Toward a Better Biology Experience: The Impact of Implicit Instruction in the Nature of Science in an Undergraduate Biology Survey Course

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Abstract

Biology 101 is an introductory survey course for non-majors. The original instructional model of the course included lecture sessions focused primarily on content knowledge and laboratory activities that were designed to demonstrate and reinforce that knowledge. Any instruction regarding the Nature of Science was implicit and students did not have opportunities to engage in scientific practice. Survey data shows that students participating in this course framework did not significantly increase their NOS understanding beyond gaining some understanding about hypothesis testing and theory development, and their feelings about the personal relevance of biology class to them became increasingly negative. Revisions to the course laboratory experience to increase hands-on and locally relevant activities did improve students' attitudes about attending lab, but NOS understanding and personal attitudes did not improve compared to the attitudes of students taking unrevised labs.

Introduction

What constitutes a necessary foundation in science? It is a question that those of us who teach introductory science courses frequently ask ourselves. Ryder et al (1999) describe both knowledge in science, which are the contents or facts of science that comprise traditional undergraduate curricula in introductory courses as well as knowledge about the nature of science (NOS), which is the way that scientists "develop and use scientific knowledge" (Ryder et al 1999, p. 201). Historically, science education has focused primarily on knowledge in science but education researchers and government agencies have, in the past few decades emphasized the importance of NOS knowledge (AAAS 1989; AAAS 2010; NSTA 2000; NRC 1996). Such knowledge is widely considered critical to the ability to scientific thinking and knowledge to problems that arise in daily life. As most people in public surveys are not able to effectively answer questions about scientific issues (Laugksch, 2000), it seems clear that currently NOS knowledge is not in evidence in the general public. While a college or university experience might seem the best way to address these shortcomings, the recently published results of a 20-year survey of science knowledge and attitudes among undergraduates taking a general survey course in astronomy demonstrated “no detectable improvement in undergraduate scientific literacy” (Impey et al, 2011, p. 31).

While there is a sense is that all students would benefit from learning both the content and nature of science, research has focused more extensively on such activities at the K-12 level (Karakas, 2009; Nelson et al., 2010). Generally, findings have determined that K-12 students benefit from instruction in NOS, and that such instruction is more successful when it explicitly points out how scientific knowledge is generated and used. Student understanding of NOS tends to be contextual and grounded within the content or task being conveyed. Finally, NOS is best implemented through constructivist, inquiry-driven experiences that allow students to build their own knowledge through genuine long-term experience with authentic scientific investigations. These ideas are the foundation for recent recommendations by the American Association for the Advancement of Science regarding teaching biology to undergraduate students (AAAS, 2011).

Activities that give students NOS experience are more common amongst upper division and graduate science courses in college settings, but traditional science teaching at the undergraduate nonmajors level tends to focus on large survey courses of lots of knowledge. But aren’t these the students in greatest need of better understanding of NOS? Can they get NOS from exposure through content and descriptions of how content has been gained? That is, can they understand how research proceeds without participating in primary research themselves? Certainly laboratory activities are an important- perhaps even essential- part of science instruction in introductory science courses for undergraduates (Nelson et al., 2010). But participation in pre-planned or step-by-step lab activities is not the same as engagement in the authentic practice of science (Windschitl et al., 2007).

The idea that students will gain knowledge about NOS if they are engaged in the study of science at all, almost as if by osmosis, is common amongst instructors (MacDonald, 1996; Abd-El-Khalick et al., 1998; Crawford et al., 1999; Ryder & Leach, 1999; Moss et al., 2001). Research at the K-12 level indicates that students can better gain conceptions about NOS if ideas are explicitly communicated to them (Moss et al., 2001). However, such instruction takes time, and at the college level many instructors are particularly reluctant to sacrifice time needed to cover a broad range of content. The hope is that students may still gain ideas about the nature of science and understand the practice of science if they are exposed to content that emphasizes these practices (for example, the story of the discovery of penicillin by Fleming, or the painstaking work of Gregor Mendel).

It is important to recognize that even laboratory based courses, which are essential components of many College's and Universities' general education or liberal arts core requirements, may not explicitly expose students to the Nature of Science (NOS), although such exposure is in part the rationale for their inclusions in general education. Laboratory activities in introductory level courses are often focused on step-by-step procedures that demonstrate forgone conclusions (e.g. counting corn kernels to demonstrate independent assortment and segregation) or activities that expose students to the use of basic equipment (microscopy) or provide opportunities to examine specimens that illustrate points or principles covered in the course. None of these activities, which are standards in undergraduate science laboratories, wholly represent the full practice of, and thus the nature of, science (Windschitl et al., 2007).

The questions then, when considering how to teach science to college students, particularly in courses designed for nonmajors, are these: Is some exposure better than none? Can students gain NOS knowledge if it is not explicitly taught to them? If students are not themselves immersed in the full practice of science, can they still gain some understanding about NOS by learning about how the content covered in class was discovered or by reading or hearing about scientific process in their lecture courses? Does implicit instruction in NOS through regular course content result in gains in NOS understanding by undergraduate nonmajors?

