

"Science as Storytelling" is a program we developed to teach the NOS in introductory college science classes to address the problems outlined above. We discuss the empirical, tentative, and creative NOS in a frank and non-manipulative manner, and characterize the science-religion interface in a realistic way. These concepts are introduced using exceptionally plain language designed to help students confront their misconceptions (e.g., naïve realism.)

Although the program can be (and has been) altered in various ways, during our pilot students were given an essay called "Science as Storytelling" as required reading on the first day of class. The essay can be obtained from the SERC website at: http://serc.carleton.edu/teacherprep/resources/activities/storytelling.html. This essay introduces science as a form of "storytelling" that follows certain rules so that the stories (i.e., explanations) produced are useful for predicting, and possibly controlling, nature. A rationale for each rule is given along with historical examples to show both its usefulness and limitations.

The Rules of Scientific Storytelling

The first rule of scientific storytelling is that the observations the story is meant to explain must be reproducible in some way. We explain that this does not mean the story has to be reproducible. (E.g., it is a common misconception that evolutionary theory is not scientific because we cannot reproduce it in a laboratory. Rather, if a paleontologist bases a hypothesis about evolution on observations of the fossils found in different rock strata, another paleontologist ought to be able to go to the same strata and find similar fossil assemblages.) We also emphasize that this rule both empowers and limits science. On the one hand, just because we cannot reproduce an observation does not mean it was not real. On the other hand, if we allowed non-reproducible observations to form the basis of scientific stories, we would be stuck with all kinds of conflicting information, including hallucinations and lies.

The second rule is that scientists prefer stories that predict possible observations beyond the original set it was based upon. That is, scientists prefer *testable* stories. But while this is a fundamental feature of the scientific enterprise, it is a mistake to push this rule too far (think of string theory, for example.)

The third rule is related to the second; i.e., scientists prefer testable stories because they want the stories to be amenable to improvement. We can never know when our stories are completely true descriptions of ultimate reality, but if they can be improved in response to new observations so as to be more predictive, we suspect the story to be closer to ultimate reality than it was before, and certainly it is more useful. Thus, the iterative process scientists go through to formulate, test, and reformulate hypotheses (often called "the scientific method") is an essential part of the nature of science. We emphasize one point about this process, however, that others have sometimes left out. That is, if a hypothesis fails some test devised for it scientists do not automatically set about modifying or replacing it. Rather, it may be that the hypothesis in question explains so much, so successfully, that a few contradictory observations will not move us to change it. After all, it could be that there was something wrong with the design or implementation of the test, or that some minor auxiliary assumption of the hypothesis is wrong, but it is correct in the main. Therefore, scientists are perfectly capable of ignoring it for a while when a hypothesis is falsified by testing.

The fourth rule for scientific stories is that they do not appeal to the supernatural, i.e., causes that are not bound by the regularities of nature. Although this rule is a commonplace, we emphasize that there is no *a priori* reason why scientific explanations have to be naturalistic, but there are a number of practical reasons for it. For example, even though religious claims involving the supernatural may sometimes be amenable to testing (Barbour, 1974, 2000; Bickmore et al., this issue) they are usually more difficult to adequately test, because science relies on regularities in nature. Second, it is often difficult to distinguish between competing supernatural explanations. Finally, if we want to test a claim such as that God created the world, then we would have to define how God could have and would have done such a thing. And since different religions espouse different ideas about such things, we might end up with an endless list of religious schools of scientists. In an age where science is usually publicly funded, would it be wise to allow science to be Balkanized into a mass of competing religious factions? Therefore, even deeply religious scientists who believe in the possibility of supernatural events usually have no problem with this rule. They view it simply as a necessary limitation on what science can do. We then note that since scientific stories leave out supernatural elements, while they are included in many religious stories, it is only to be expected that conflicts between the two will sometimes arise.

The fifth rule has to do with Uniformitarianism—the assumption that the same physical laws we observe today have operated at all times in the past. We relate this to the rule about Naturalism, and explain that if we did not make this assumption, we would have no way of reconstructing past events from the present state of things. Once again, even scientists who do not rule out the possibility of supernatural events in the past will go along with this, because they see that even if the assumption of Uniformitarianism is only true *most of the time*, it is still probably a necessary limitation on science.

The sixth rule is that scientific stories must be based on the assumption that the universe is simple enough for human minds to understand. While this is not necessarily true, and may even be unlikely, it is an assumption that must be made for science to progress. However, we also explain that this rule does not mean we assume the universe conforms to what we call "common sense." That is, when scientists try to create stories based on very precise measurements, they often find that they must craft some strange tales to account for their findings (e.g., relativity theory and quantum mechanics.)

Finally, the seventh rule is that scientists try to create stories that harmonize with one another, so that the end result will be more likely to approximate the truth. Naturally, scientific stories do not always mesh together perfectly, but when they do not, it becomes a red flag warning scientists that something is wrong.

IMPLEMENTATION

During the first lecture period of our pilot, the major points of the essay were summarized, and the class discussed student answers to the "questions for thought" included in the text. Many of these questions were designed to incite the students to consider their own beliefs in relation to the assumptions scientists make in their work. For instance, they were asked whether they believe the assumption of naturalism is never, sometimes, or always correct. Then they were asked to consider whether they thought the rule was worthwhile. In this way, they were encouraged to engage with the NOS in a way that they could clearly see the limitations of science, but were challenged to come up with ways to do the job better if they did not agree with some of the "rules" for scientific discourse.

Throughout the semester, the professor periodically paused during lectures and asked which parts of the topic being discussed were the observations, and which were the "story," i.e., the explanation. Also, several short, in-class writing assignments were given throughout the semester to help students reflect on how their views of the NOS changed via the course, and how their understanding of the NOS affected their understanding and acceptance of the topics discussed in class.

