

# Student Understanding of Scientific Hypotheses, Theories & Laws: Exploring the influence of a non-majors college introductory Biology course

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## *Abstract*

Although an important part of scientific literacy, most students hold misconceptions regarding the nature of science (NOS). We investigated the influence of a non-majors' introductory biology course on college students' understanding of NOS in the context of instructor's NOS conceptions and instructional practices. Five instructors and 287 students were administered Views on Science-Technology-Society (VOSTS) questionnaire. Students took VOSTS as pre-post test. All instructors and selected students were interviewed to corroborate VOSTS responses. Selected class sessions of all instructors were video recorded and transcribed to document instructional styles and communication of NOS. Results indicate that in some areas of NOS the course impacted the students negatively, in others there was no impact, while in still others the impact varied by instructor. Whether negative or positive, several instances indicate that the course did impact student understanding. Here, we focus on change in student understanding with regard to the relationships and distinctions between scientific hypotheses, theories and laws.

**Key words:** College science instruction; introductory biology; nature of science; non-majors biology; student perceptions of the nature of science

## Introduction

Several authors and documents addressing desirable elements of K-16 science education have been contending that education in the sciences ought to result in more than rote memory of scientific facts and practice of a few scientific processes such as observing, measuring, and using the microscope (American Association for the Advancement of Science [AAAS], 1994; George et al, 1996; Halyard, 1993; National Research Council, 1996; Slaughter, 1993). A key goal of science education over the last quarter of a century has been the development of ‘scientific literacy’. While the term ‘scientific literacy’ is construed differently by different scientists and science educators, its characterization provided by the AAAS (1994) forms the framework for our study. According to AAAS (1994, p. *xiv*), “The life-enhancing potential of science and technology cannot be realized unless the public in general comes to understand science, mathematics, and technology and to acquire scientific habits of mind.” Coming to understand science, according to AAAS (1994), involves understanding the nature of science (NOS), which it describes under three components—the scientific world view, scientific methods of inquiry, and the nature of the scientific enterprise. A certain level of understanding of these three components is a “requisite for scientific literacy” (AAAS, 1994, p. 1). Specific recommendations to help foster appropriate understanding of the nature of science has been in place since the early 1990s (National Research Council, 1996; National Science Teachers Association, 1992-93; George et al, 1996). It can, therefore, be argued that science education reform efforts toward the end of the last century placed a heavy premium on fostering appropriate understanding of NOS in K-16 science education.

### *The Need to Focus on Student Understanding of the Nature Of Science (NOS)*

It is impossible to deny the importance of science-related issues in modern society. Stem cell research, alternate energy resources, cloning, global warming, avian flu, genetically modified foods, and the rising number of obese people in the United States have all been discussed in the media during the recent past. The decisions and choices made regarding these issues have global influence on economy, policy formulation, the environment, and health. These policy decisions are usually made by politicians who must weigh the pros and cons of their choices based on the specific positions of their constituents. The average politician and citizen are not scientists, yet they must make choices and influence decisions that require some knowledge of science. We will use the term ‘scientific literacy’ to refer to the ability of laypersons to evaluate science-related issues and draw scientifically informed conclusions about them (DeBoer, 2000; Driver et al., 1996; Laugksch, 2000; Shen, 1975), which includes an adequate understanding of NOS as a major component (AAAS, 1994; NRC, 1996; Lederman, 1999).