To answer this question, we examined the responses of students to questions about NOS and personal attitudes about biology and science in a large introductory survey course. Biology 101 (Bi 101) is a 5-credit laboratory course that is included as an option within the Liberal Arts Core Curriculum offered at Western Oregon University (WOU). This course is content-focused and consists of three hours of lecture and two hours of lab per week. Course content focuses on evolution, ecology, and biodiversity. Initial course laboratory activities were primarily instructor-directed. One laboratory activity emphasized the process of developing a model based on hypothesis testing, but the remaining lab activities included two computer simulations (one lab on population genetics and evolution and the other on ecosystem dynamics) two paper-based simulations (one lab on classification and the other on food webs) and two on a project that engaged students in library research to examine the ecological impacts of human behaviors on an isolated tropical Pacific atoll. Only one laboratory involved any direct hands-on activity with scientific equipment and organisms; this microscope lab required students to observe and describe pond microorganisms, which were later used to build the paper food-web simulation. Students did not conduct any experiments or develop any investigations based on their own questions. All laboratory activities focused on the reinforcement of course content through demonstration. The focus of these activities was essentially on content rather than process, although process was described both within the lecture and the laboratory activities.

Methods

Initial Course Evaluation. I conducted a survey of students in the course for both content and skills knowledge using the online data collection program *Survey Monkey*™. All students participating in a Biology 101 course were asked to complete pre- and post- course surveys. Both pre and post surveys include a code number, demographic questions, attitude questions, and a concept inventory. I included demographic questions about the student's year in school, previous experience with college-level biology, and whether they identified as a first-generation college student. I based on the attitude questions on the Foundationally Approaches to Science Teaching survey of scientific indicators (© University of Hawaii). These questions were pilot-tested and edited based on an item-analysis that revealed correlations between items. Each item required students to respond to each statement using a 5-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = unsure, 4 = agree, 5 = strongly agree). For the initial data collection, I surveyed eight course sections taught by six instructors over three terms. For this study of student attitudes about science and knowledge about the nature of science I focused on student demographics and responses to attitude questions. Concept inventories were not analyzed for use in this study.

I divided the attitudinal survey items into two broad categories (listed in Figures 2 and 3). The first set of questions related to knowledge and understanding about NOS. These were statements about scientist attributes and scientific practice. The second set of attitude questions was specific to students' personal attitudes toward science. These statements related to personal feelings about science or about biology class or ability to use scientific information or practices.

I was able to pair student responses using the code numbers on each survey, and analyzed data for students who completed both a pre- and post- survey for control-comparison purposes. I compared student responses to each attitude question before and after taking Bi 101 using paired t-tests. I used MANOVA to examine the impact of different demographic indicators (year in school, previous laboratory science, first-generation status, English-language proficiency, and gender) upon attitudinal changes.

Impact of Laboratory Revisions. Following the initial data collection, revisions were made to laboratory activities. These revisions were based partially upon suggestions made by students on their post-course laboratory surveys. The first round of laboratory revisions (Fall 2010 term) retained the library-research emphasis of the course project but shifted the focus to a more local issue (salmon population decline in the Pacific Northwest). The two and two pencil-paper labs were also modified to become more hands-on. For example, a laboratory using simulated "cartoon" organisms to prepare a phylogenetic tree was modified to use living plant specimens to prepare a data matrix from which to develop a tree. The second round of laboratory revisions (Spring 2011 term) eliminated the course project entirely – although all labs connected in some way to the theme of salmon decline – and introduced two new hands-on labs in place of the project. One of the new labs focused on testing water quality and the other on simulating fish population changes based on harvest practices.

Students participating in the revised laboratory activities (six course sections taught by three instructors) completed the same surveys as students in the initial course data collection. For all groups of students I calculated the amount of attitudinal change between pre- and post- surveys. To examine the impact of including more thematic, hands-on laboratory activities on student attitudes, I used unpaired t-tests to compare these pre-post changes in attitudes in the original group of students to those of the students who took part in the revised labs. I also used unpaired t-tests to examine changes in student responses to questions about the usefulness and effectiveness of laboratory activities following each revision to determine how students were explicitly responding to the laboratories and the changes made each term.

Results

Student Demographics. In the initial data collection period, approximately 90% of the students enrolled in each section completed surveys. About 10% of students completing surveys completed only a pre- or a post- survey. Thus, the total pre- post- survey return rate was 81%. Figure 1 outlines the demographics of the course represented by this group of students. Biology 101 is primarily populated with freshmen (47%) and sophomores (33%). The course is representative of the larger WOU population with 57% of students identifying themselves as first generation college students. The majority of the students surveyed (91%) did not have any previous experience with college-level biology. Just under 10% of students identified as non-native speakers of English.