Key Strategies Employed

Some key strategies of "Science as Storytelling" can be summarized as follows. 1) The word "storytelling" is meant to send a strong jolt to students who have the misconception that science is supposed to essentially be "just the facts." Once they see the word, there can be no question but that this will not be the same old story about "the scientific method" that they have heard before. Some scientists find the word "storytelling" off-putting, since for them the word carries strong fictional connotations. The characterization of scientific thinking as a kind of "storytelling" or extensively employing conceptual metaphor is not new, however (Brown, 2003; Grobstein, 2005), and we are careful to distinguish "stories" that are completely fictional from those that are based largely on observation and testing. 2) We are careful to note exceptions to the rules of science when appropriate. We hope that this clearly shows students that the rules are human creations, and that the NOS has developed over time in response to various quality control issues. 3) We clearly point out that the rules limit science in some ways, but they also allow science to advance without being bogged down. We ask the students to decide for themselves whether the gains are worth the limitations imposed. 4) Supernatural causes that intersect with the natural world are presented as real possibilities, but students are given very practical reasons for excluding such things from scientific discourse. In this way, we hope to avoid making students feel manipulated into accepting science as it is, but instead help them see that science is not necessarily naturalistic because it is "anti-religious." 5) We are completely honest about the fact that science-religion conflicts are to be expected from time to time. But because we do not discount, or even downplay, the possibility of supernatural forces, but instead note that science ignores that possibility for practical reasons, we hope that the perception of science-religion conflicts will be less of a barrier to student learning.

PROGRAM EVALUATION

Our evaluation of "Science as Storytelling" was primarily designed to address the following questions. Did it actually help our students understand the NOS better than they had before? Did it help them adopt a more positive view of science, or make them more prone to reject scientific theories without a proper hearing? Did it help them adopt more irenic approaches toward perceived science-religion conflicts, or again simply give them license to summarily reject scientific points of view? We also more informally addressed whether the program could successfully be transferred to other instructional settings.

From the beginning, we planned to directly address the questions about whether student conceptions of the NOS and attitudes toward science improved by administering pre- and post course surveys. As we proceeded, though, we perceived the need for more qualitative information, and added some in-class reflection essay questions to our protocol. We could not administer pre-course versions of these essay questions, so the results of these must be treated with greater caution than those of the surveys. Even so, we believe they add considerable weight to our conclusions.

Although there were approximately 120 students in the class during the semester we evaluated the program, only 85 were selected as subjects for the evaluation. These students were selected because they 1) indicated willingness to participate as human subjects on a consent form approved by our Institutional Review Board, 2) showed up on the first day of class to take the preliminary surveys, and 3) showed up on the last day of class to take the post-course surveys. The number of responses to open-ended essay questions given throughout the semester was somewhat lower, since we only included those by students who fulfilled our initial criteria, and sometimes they were not present or did not answer all the questions given.

Student Conceptions of the Nature of Science

To track student conceptions of the NOS, we used pre- and post-test implementations of the Conceptions of Science Survey (COSS) developed by Libarkin (2001). This is a simple survey designed to address several key points and common misconceptions about the NOS, using 14 True/False questions. The COSS survey questions are listed in Table 1. We chose this particular survey because 1) it is a very simple, quantitative instrument we could apply to the entire class, and 2) the language used in the survey questions was very different from that employed in our presentation. Thus, we felt that students answering these questions would not simply be parroting key words.

Our implementation of the COSS was slightly different than that of Libarkin (2001), however. Libarkin conceived of the questions as True/False, but had students answer the questions via a 5-point Likert scale with answers ranging from “Strongly Disagree” to “Strongly Agree.” She tested the instrument for internal consistency among the questions by calculating Cronbach’s alpha scores. We considered this kind of implementation to be problematic for the following reasons.

First, it is often difficult to make True/False questions that are absolutely true, or absolutely false. Consider the statement, “Scientific laws, theories, and concepts are tested against reliable observations.” Clearly, this statement is *generally* true, but is it *always* true? Students with more sophisticated conceptions of the NOS might very well respond that they “Agree” with this statement, whereas students with less sophisticated conceptions might “Strongly Agree.” Libarkin, nevertheless, scored the COSS in such a way that a “Strongly Agree” answer to this question would indicate a better conception of the NOS. Several of the questions in Table 1 are similarly problematic.

Second, Cronbach’s alpha is a statistical parameter designed to test for consistency among questions in surveys intended to provide a score representing a single “construct.” In the next section, for instance, we describe the Attitude Toward Science Survey (see Table 2,) that includes eleven questions. Strong agreement with any of these questions would tend to indicate a positive general attitude toward science, and the questions are strongly linked to one another. Anyone who says they “have good feelings toward science” would be very likely to agree that they “enjoy science courses,” for example. A high Cronbach’s alpha score for this survey would be meaningful, because we are using the various survey questions to get at different aspects of the same “thing.” The questions in the COSS, however, are not so related. It would be fairly likely, for example, that a student with a naïve realist conception of the NOS would understand that scientific beliefs change over time (since scientists are always out there “discovering” new facts,) but not understand that scientists typically aren’t so egotistical as to think that they will one day know “everything there is to know” about the Universe. The “internal consistency” between such questions is somewhat beside the point, in such a case.

TABLE 1. QUESTIONS AND ASSOCIATED ANSWERS FROM THE CONCEPTIONS OF SCIENCE SURVEY, DEVELOPED BY LIBARKIN (2001)

Question	Answer[1]
1. Scientific beliefs do not change over time.	False
2. Scientific laws, theories, and concepts are tested against reliable observations.	True
3. Scientists will accept scientific information even if test results are not consistent.	False
4. Today’s scientific laws, theories, and concepts may have to be changed in the face of new evidence.	True
5. The laws, theories, and concepts of all areas of science are not connected.	False
6. When scientific investigations are done correctly, scientists gather information that will not change in future years.	False
7. Scientists reject the idea that we will one day know everything about the universe.	True
8. When scientists classify something in nature, they are classifying nature this way because that is the way nature is; any other way would be incorrect.	False
9. Scientist classify nature through schemes which were originally created by another scientists; there could be other ways to classify nature.	True
10. The evidence for scientific information does not have to be repeatable.	False
11. The laws, theories, and concepts of all areas of science are related.	True
12. Even when scientific investigations are done correctly, the information that scientists discover may change in the future.	True
13. The truth of all scientific knowledge is beyond question.	False
14. Scientists believe that we will one day know everything there is to know about the universe.	False

Notes:
[1]Although Libarkin (2001) had subjects answer the survey questions via a Likert scale, we presented them as simple True/False questions, for reasons discussed in the text.