### *What is NOS?*

When speaking about NOS we are referring to the ideas people hold about science as opposed to their knowledge in science (Ryder, Leach, & Driver, 1999). There are nine core components of NOS that all Americans should understand (McComas, 2004): (1) science demands and relies on empirical evidence; (2) in spite of commonalities there is no single step-by-step scientific method by which all science is done; (3) scientific knowledge is tentative but durable; (4) laws and theories are related but distinct kinds of scientific knowledge; (5) science is a highly creative endeavor; (6) science has a subjective element; (7) science is a complex social activity; (8) science and technology impact each other, but they are not the same; and (9) science cannot provide complete answers to all questions. Like science, the nature of science is not static, as current scientific thought is different than that of 20-30 years ago (Kimball, 1967-1968; Matthews, 1994). These core components of NOS represent a contemporary view of science as opposed to the traditional view that had been

taught in schools prior to the 1960s and continues to be taught in many places (Munby, 1976; Ryan & Aikenhead, 1992). The traditional view of science promotes a mechanistic nature of science, which stemmed from logical positivism and empiricist philosophy (Duschl, 1988). Although agreement in philosophy is rare, there are a few key elements which characterize the traditional view: (1) scientific claims are objective because the theories and laws used to make such claims are based on empirical observation; (2) the testing of hypotheses is controlled by a logical, established scientific method; and (3) science progresses linearly with the ultimate goal of finding a comprehensive theory. This traditional view stands in stark contrast to the contemporary view and espouses the belief that science achieves truth and only human limitations prohibit absolute understanding and predictability (McErlean, 2000).

#### *How Well Do Students Understand NOS?*

Although the teaching of NOS components has been in place for over forty years, most students continue to have misconceptions about NOS (Abd-El-Khalick & Lederman, 2000a; Clough, 2006; Edmondson & Novak, 1993; Lederman, 1992). As a result, the general populace does not possess a contemporary view of the nature of science and we continue to have debates regarding inclusion of nonscientific views (such as Creationism, Intelligent Design, etc.) of the origin and development of biological phenomena within our biology curricula.

While students do see the tentativeness in science, confusion between the everyday use of theory and scientific theory has led students to reject scientific theories as tentative guesses, especially if they conflict with their religious beliefs (Dagher & Boujaode, 2005; Meyling, 1997) or cultural heritage. In addition, misconceptions regarding theory exist because students view the development of scientific knowledge as hierarchal: A hypothesis with proof becomes a theory, which in turn becomes a law with additional proof (Blanco & Niaz, 1997; Dagher et al., 2004; Edmondson & Novak, 1993; Meyling, 1997). Instead of viewing theories as explanations based on evidence, students view theories as having insufficient evidence to be totally proven, therefore lacking the validity of a law which students believe are based on facts (Brickhouse et al., 2000; Ryan & Aikenhead, 1992). The conception that laws are the only truly reliable scientific knowledge because they never change emphasizes students' need for absolute truths in science. This has negative consequences not only for learning science, but also for their ability to deal with socio-scientific issues in life (Edmondson & Novak, 1993; Marra & Palmer, 2005; Zeidler et al., 2002).

Considering that the theory of evolution is a unifying theme in biology and "nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973), student misconceptions about the nature of scientific knowledge can negatively affect a student's ability to understand science, particularly the theory of evolution. Songer & Linn (1991) found that a static, unchanging view of science leads students to believe that scientists simply add facts to a body of knowledge as opposed to deliberating between different viewpoints. Students with a static view of science are more likely to memorize facts as a way of learning and are therefore less likely to integrate science with their own viewpoints because they do not see science as a part of their lives and experiences (Songer & Linn, 1991). In contrast, students who view science as a dynamic process understand that scientists rely on evidence when deliberating between alternate viewpoints. Rather than trying to memorize facts, students attempt to understand new ideas and look for principles to explain ideas therefore integrating their knowledge about science with their knowledge in science (Solomon, Scott, & Duveen, 1996; Songer & Linn, 1991). Edmondson & Novak (1993) discovered that when students view science from the perspective of right and wrong, they think change in science is associated with a change in facts due to improvements in instruments as opposed to new

theoretical approaches. When students do not understand how conflict in science is resolved, they isolate their science knowledge from their everyday knowledge, and this lack of integration leads them to try to memorize scientific facts, an ineffective way of attempting to understand science (Edmondson & Novak, 1993).