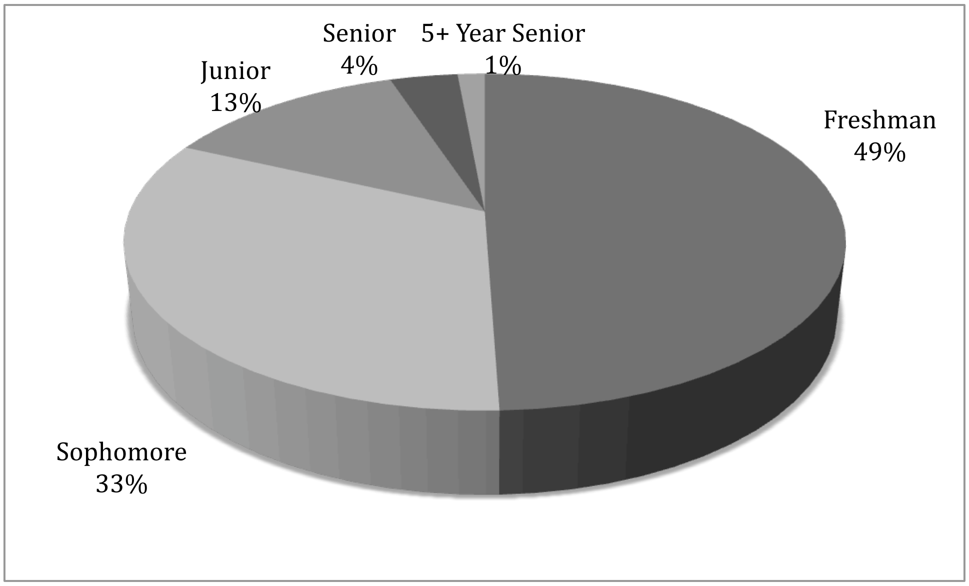

Figure 1A: Percentage of students taking Bi 100 at each class level. n = 278.

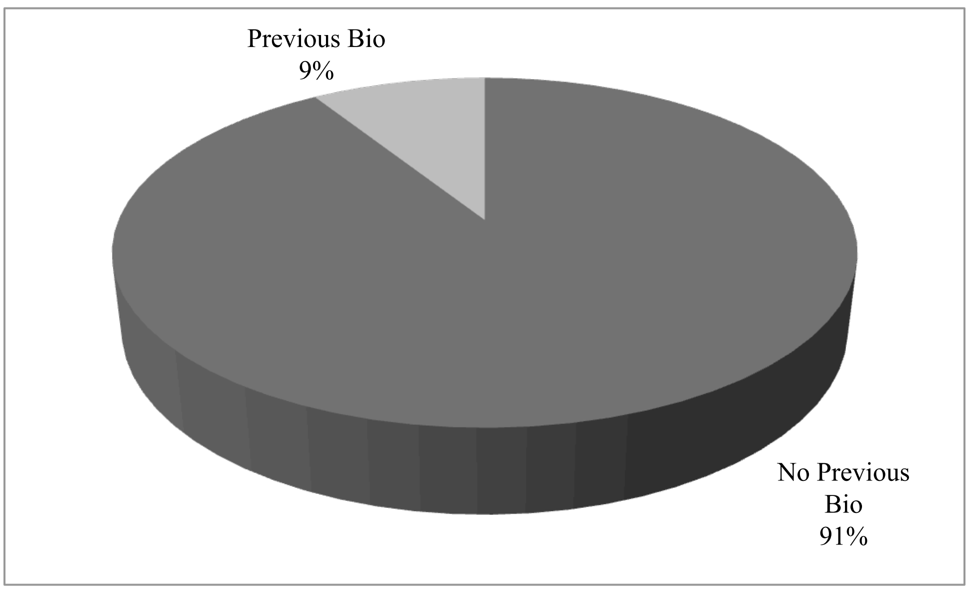

Figure 1B: Percentage of students taking Bi 100 with previous college-level Biology experience. n = 278.

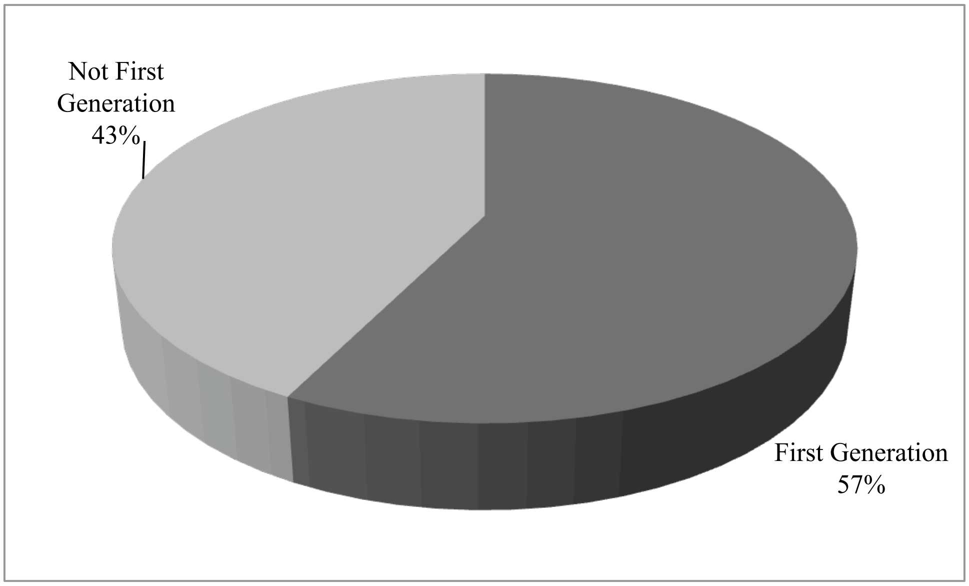

Figure 1C: Percentage of students taking Bi 101 who are first generation college students. n = 278.