For these reasons, we consider it better practice to present the questions as simple True/False propositions, and not worry about internal consistency. Either the questions address key points and misconceptions about the NOS, or they do not. We believe they do. Given the nature of the survey (simple True/False questions,) it is certainly not appropriate to use the instrument to make fine distinctions about student conceptions of the NOS. Rather, we used it only as a rough gauge of student progress, applicable to a large class.

We assessed this progress via dependent-sample *t*-tests (two-tailed) and Cohen's *d* effect size statistics (Cohen, 1988).

TABLE 2. ATTITUDE TOWARD SCIENCE SURVEY[1] AS IMPLEMENTED BY LUSK ET AL. (2006)

1. Science is fun.
2. I have good feelings toward science.
3. I enjoy science courses.
4. I am well prepared to teach science to my future students and/or children.
5. I really like science.
6. Most people can understand the work of science.
7. I think scientists are neat people.
8. I usually look forward to my science class.
9. We do a lot of fun activities in science class.
10. We cover interesting topics in science class.
11. I want to encourage my future students and/or children to learn more science.

Notes:
[1]Each question is answered via a 4- point Likert scale with the following possible answers: Strongly Disagree, Disagree, Agree, and Strongly Agree. These answers are assigned a score of 1, 2, 3, or 4, respectively, so that overall ATSS scores can range from 11-44.

Student Attitudes Toward Science

Student attitudes toward science were assessed using pre- and post-test implementations of the Attitude Toward Science Survey (ATSS,) which Lusk et al. (2006) adapted from Thompson and Shrigley (1986) and pilot tested. In addition, Thompson et al. (2007) used the ATSS on the same PS 110B class during two previous, but recent, semesters. The ATSS questions are shown in Table 2. All questions were answered via a 4-point Likert scale, and each question was assigned a score of 1-4, based on the answer given. Since the ATSS includes 11 questions, scores of 11-44 were possible, higher scores indicating a more positive general attitude toward science. Progress was assessed via dependent-sample *t*-tests (two-tailed) and Cohen's *d* effect size statistics.

In addition to this quantitative instrument, we also asked an open-ended essay question with the post-course survey, and another in an in-class reflection assignment given near the end of the course. We coded the student responses to identify recurring themes. The question given with the post-course survey was,

> In the space below, please describe in detail those aspects of this class that have most positively, or most negatively, affected your attitude toward science and science classes.

The question given in the in-class reflection assignment was,

> How do you feel the explanation of the nature of science ("Science as Storytelling") given in this class has affected your attitude toward scientific theories? Do you now feel more accepting of scientific theories? Do you feel more skeptical toward them? Do you feel like it is easier now to just dismiss scientific theories, or easier to consider them without feeling threatened? Please explain your answers.

Student Perceptions of Science-Religion Conflict

We addressed student perceptions of science-religion conflict via an in-class reflection assignment near the end of course. The students were asked to respond to the following essay questions.

> You were taught that science and religious beliefs sometimes will conflict because scientific stories do not include the supernatural. Do you think this is a good thing, as long as it is understood why scientific stories ignore those possibilities? Or, do you think science would be better off allowing the supernatural into its stories? Whatever your opinion on this issue, has the "Science as Storytelling" discussion helped you better understand the point of view of those with whom you disagree? Please explain your answers.
>
> At some point you will be expected to teach science to elementary school students, probably in public schools where overt inclusion of religion in the science curriculum has been ruled unconstitutional. Has the "Science as Storytelling" discussion helped you define how you plan to teach the nature of science to your students? Has it helped you define how you will deal with science/religion conflicts that might arise in your classroom, or in your own mind? Please explain your answers.

We coded the student responses to identify recurring themes.

Implementation in Other Settings

As we tested our program ourselves, we also made the "Science as Storytelling" essay available to colleagues. Two of them (Ann Bykerk-Kauffman, *California State University at Chico* Department of Geology and Environmental Sciences, and Stephanie Burdett, *BYU* College of Biology and Agriculture,) tried versions of our approach in their own courses, and reported their experiences to us. We share highlights from those reports with their permission.

RESULTS AND DISCUSSION

Our data supports our hypothesis that the "Science as Storytelling" program would 1) help our students gain more sophisticated concepts of the NOS, 2) encourage them to adopt more positive attitudes toward science, and 3) help them adopt a more irenic attitude toward science religion conflict. In addition, our colleagues' attempts to adapt our program to different contexts show that it is broadly applicable, at least to introductory college-level science courses.

Student Conceptions of the Nature of Science

The results of our pre- and post-course COSS surveys are reported in Table 3. There was a small, but statistically insignificant increase in the mean COSS score (pre-course mean = 12.4, post-course mean = 12.7, $p \leq 0.09$) for the class as a whole, and the effect size was small. (Cohen, 1988, categorized *d*-scores of 0.2, 0.5, and 0.8 as small,

TABLE 3. RESULTS OF THE PRE-AND POST-COURSE COSS

	N	Pre COSS (S.D.)[1]	Post COSS (S.D.)	P ≤	d	Pre Q13	Post Q13	p ≤	d
Entire Class	85	12.4 (1.6)	12.7 (1.3)	0.09	0.12	0.63	0.81	0.001	0.93
Pre-Coss 8-11	19	9.9 (1.1)	11.4 (1.4)	0.001	0.89	0.37	0.79	0.002	1.97
Pre-Coss 12	20	12 (0)	12.65 (1.2)	0.02	0.66	0.50	0.80	0.03	1.36
Pre-Coss 13-14	46	13.6 (0.5)	13.2 (1.0)	0.02	-0.58	0.80	0.83	0.71	0.14