#### *What Contributes to Student Understanding of NOS?*

The question may be asked regarding the sources of student conceptions of NOS? Textbooks have largely been responsible for promoting a traditional image of science as just a collection of facts (Duschl, 1988). McComas (2003) found that many biology textbooks contain incomplete or misleading information and rarely include discussions of the nature of science. While textbooks and the media may have significant influence on student conceptions, teachers continue to be a critical factor in influencing their students' conceptions of NOS (Solomon, Scott, & Duveen, 1996). Teachers at all levels of education, including scientists teaching at the university level often have inadequate, traditional conceptions of NOS (Lederman, 1992; Pomeroy, 1993; Southerland, Gess-Newsome, & Johnston, 2003). Teachers' conceptions about NOS are important because these conceptions are associated with their beliefs about learning and teaching (DeCoito, 2009; Hashweh, 1996; Palmquist & Finley, 1997; Trumbull, Scrano, & Bonney, 2006; Tsai, 2002). Even when teachers have contemporary conceptions of NOS, they may not effectively communicate their conceptions of NOS to their students (Abd-El-Khalick, 2001; Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, Buzzelli, & Donnelly, 2010; Lederman & Zeidler, 1987). Research has indicated that specific instructional behaviors influence students' conceptions of NOS (Tsai, 2006; Lederman & Druger, 1985) and that the language used during science instruction can be significant in conveying understanding of NOS (Abd-El-Khalick & Lederman, 2000; Bell, Matkins, & Gansneder, 2011; McDonald, 2010; Munby, 1976).

The vast majority of research regarding student and teacher conceptions of NOS has been conducted in the context of K-12 science instruction. Fewer studies have investigated conceptions and instruction at the college level and the majority of those have focused on conceptions of students majoring in biology (Ameny, 1999; Kenyon, 2003; Waterman, 1982). There is a dearth of information about development of NOS conceptions in college students not majoring in science. Recognizing the key role of appropriate understanding of NOS in developing scientific literacy, the role of the teacher in fostering appropriate understanding of NOS, and the dearth of information regarding NOS understanding of college students not majoring in a science discipline, we examined the influence of a college introductory, non-majors, biology course on student understanding of the following broad aspects of NOS: Nature of scientific knowledge; nature of the construction of scientific knowledge; and characteristics of scientists. We framed our study to investigate the following question: To what extent does a one-semester introductory biology course influence student understanding of these three broad aspects of NOS? For the purpose of narrowing the focus of this article, we present only the impact on student understanding of the nature of scientific knowledge, particularly the relationship between hypotheses, theories and laws.

## **Research Design**

### *Context of Study*

This study was conducted in the Biology 1101 (BIO 1101) course at a comprehensive (Masters degree granting) university in southeastern USA. The BIO 1101 course is the first in a sequence of two biology courses that meet the natural science requirement for the core curriculum at this university. In a fall term approximately 1000 students enroll in the BIO

1101 course. About 500 students take this course either in the spring or summer terms. Therefore, roughly 1500 students a year select this biology course to meet their core curriculum natural science requirements. Ten lecture sections of BIO 1101 were offered during Fall 2005. Of those, 7 sections (taught by 5 different instructors) participated in the study. The lecture sections were taught as either a Monday, Wednesday, Friday class meeting for a 50-minute block or a Tuesday, Thursday class meeting for a 75-minute block. Classes met for approximately 15 weeks of instruction. Sections were selected on the basis of the convenience of the class meeting time and instructor's willingness to participate.

### *Participants*

*Instructors.* All instructors (5 in total), excluding Instructor B, held Doctoral degrees. Instructor A, the only female of the group, had 4-8 years of teaching experience. She had spent most of her career as a research scientist and although she had attended a workshop related to science education, she did not have any formal science education training. Instructor B had recently finished his Master's degree in Biology; although this was his first time teaching the BIO 1101 lecture, he had been teaching introductory biology and zoology labs for the past 3 years. He had never attended any workshop related to science education and had no formal science education training. Instructor C had been teaching 4-8 years. In addition to having attended a workshop on science education, he had taken a couple of science education courses. Instructor D was the only instructor who held an education doctorate degree (Ed.D.) with a concentration in science education. He had organized science education workshops and had been teaching for over 20 years. Instructor E had been teaching for over 20 years. Although he had never taken any formal science education courses, he had attended at least 4 workshops related to science education.