Initial Student Attitudes. Generally, students showed little significant change to their NOS knowledge (Figure 2). Significant positive changes were indicated in response to the statements: “Scientists are just like everyone else” (df = 259, t = 2.072, p = 0.0048), “Scientists work alone” (df = 259, t = 2.072, p = 0.0393), and “Science is the search for the best-supported answer” (df = 257, t = 3.172, p = 0.0017). Significant negative changes were indicated in response to the statements “Scientists can prove hypotheses” (df = 259, t = 6.430, p $\leq$ 0.0001) and “A theory is a best guess or predication of what will happen” (df = 257, t = 7.8111, p $\leq$ 0.0001). Other statements did indicate slight changes, but these were not significant.

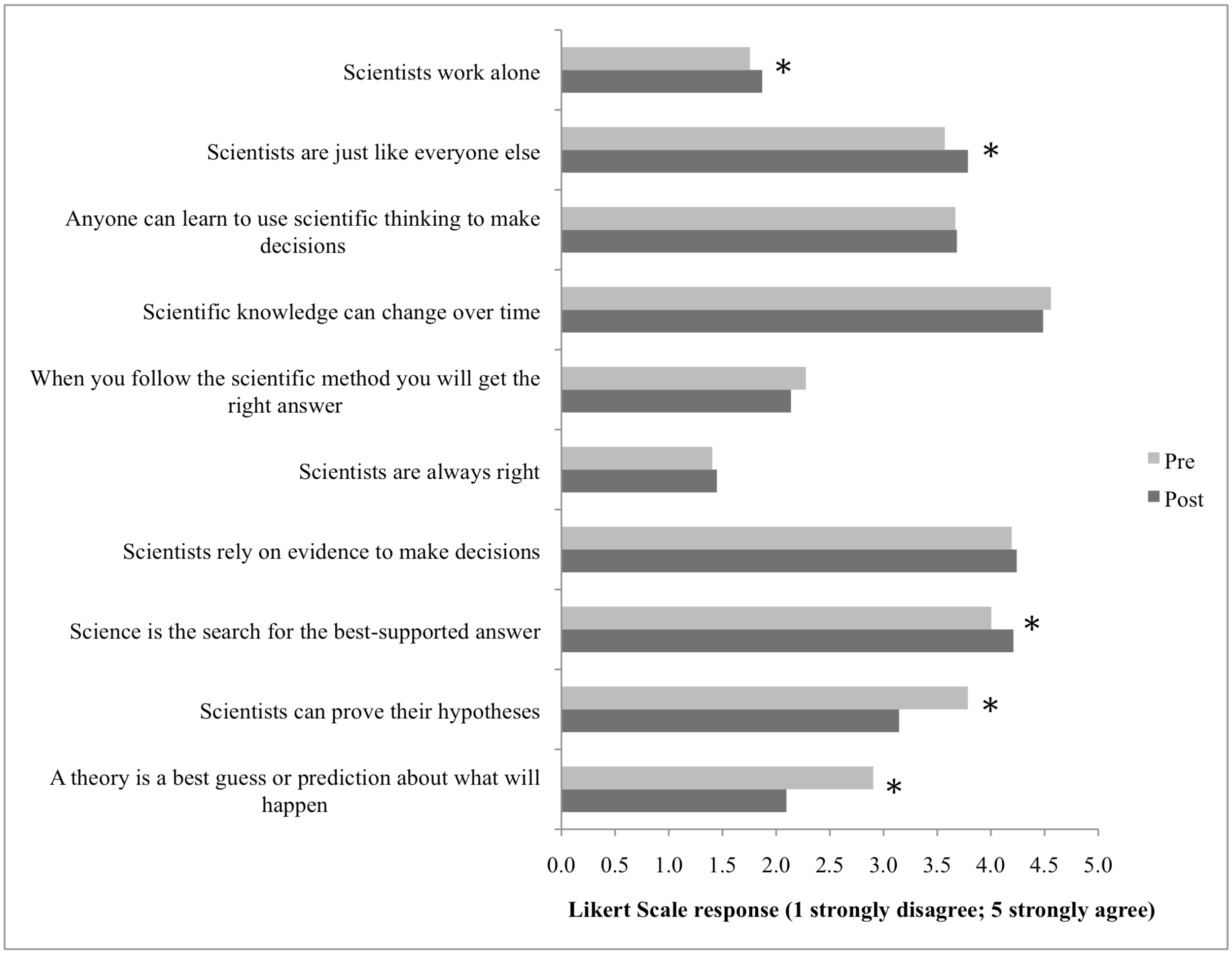

Figure 2: Student attitude response to Nature of Science statements. n = 277; * indicates significance.