Notes:
[1]standard deviations in parentheses

medium, and large, respectively.) Since over half the students (46 out of 85) scored 13 or 14 out of 14 possible on the pre-course survey, we were concerned that if we aggregated the results of the entire class, a ceiling effect would mask the treatment results. Therefore, we split the class for analysis, isolating those who scored 8-11, 12, and 13-14 on the pre-course survey. (These were chosen because they yielded three groups that were as equal as possible in number, given the preponderance of scores of 13 or 14.) The students who scored 8-11 (mean = 9.9) on the pre course survey improved dramatically, with a mean score of 11.4 on the post-course survey ($p \leq 0.0009$), and a large effect size. The students who scored 12 on the pre-course survey improved moderately, with an average post-course survey score of 12.65 ($p \leq 0.02$) and a medium effect size. The students who scored 13-14 (mean = 13.6) on the pre-course survey actually scored lower on the post -course survey (mean = 13.2, $p \leq 0.02$), with a medium effect size.

Most of the improvement involved only a small number of the questions, e.g., 9 of the 14 questions were answered with over 90% accuracy on the pre-course survey, so there was little room for improvement on these. The students showed by far the greatest improvement in performance on question 13 (Table 1), which proposes the statement, "The truth of all scientific knowledge is beyond question." Only 64% of the students correctly labeled this "False" on the pre-course survey. However, 81% answered this question correctly on the post-course survey, yielding a statistically significant improvement and a large effect size ($p \leq 0.001$, $d = 0.93$). These results are more striking, once again, when we break them down according to the pre-course COSS scores. While only 37% of the students who scored 8-11 on the pre-survey answered question 13 correctly, 80% answered it correctly on the post-survey ($p \leq 0.002$, $d = 1.97$). Of the students who scored 12 on the pre-survey, 50% answered it correctly on the pre-survey, while 80% answered it correctly on the post-survey ($p \leq 0.03$, $d = 1.36$). Of the students who scored 13-14 on the pre-survey, 80% answered question 13 on the pre-survey, and 82% answered it correctly on the post-survey, which was not a statistically significant change at the 95% confidence level ($p \leq 0.71$, $d = 0.14$).

We could quibble about wording issues—i.e., in the "Science as Storytelling" presentation we made clear that both observations and explanations could turn out to be wrong, but we never spoke of either as "knowledge." Some students might take this word to connote something more absolute than was intended (Cobern, 2000). In fact, 16 students gave the wrong answer to question 13 on the post-survey, and 11 of those submitted answers to the open-ended reflection essays. Of these 11 students, 7 gave answers that clearly indicated the understanding that scientific theories are tentative. Therefore, it is likely that more than 80% of our students understood that scientific theories are tentative.

Even if we do not consider this problem with the wording of the question, such a large gain on question 13 is surely significant, given that our main concern was to shock students out of their naïve realist preconceptions. And the fact that we succeeded in raising the achievement on this question among the low-, medium-, and high-scoring students to essentially the same level is heartening, as well.

Given the minimal nature of the treatment, perhaps this is the best that could have been expected. All we did was assign a short reading, devote a single 50-minute class period to discuss it, and then sporadically refer to some of the ideas presented in "Science as Storytelling" throughout the semester. This is hardly the equivalent of a course in the philosophy of science, after all. Furthermore, the treatment targeted students who had built up misconceptions about the NOS over years of science courses. If our past experience with students in college science courses is any guide, nearly all of them undoubtedly thought they knew "the Scientific Method" pretty well coming into the course. We consider it a significant achievement, therefore, to have convinced so many of our students that scientific knowledge is truly tentative and creative.

Student Attitudes Toward Science

It is perhaps not surprising to find that a program that equates science with "storytelling" would help students realize that science has creative and tentative aspects. But a number of our colleagues express reservations about our program because they fear it might work too well—convincing students to dismiss science outright. We found that, if anything, our approach positively affected student attitudes toward science.

Table 4 shows the results of the mean pre- and post-course ATSS scores, with associated statistics. The mean score of the entire class improved by 2.3 points, which was statistically significant, but the effect size was small. Again, we broke up the class as closely as possible into thirds according to the pre-course ATSS scores, in order to obtain a more detailed view. We found that those who scored less than 30 on the pre-ATSS improved by an average of 4.8 points, which was statistically significant,

TABLE 4. RESULTS OF THE PRE-AND POST-COURSE ATSS.

	Pre-Mean ATSS	Post-Mean ATSS	*N*	*p* ≤	Cohen's *d*
Entire Class	30.8 (3.6)[1]	33.1 (4.3)	85	0.001	0.15
Pre-ATSS <30	27.0 (1.8)	31.8 (4.0)	28	0.001	0.42
Pre-ATSS 30-31	30.4 (0.5)	32.8 (4.6)	25	0.02	0.16
Pre-ATSS >31	34.4 (2.3)	34.6 (3.9)	32	0.8	0.01

Notes:
[1]standard deviations in parentheses.

and the effect size was roughly medium. Those who scored 30-31 on the pre-ATSS improved by an average of 2.4 points, which was statistically significant, but the effect size was small. Finally, those who scored more than 31 on the pre-ATSS improved by an average of 0.2 points, which was not significant.

Again, the students who exhibited the poorest attitudes toward science in the beginning were the most positively affected by the treatment. But the treatment was minimal, which brings up the question of how much of this gain was caused by other factors. According to the students, "Science as Storytelling" was one of several factors positively affecting their attitudes toward science,

TABLE 5. STUDENT RESPONSES TO THE OPEN-ENDED QUESTION INCLUDED WITH THE POST-COURSE ATSS

Factor[1]	Positive	Negative
Instructor/TA attitude	28	2
Experience in lab	25	2
Concepts related to real life	23	0
Science as Storytelling	22	0
Class project at a local elementary school	19	0
Tests/class structure/ topics covered	17	23

Notes:
[1]Coded according to the factors they listed as most positively or negatively affecting their attitude toward science and science classes. 85 students responded, and some listed multiple factors.

and none of them mentioned it as negatively affecting their attitudes. Table 5 summarizes the student responses to our open-ended question regarding "those aspects of this class that have most positively, or most negatively, affected your attitude toward science and science classes."

Following are some representative quotations from students who pointed to "Science as Storytelling" as a positive factor.

> The concept that scientists come up with theories in order to help explain the universe and the world has made me more interested in science. The idea that scientific theory was concrete and absolute truth always irked me a little, but the concept that science is storytelling makes me more open-minded and more interested in knowing what scientist[s] believe, and how they explain the origins and workings of the world. My attitude towards science has significantly improved since reading the science as storytelling article and exploring its ideas. Viewing science as an exploration process is very helpful to me.

> My attitude towards science has improved during this class. "Science as Storytelling" and discussions on religion vs. science have made science more interesting to me. Also, I have been able to consider other possibilities in science that I before completely rejected.

Given these results, it seems reasonable to conclude that "Science as Storytelling" was a significant factor in the improvement of attitudes indicated by the ATSS scores, or at the very least did nothing to harm student attitudes toward science. But the themes indicated by the above quotations are provocative. Two of the students quoted explicitly wrote that they were formerly naïve realists who thought scientific theories are meant to express absolute truths, and two of them explicitly said the program helped them to be more open-minded toward scientific theories.

This theme is also found throughout the responses to the in-class reflection question about how "Science as Storytelling" affected their attitudes toward scientific theories (Table 6). The major theme taken from these student responses is that the program helped them to understand that scientific theories are explanations ("stories") rather than absolute truth, or at least that scientists do not view them as facts. The vast majority of the respondents said this actually made it easier to accept scientific theories and consider them without feeling threatened. A few mentioned that they feel less threatened because they now understand why science excludes the supernatural, and that they no longer felt that science was a personal attack against their beliefs. Here are some representative quotations.

> The explanation of "Science as Storytelling" has helped me see that theories don't have to be and aren't necessarily considered to be absolute total truths. It just means scientists have observed things in our world and are trying to explain it considering the "rules" of science. I'm more willing now to think about theories instead of just immediately rejecting them. I don't feel so threatened by theories now because they don't have to be absolute truth.

> Mostly, I just feel more forgiving towards scientists. If I can think of their stories as the best explanations so far instead of them trying to shove it down my throat as the absolute truth, I can be more accepting and feel less threatened.

> I feel more accepting of scientific theories now. They are simply stories, not facts. I don't feel as if it is easier to dismiss scientific theories, though. I think it is easier to

TABLE 6. STUDENT RESPONSES TO THE OPEN-ENDED ESSAY QUESTION

Issues, Responses, and Explanations[1]	**# Responses**
(I)[2] More accepting or more skeptical about scientific theories?	
(R)[3] More accepting	38
(R) More skeptical	9
(R) Neither	7
(R) Both	3
(E)[4] I now realize that science is not just "the facts", and is not meant to be.	36
(E) The process of science now makes more sense to me.	8
(I) More dismissive of, or less threatened by, scientific theories?	
(R) More dismissive	2
(R) Less threatened	24
(R) Neither	1
(R) Both	2
(E) If science is tentative, it seems less threatening.	24
(E) If science is tentative, it is easier to dismiss.	1
(E) I understand now why the supernatural is kept separate from science.	4

Notes:
[1]About how the "Science as Storytelling" program affected their attitudes toward scientific theories.
[2]Two issues (I) in the question are separated in the table.
[3]Categories of student responses (R) to those issues.
[4]Explanations (E) for the responses, are identified.

> consider them without feeling threatened. Scientists are very intelligent and sometimes we may feel threatened by all of the knowledge they have. If we think of some of these complex theories as just stories, it is much easier to consider without feeling threatened.
>
> I am more accepting of theories because of this class now because they have to fit a lot of criteria. It is easier for me to consider them—especially ones involving evolution—because I realize the necessity of eliminating the possibility of divine intervention for scientific reasons.
>
> The "Science as Storytelling" explanation changed my whole attitude and approach to science forever. I used to hate science classes because I felt that everything was being explained from a biased view, and that when my views did not correspond, that they were not valid. I do feel more accepting of scientific theories now and also that I can speak my mind with validity. I actually like science now…. I think
>
> I can accept them easier because I don't feel like they're bashing on me personally.

Only nine of the respondents said that the program persuaded them to be more skeptical of scientific claims, but only two of these equated this with being "dismissive" of scientific claims. Rather, most of them claimed that they were naïve realists before they realized that theories are not facts, and either just accepted, or resented, what they were taught. After the "Science as Storytelling" experience, they said they felt empowered to be more discriminating, even though some of them realized that this entails a lot of extra work.

> I feel perhaps a little more skeptical of scientific theories and believe they are more like incomplete stories than absolute, observable truth. Though we have much evidence to explain and support the theories, we continue to learn more and more about our world. Thus, the theories we have now are still incomplete.
>
> I think I am less accepting of scientific theories because before I accepted them as FACT, and I have learned to investigate and think more about whether those things could really be true. I am not more skeptical, but more critical. It is easier now for me to both see the flaws in theories and to consider them without feeling like my beliefs are threatened….
>
> I think my problem was not in accepting scientific stories, but not questioning them. I need to dig in and figure it out for myself.
>
> I think that after discussing the nature of science as storytelling, I feel like I don't have to accept all theories that are out there, and I really don't feel as threatened, and I feel like I'm allowed to think about things differently, and I don't have to feel stupid or wrong all of the time.

A couple students, however, claimed to be more dismissive of scientific theories. One of them expressed disappointment with the program because her former faith in science was diminished because of it.

> Now I trust science less due to the fact that it is not rock solid.
>
> I actually didn't like the explanation of "Science as Storytelling". It's a nice idea and I know its true, but for me it made science seem really fake. I already knew that nothing in science is absolute, so I feel like it was pushed too hard on us. Science used to be one of my favorite subjects, and after I heard the explanation I was more annoyed with it. I feel a little bit more skeptical about theories now, since they are after all just stories. I guess I do feel like I can dismiss scientific theories easier now because it has been reiterated over and over that they are not absolutely true.