Students' personal attitudes about science were primarily negative (Figure 3). Significant increases were indicated in response to the statements "I do not feel like I have anything to contribute to class (df = 257, t = 2.559, p = 0.0111) and "Science is boring" (df = 257, t = 2.242, p = 0.0258). There was a significant decrease in response to the statement "I can use what I learned in biology class in my daily life (df = 258, t = 1.987, p = 0.0479). The remaining attitude statements did not change significantly, but the overall changes were primarily an increase in negative attitudes about biology and science. Students did indicate that they did gain more sense that they were learning in class was important, but they also increasingly felt that science made them uncomfortable and that attending class made them uneasy and confused. None of the demographic indicators had a consistent statistically significant impact upon student attitudes about NOS or the personal relevance of biology class.

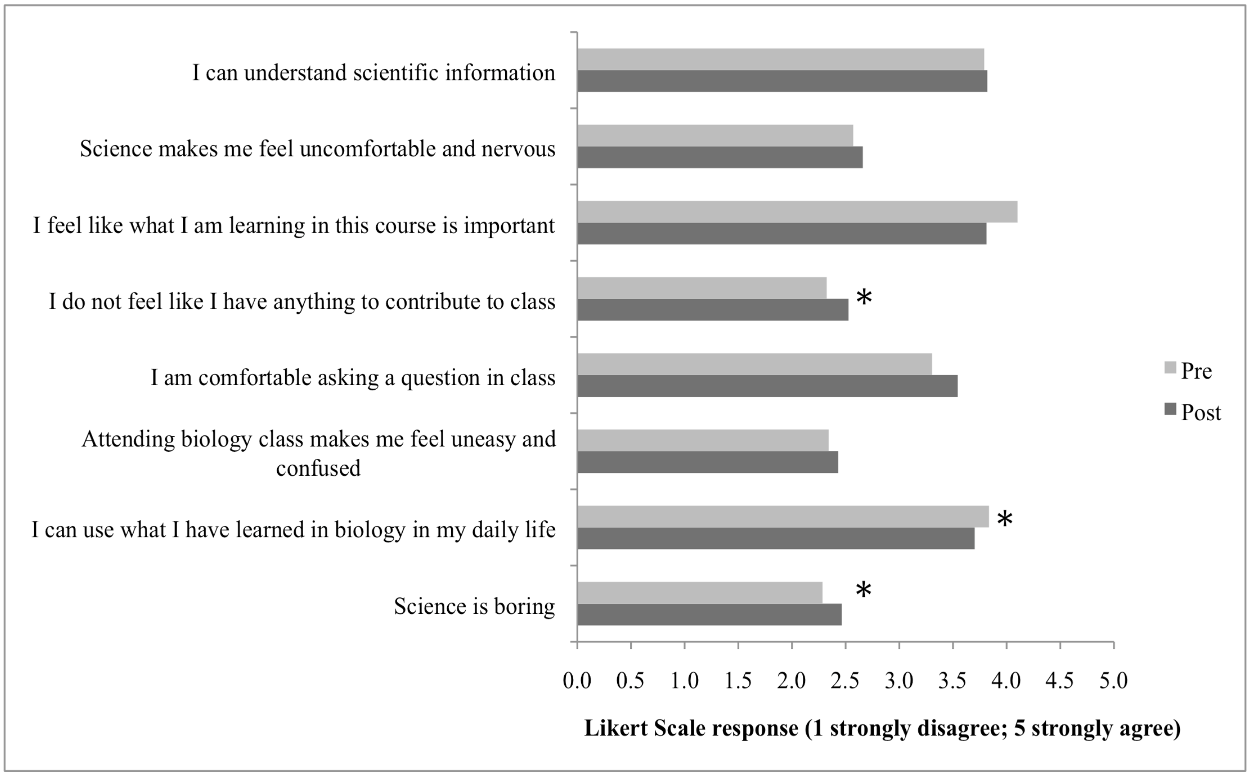

Figure 3: Student response to statements about personal attitudes science and biology class. n = 277; * indicates significance.

Impact of Laboratory Revisions. Following laboratory revisions intended to address some of the shortcomings identified in the initial evaluation, student attitudes did not show significant changes compared to unrevised laboratories. Regarding NOS, students experiencing the revised laboratories only showed significant differences in response to the statements "Scientists can prove their hypotheses" (t=2.888, df=286, p = 0.0049), and "Scientific knowledge can change over time" (t=2.508, df=367, p = 0.0265) (Figure 4). Interestingly, the response to the hypothesis statement showed improvement in students taking the revised laboratories, while the statement about changing scientific knowledge showed a decline in appropriate attitude. Students did not show any significant changes in their personal attitudes when taking revised laboratories (Figure 5). Students did indicate that they felt the laboratory revisions did improve their overall course experience (Figure 6). Improvements were significant when comparing the unrevised labs to all revised labs regarding the statements "I felt like each lab prepared me for the next lab" (t=2.141, df= 278, p=0.0427), "Participating in lab helped me understand the lecture material" (t =1.962, df=264, p =0.0497), and "Participating in lab was a valuable use of my time" (t = 2.592, df = 267, p = 0.0118).