These last quotations make it clear that our colleagues' fears that "Science as Storytelling" would negatively affect student attitudes toward science have some basis. But the vast majority of our students reported being positively affected in ways that many science educators would not have anticipated. Most resources we have encountered for teaching the nature of science and evolution, for example, claim that students need to be disabused of the notion that "theories" are just "hunches" or "guesses" (e.g., NAS, 1998; NAS and IM, 2008; Scott, 2004). Previous teachers seem to have taken this advice so fully to heart that some of our students came into our class largely thinking either that theories are essentially facts, or that scientists view them as facts.

Consider what this might mean about how these resources have affected science classrooms. Here we get the picture of many religious students dreading science classes because they anticipate being confronted with supposed facts, like evolutionary theory, that contradict their deeply held beliefs. So what does the teacher do? She hammers home the point that a theory is much better established than a "hunch," or a "guess," further entrenching the students' naïve realist beliefs, even if she mentions that theories are not "Absolute Truth." Most of the students suffer through the class in silence, resisting learning all the way. And yet, their naïve realist belief system is exactly what keeps these students from relaxing enough to consider alternate points of view.

Student Perceptions of Science-Religion Conflict

Rather than artificially separating science and religion into "non-overlapping magisteria," one of our key strategies in "Science as Storytelling" was to frankly admit that science and religion are bound to conflict, at times. We felt that if students could grasp the tentative and creative NOS, they would not be bothered as much by the occasional science-religion conflict. Our students reported that our suspicion was correct.

Table 7 summarizes the student responses to the two questions, asked in an in-class reflection, regarding whether students thought the exclusion of the supernatural from scientific explanations was a good idea, and how they perceive the effect of "Science as Storytelling" on their ability to deal with science-religion conflicts. The vast majority thought it was better to exclude the supernatural from science, and those that gave support for this conclusion almost uniformly cited reasons given in the "Science as Storytelling" essay. The most popular reason given was that different religions would pose different supernatural explanations, giving rise to more bickering among scientists. By contrast, the most popular reason given by those who thought it was better to include the supernatural was simply that they know God exists, so science is bound to go wrong by excluding him. These students almost uniformly said that "Science as Storytelling" had helped them understand the opposing point of view, however.

> In my opinion, the world is fine with science and theology as separate fields, as long as we have both. Wherever they overlap is good too, and where they go against each other it gives us the opportunity to have an opinion about [it] and figure out why. Things don't work out entirely harmoniously. "There will always be vexation and strife," to quote Jane Austen. When two ideas conflict there is a place for all mindsets to put their theories forward. As we see science as a story, it makes it easier to accept or at least be tolerant of others' ideas.

> I think it's good that religion and science are separate. Sometimes we can be closed minded about observations and our discovery of the world around us may be hindered.

> I think that in a public realm it is important for scientific stories to not include the supernatural. The reason for this is that there are so many different religions, but more importantly, we do not know exactly how God works and it would be presumptuous to try and act as if we know all about his universe and the way it works.

> It used to bother me that religion was left out of science, but now I see that it makes good sense, as all curiosity might be lost if we chalk it all up to things we think we cannot understand. Plus, I think there is always the danger that the "wrong" supernatural explanations would prevail.

> While I think science will never be able to explain everything without supernatural things, they are still better off excluding it from science. I do think the discussion of science as storytelling has helped show me why science is not able to take the supernatural into its theories.

> Science, to me, is possible because of God. If God, in my opinion, didn't make it, we couldn't study it. So why should we take him out? I understand both sides, but I think God should be included.

> I believe and know that God has a hand in everything. I understand that including the supernatural into scientific stories may conflict with others beliefs, but it doesn't mean that it should never be included or talked about, or that it's not true. Science has to do with everything, and so does God, so why not include the supernatural? The "Science as Storytelling" has helped [me] to understand others' viewpoints and to not totally disregard others' beliefs.

Although we could not measure what student responses to these questions would have been before the course, the fact that most of them cited reasons specifically articulated in the "Science as Storytelling" essay seems significant.

The pre-service elementary teachers in our course also reported that "Science as Storytelling" helped them plan how they will approach the NOS in their future classrooms, and to deal with science-religion conflict (Table 7). Those who gave reasons for their comments on future plans for teaching the NOS mainly said that the program makes the NOS (especially the idea that theories are not set in stone) more understandable, and/or that they thought it was a good way to get students thinking "out of the box." Those who gave explanations for their comments on science-religion conflict mainly said that the program helped them see how to make such things seem less troubling for themselves or their students, usually because the idea that theories are not the same as facts takes off some mental pressure. Others mentioned that they could now explain why the supernatural is kept out of science, which helped some feel better about teaching secular theories that they do not entirely agree with. Following are some representative quotations.

> Yes, because now I better understand theories and what theory is overall, so I can therefore teach that to the children.

> Yes, I now know why I hated science so much as a kid. It was because I felt constricted and like I was always supposed to be giving "the right answer" when quite often there was no "right answer"!

> I plan to emphasize that evolution is a theory and that they do not have to believe it. I will encourage them to talk to their families about the religious side of the issue, while I will present them with all the scientific evidence that favors

it. I think the conflict in the schools stems from such issues being taught as complete fact and not as a logical story, which results in very confused children. I always held the impression that it was believed by the scientific community to be absolute and unchanging, so the discussion helped me realize that I was wrong and it is just a theory, although it is one that I personally believe in.

"Yes, I think the science as storytelling approach will be very helpful to me as a teacher in my approach to presenting science. As I commented in class, I plan to present science as one explanation based on the best testable facts that we have—but I will make the distinction that the theories we teach in school are not absolute facts.

In teaching science, I will explain the scientific method and how theories are formed from following this method. Although I don't particularly agree with evolution (or at least some parts,) I still plan on teaching that and not getting too much into the religious aspects. By doing so, I will be able to present the science as based on observable, physical evidence. I think that by presenting "Science as Storytelling" to my students, they will be able to understand that although many accept theories, they are not set in stone. The students will be able to understand that different ideas can also be presented and that students can accept what "story" they think explains [things] the best.

Yes, because I did not understand as well before why religion needed to be left out of science. No one religion or belief can be proved correct, so it is not useful to bring it into the argument and it prevents further progress.

This has definitely been an issue for me as I have always felt that science and religion are intertwined. Learning from "Science as Storytelling" has helped me to understand the creation and legitimacy of theories from a completely secular perspective. I don't feel that I could answer any question without God and my religious beliefs, yet I feel that I have a much better grasp.

Yes, it has helped me define how I plan to deal with teaching the nature of science. I plan to outline it very close to the way "Science as Storytelling" does and explain everything (including religion) in very much the same manner. I think it provides a very good explanation that's logical and can be understood by a wide variety of children who carry different beliefs and opinions.

When I teach my students science I hope to be able to explain the "Science as Storytelling" method. I think kids will be less confused about science if they know that theories are theories and not facts. They will be able to use their own storytelling skills to bring God and science together, without feeling confrontation with science and religion.

Yes, the "Science as Storytelling" discussion has helped me because I will be better able to discuss with parents why or why not we are studying a certain issue. It has also helped me to better understand the nature of science.

I do like the Science as Storytelling, and it will make it easier to teach without religious aspects, and I won't be leading them astray. They would be just hearing possible stories, not telling them (the kids) that they have to believe what I say is true when it comes to the theories that go against my religious beliefs.

TABLE 7. STUDENT RESPONSES TO THE TWO OPEN-ENDED ESSAY QUESTIONS[1]

Issues, Responses, and Explanations	# Responses
(I)[2] Should scientific stories exclude the supernatural?	
(R)[3] Exclude the supernatural?	44
(R) Include the supernatural?	12
(R) Undecided	2
(E)[4] Supernatural explanations are generally not very predictive.	8
(E) It is hard to discriminate between different supernatural explanations.	1
(E) Different religions would pose different supernatural explanations.	22
(E) You can explain anything by invoking the supernatural.	2
(E) We don't know enough to predict how God would do things.	1
(E) God exists, so science will go wrong by not including him.	7
(I) Has Science as Storytelling helped you understand those who disagree with you about whether to exclude the supernatural from scientific stories?	
(R) I can understand opposing view	30
(R) I cannot understand opposing view	0
(R) *Science as Storytelling* helped.	25
(R) My view is the same as before.	1
(I) Has Science as Storytelling helped you define how you plan to teach the nature of science to your student?	
(R) It helped	46
(R) It did not help	5
(E) It seems like a good way to get students thinking more deeply.	12
(E) It makes the NOS easy to understand.	13
(E) I worry about losing authority in the classroom.	1
(I) Has Science as Storytelling helped you define how you will deal with science/religion conflicts that might arise in your classroom, or in your own mind?	
(R) It helped	21
(R) It did not help	2
(E) It helps make the conflicts seem less troubling.	10
(E) It shows why the supernatural is left out of science.	4

Notes:
[1]whether science should exclude the supernatural, and how they considered the *Science as Storytelling* program to have affected their abilities to teach the NOS and deal with science-religion conflicts
[2]four issues (I) in the question are separated in the table.
[3]categories of student responses (R) to those issues
[4]explanations (E) for the responses

> Yes, Science as Storytelling has helped me think about science differently. It helped me see more clearly that science is an attempt to explain the world around us, and should be taken neither as fact nor as complete bunk, but as what it is—an ever-changing set of stories. As I teach, I want to portray the idea that it is okay to believe what you will religiously or scientifically, but it is important to keep searching for better answers to see how it all fits together.
>
> I think it has helped, as I will be able to explain that although there is a lot of scientific evidence to go along with each theory, it is just a theory and a story. They should then be able to understand that it isn't concrete, but it does have a lot of basis in the truth.

A few students said that Science as Storytelling did not help them with these issues, either because they did not like the storytelling analogy, or they were afraid to encourage students to doubt their teachers.

> I really have not thought much about me teaching and having the science/religion conflicts. I suppose I have always just assumed that I will teach the curriculum. I think that tell[ing] young students that science is 'storytelling' could be confusing and [might] start to plant seeds of doubt in them about teachers.
>
> All I can say is that I will not teach my students that science is storytelling. I will teach them that science is not absolute truth but not that science is a story. In my own mind, I already rejected the scientific theories that go against my religion so it didn't really help me. Except now I feel like I can reject them a little easier. I haven't decided what to do yet if these issues come up in my classroom.

Once again, it is clear that there is a danger that our storytelling analogy will enable some students to reject unpopular scientific claims out of hand, but our experience has been that a much, much larger problem is the tendency of students to reject or resist scientific claims because they think they are being presented as absolute truth.

Implementation in Other Settings

We have provided evidence that our choice of metaphor—calling science a kind of "storytelling"—had a positive effect on many of our students, even though the extent of the treatment was minimal. This makes the program ideal, in our opinion, for adoption or adaptation in all sorts of introductory science classes. When we circulated the *Science as Storytelling* essay among a number of colleagues, two of them actually used it in their own courses, and reported excellent results.

Ann Bykerk-Kauffman is Associate Professor of Geology and Environmental Sciences at the California State University at Chico. For a number of years, she has taught an introductory geology course for non-science majors, but until recently she did not include a unit on evolutionary theory. She felt a little guilty about this, so she prepared a lecture on the subject. She described her experiences teaching this unit before and after including the *Science as Storytelling* approach on the SERC website (http://serc.carleton.edu/NAGTWorkshops/affective/workshop07/participants/16256.html).