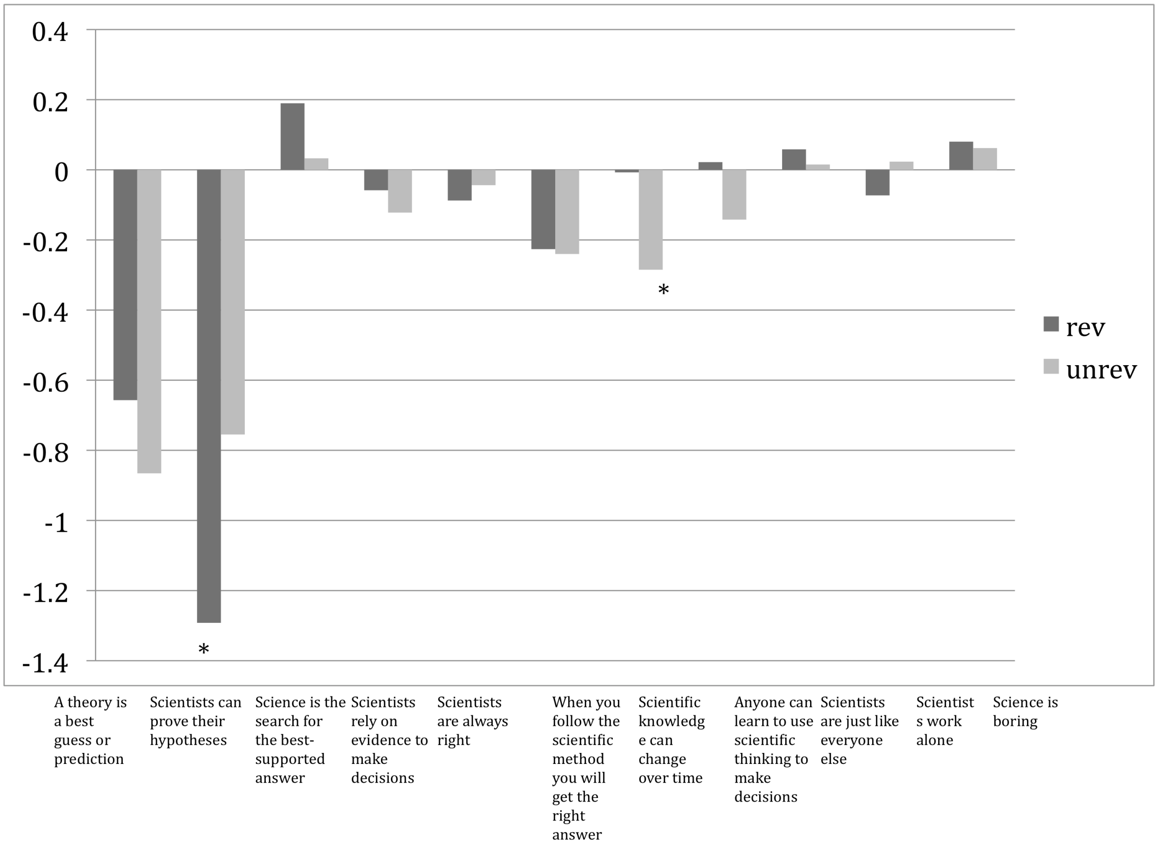

Figure 4. Comparison of pre-post attitudinal change about Nature of Science by students taking revised and unrevised laboratory courses. n = 414. * indicates significant differences.