> "I thought I had a clever way to deal with the topic and proceeded to build the lecture that way. My gimmick was this: I admitted that 'If there is an all-powerful supreme being, s/he can do whatever s/he wants and scientists can never disprove it.' I said that it was perfectly possible that some supernatural being had really created the universe in one week, 6000 years ago, but that s/he created it with a huge built-in body of amazingly consistent evidence for a very specific and very ancient history. And so s/he must have, for some reason, wanted us to discover and interpret that evidence and to reconstruct that ancient history. I then talked a bit about the scientific method and stated that biological evolution is the only scientifically valid theory for the origin of species. I quoted Phillip Johnson's (1991) book that launched the 'Intelligent Design' movement, 'This isn't really, and never has been, a debate about science. It's about religion and philosophy.'
>
> "With this (I thought) clever and disarming preamble, I proceeded to describe Darwin's theory of natural selection, using material from the excellent 'Understanding Evolution' web site at UC Berkeley. I presented a bit of evidence, stated that there are mountains more of it, and went over some common misconceptions. I delivered this lecture with some humor, illustrating it with cartoons. I thought I did a great job and so I presented the lecture much the same way the next semester.
>
> "But then I noticed that, on the course evaluations, a number of students specifically mentioned this lecture. They complained that it was 'sarcastic,' and in bad taste. Their perception was that I was making fun of them. Some said I shouldn't be teaching this material at all. I was stunned.
>
> "The next semester, with some trepidation, I put the topic of evolution on the syllabus again. I had no idea what I would do differently this time. But then, just a week before the lecture, I attended an excellent GSA talk by Barry Bickmore entitled Science as 'storytelling' for teaching the nature of science to preservice teachers…. I based the preamble to my lecture on Barry's talk and the essay he graciously provided… which presented seven 'rules for scientific storytelling,' including the rule that 'scientific explanations do not appeal to the supernatural' and why scientists follow this rule even when they themselves believe in the supernatural. After describing these rules, I again presented the material from the UC Berkeley web site. This time, students were able to take in the material. Several specifically told me how much they enjoyed the lecture. The theory of evolution finally made sense to them."

Note that Professor Bykerk-Kauffman did not even have the students read our essay—she just covered the main points in the preamble to a single lecture. And yet, it still made a noticeable difference in how her students accepted her presentation of evolutionary theory.

Stephanie Burdett is the Biology 100 coordinator at Brigham Young University, where most of the ~30,000 undergraduates are required to take this course. She was redesigning the course, and asked the staff of the BYU Center for Teaching and Learning for help finding good resources for teaching the NOS. The center referred her to us, and we gave her the *Science as Storytelling* essay.

Stephanie's goal for the course was to bring the students to a point where they could apply biological knowledge to make rational decisions about public policy issues and personal beliefs. But she found that most of the students were totally unprepared for this kind of thinking. They could memorize and regurgitate "facts," but when confronted with a question like, "Should Intelligent Design be taught in public schools?" many of them responded with comments like, "Well, scientists are atheists."

She decided that she had to 1) teach the students some critical thinking skills, and 2) find some way to help them get past their perceptions of science-religion conflict so they could participate in rational conversations about hot-button topics. She began by having the students read the Science as Storytelling essay, taking a couple lecture periods to help them pick apart and analyze the written argument. Stephanie finished off her discussion of the NOS using a classic "Black Box" experiment (Lederman and Abd-El-Khalick, 1998). Throughout the semester, she also had them read and analyze other articles about the controversy over Intelligent Design, environmental issues, stem-cell research, and so on. She continually referred the students back to the Science as Storytelling article for context.

Stephanie reports that her experience using Science as Storytelling "has been great," because it is very successful at helping her students understand the value and limitations of science. She says that this is "an epiphany" for many of them, and "they may not buy into evolution… but they're not screaming about it, and they're not telling me I have cloven hooves and horns…. They're [saying,] 'Ok, I see why science is saying what it's saying. I don't necessarily agree, but I can talk about it in a rational manner….'"

While the vast majority of her students loved the Science as Storytelling approach, it received some resistance from unexpected quarters—two pre-Nursing majors and her teaching assistants, who were mainly pre-professional students, as well. These students complained that they "thought were going to learn about biology," instead of learning the NOS and associated critical thinking skills. The TAs were worried that the students would miss out on some of the "cool stuff in biology" if they spent so much time on these other issues. Stephanie's impression was that these particular students were used to learning as memorization and regurgitation, as if the purpose of their courses were to help them prepare for the MCAT, or some similar exam. When she got fed up with the complaints from her TAs, she asked them to solve a short problem that is sometimes given to students in their first year of medical school. The exercise only required the use of basic biological principles, but the TAs could not solve it. "And that just shut them right up," Stephanie reports. "And so [now], I'm getting a lot more support."

CONCLUSIONS

Our implementation of the "Science as Storytelling" program seems to have been generally successful at helping our students to understand that science has creative and tentative aspects, and many reported adopting more irenic attitudes about science-religion conflict. Although our instructional setting was atypical in some ways—e.g., essentially all of our students were conservatively religious—the experience of a colleague at a secular university seems to indicate that our approach is applicable to other settings.

Our experience challenges several notions common among scientists and science educators. 1) Our conservative religious students reported being much more prone to reject theories that contradicted their beliefs because of naïve realist preconceptions or the perception that their teachers held such views, than because they thought of theories as "hunches" or "guesses." 2) Our students, in general, responded very positively to a rendition of the NOS that was designed to confront naïve realist preconceptions. Although there were a few exceptions, the fear that such a course would make students more dismissive of science proved largely unfounded. 3) We found that students do not need to get past the idea that science and religion sometimes conflict, provided they have been disabused of their naïve realist preconceptions. Many students reported that they found science much less threatening once they realized that theories are not meant to be absolute truths. Since science and religious beliefs do, in fact, sometimes conflict, we consider it preferable to tell the truth about the matter.

A key point to note about the program is that significant progress was made in students' conceptions and attitudes, even though the intervention was fairly minimal. This makes "Science as Storytelling" an excellent choice for instructors worried about displacing too much science content by teaching the NOS. But in addition, we believe that the program provides a clear enough framework for understanding scientific thought that it can be used to scaffold much more radical course redesign.

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