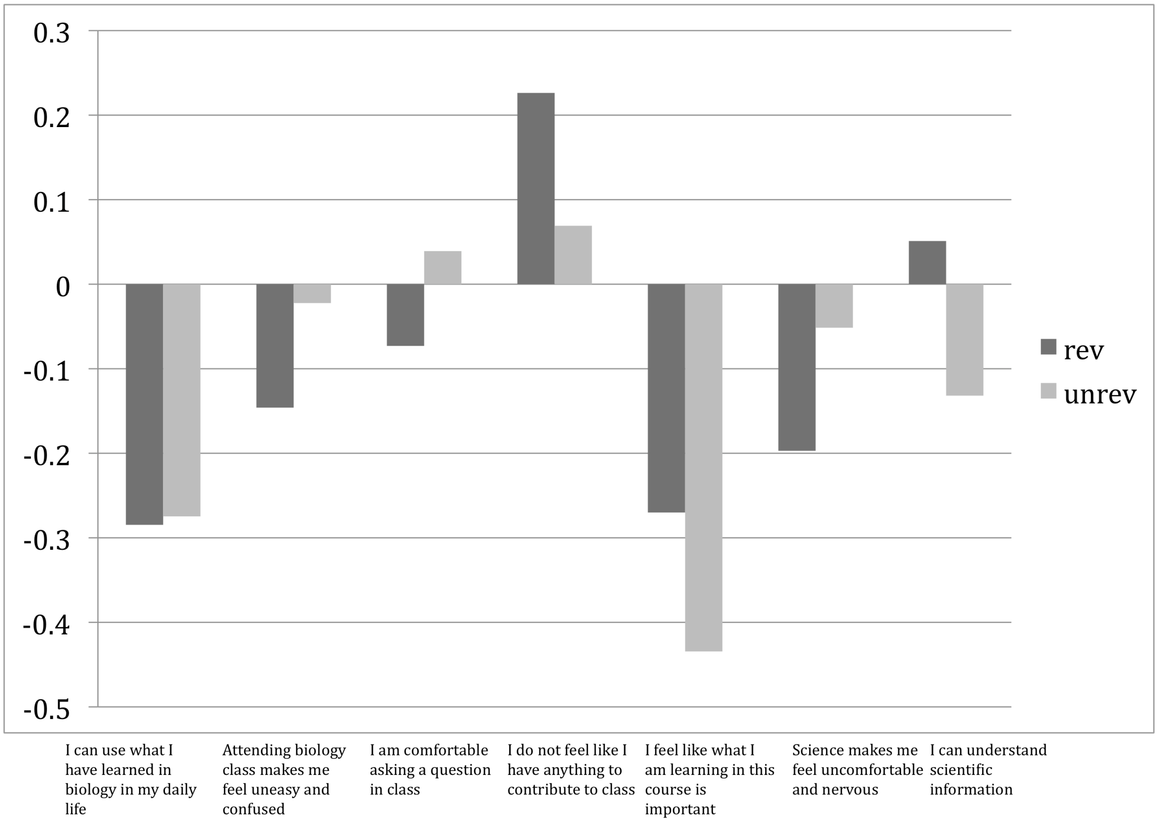

Figure 5. Comparison of pre-post attitudinal change regarding personal feelings about science and biology class by students taking revised and unrevised laboratory courses. n = 414.

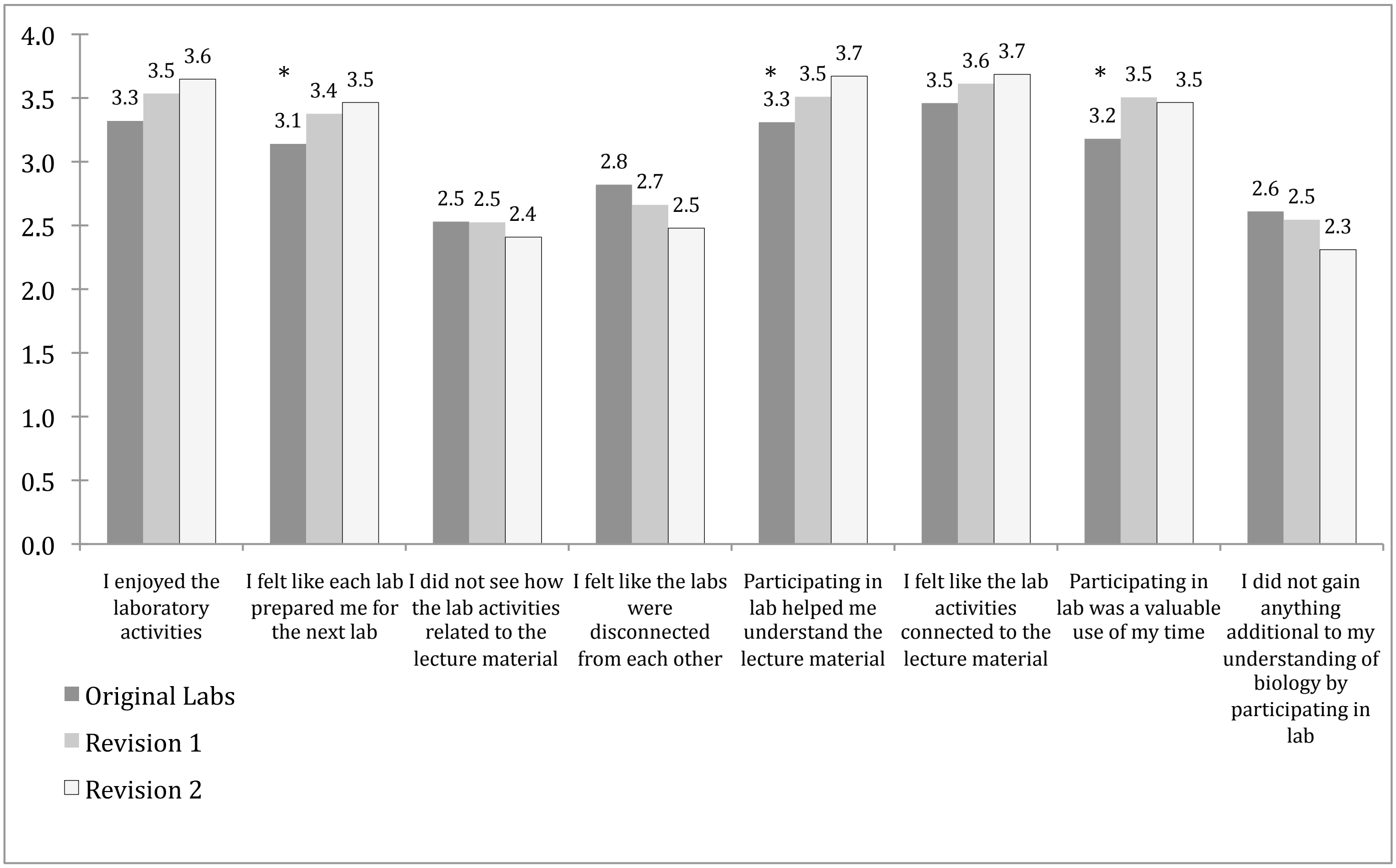

Figure 6. Comparison of student responses about specific laboratory experience in original labs, first round and second round of revisions to labs. n = 490. * indicates a significant difference between original labs and other labs.

Discussion

Initial Student Attitudes. Following the initial instruction, which primarily focused on implicit communications about the nature of science, students gained minimal basic NOS knowledge. One of these ideas is what a scientific theory really represents. As the understanding of scientific theories as cohesive, well-supported explanations is related to concepts like evolutionary theory as the best-supported explanation of the diversity of life on earth, this would seem to be a positive result. Students also gained some understanding of how hypotheses are tested in the search for the best-supported answer, and of the corollary idea that hypotheses cannot be proven. This gain in understanding about NOS could be helpful as common misconceptions about science are that it is about non-changing "facts" and that a "failure" to prove a hypothesis or theory means that there is something wrong with that hypothesis or theory.

Although not significant, students also increased some misconceptions about NOS. They maintained and even increased their notions that scientists are always "right" and decreased their idea that scientific knowledge can change over time. Students also seemed to hold some conflicting ideas about scientists.

They did significantly increase the idea that scientists are just like everyone else, but also that scientists work alone. They did not gain in their understanding of science as a collaborative process and that scientists often work with other scientists to answer questions or solve problems.

The personal attitudes of students toward science were even more discouraging. Students did not significantly gain any positive attitudes about biology class or science. In most cases student attitudes became more negative and the only *significant* changes to student attitudes were those that became negative. Students did not recognize any personal relevance of biology, indicated by their increasing response to statements that they did not have anything to contribute to class and that they did not feel like they could use what they were learning in their own lives. Further, this lack of relevance is demonstrated by the boring nature of biology class identified by students. As one of the major goals of the course is to help nonmajors recognize the importance of biology to them as humans and as citizens, these results require special attention in decisions made about course content. Clearly some course content is – to students' perceptions – divorced from their daily experiences.

Impact of Laboratory Revisions. The initial course survey results provided impetus for revisions to increase the relevance of the course to students. Laboratory revisions focused more on local problems. For example, the original thematic focus of the laboratory activities on a small tropical Pacific island was revised to focus on diminishing salmon runs in the Columbia River Basin. Laboratory revisions also attempted to provide more direct experience with actual problems and tools used by scientists and to provide increased opportunities for students to engage in hypothesis testing as a mechanism to improve self-efficacy and recognition that such scientific thinking can be used to solve a variety of problems and answer personal questions.

The original question under investigation was whether or not implicit instruction could increase student NOS knowledge. While some aspects of this knowledge did demonstrably increase, it certainly appears that students did not gain much NOS knowledge and more alarmingly, that this introductory course reinforced and increased negative attitudes about science. As positive attitudes and self-efficacy are essential elements of scientific literacy, the implicit instruction initially used in this survey course has failed. Unfortunately, the revisions made to the laboratory activities still fell short in building the desired improvements in student attitudes about NOS and about personal connections to biology. Thus, the need for more explicit instruction means that future iterations of Biology 101 must provide students with opportunities to use scientific thinking and that these skills be clearly identified to them with opportunity for practice.

So where do we go next? It is encouraging that students have reported finding each iteration of the revised laboratories to be more enjoyable and valuable to their experience in Biology. However, the impact of these laboratory revisions has yet to become apparent in their ability to improve student attitudes about NOS and about the personal relevance of science and biology. While the increasing amount of hands-on activities provided a good start to improving the course experience for students, the revisions need to go further. The goal for the next series of laboratory revisions is to increase the amount of student-driven investigations, including more opportunities for hypothesis formation and testing and data interpretation. Moreover, as students spend significantly more time in their lecture sections (assuming they attend class regularly) than they do in laboratory, the inquiry-based instruction needs to infiltrate the lecture sections as well. Our team of instructors recently finished a two-day workshop in which we worked to align the lecture and laboratory activities to the recommendations contained in AAAS Vision and Change in Undergraduate Biology. These alignments include reducing content in favor of contextual activities that emphasize the process and practices of science and an increasing use of active learning activities in class, including use of audience response systems (or “clickers”), student discussions and analysis of case studies. Given that none of the demographic indicators recorded had a consistent influence on student attitudes, it seems reasonable to assume that all students would benefit from improvements to course delivery. By coupling these efforts with continued collection of student survey data, we hope to continue to make data-driven decisions to effectively improve the experience of undergraduate non-majors taking biology at WOU.

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