*Students.* All students who were enrolled in the seven participating sections were invited to participate in the study. As an incentive to encourage participation, instructors agreed to offer extra credit for each stage of the study that the students completed. Alternate forms of extra credit were offered for those students who did not want to participate in the study. During Fall 2005, 976 students enrolled in BIO 1101. Of these, 714 students were enrolled in the 7 sections that participated in the study. Approximately 54% of those students were sophomores, 27% were freshman, 16% were juniors, and 3% were seniors. However, only 295 of these students completed the post-test administration of the questionnaire (described in the Methodology section below). Thus the participant sample size ( $N$ ) is 295. Of the 295 participating students, 85 (29%) were male and 210 (71%) were female.

## **Methodology**

### *Quantitative Data Collection and Analyses*

*The Instrument.* In order to determine students' conceptions regarding selected aspects of NOS before and after the course, the 'Views on Science-Technology-Society' (VOSTS) questionnaire was administered as a pre-posttest. This empirically developed questionnaire (Aikenhead, Fleming, & Ryan, 1987) has been used previously with both high school and college students and their instructors to measure conceptions of NOS (Bradford, Rubba, & Harkness, 1995; Dass, 2005). The validity and reliability of VOSTS had been reported elsewhere (Aikenhead & Ryan, 1992; Botton & Brown, 1998; Yalvac, Tekkaya, Cakiroglu & Kayhaoglu, 2007). We selected 25 VOSTS items (Appendix A) for our study. These items were selected because they encompassed aspects of NOS that have been recommended by the American Association for the Advancement of Science (AAAS, 1994) as essential for a scientifically literate society.



The pre-course questionnaire was administered to students during the first week of class in August 2005; students had approximately 2-3 days to complete and return the questionnaire (so that their responses represented their understanding prior to being influenced by the course). The post-course questionnaire was given to students during their first lab meeting of Biology 1102 (the second course in the sequence) in January 2006 and they were allowed one week to complete and return the questionnaire. In addition to the 25 selected VOSTS items, the pre-course questionnaire also included demographic questions (Appendix B). Instructors were administered the same VOSTS questionnaire (the demographic questions were replaced with teaching experience questions, Appendix C) once in fall 2005 to determine their conceptions of NOS at this point in their careers.

There are no correct or incorrect response choices on the VOSTS questionnaire; however certain response choices correlate with a contemporary view of NOS while others correlate with a traditional view of NOS. Therefore, response choices were collapsed into three categories as follows, similar to those used in previous studies using the VOSTS questionnaire (Rubba, Bradford, & Harkness, 1996; Dass, 2005):

- Desirable (D): The choice clearly expresses a contemporary view.
- Acceptable (A): The choice expresses a view that includes a number of legitimate components of the contemporary view.
- Undesirable (U): The choice expresses a view that doesn't match any aspects of the contemporary view.

In order to determine which category each response choice would be assigned, we individually assigned each choice to a category for each of the 25 questions and then met to discuss the categorization for each question. Our three-member panel allowed for the most unbiased categorization possible as each member represented a different perspective: science teacher; science educator; and biology content specialist. Agreement on how to categorize response choices was not always easy; choices were debated until each member of the panel was satisfied with the categorization. Although there is no correct or incorrect response, the inability to have an opinion at all (especially after completing the course) is undesirable, therefore the last three response choices: "I don't understand," "I don't know enough about this subject to make a choice;" and "None of these choices fits my basic viewpoint" were always assigned to the UNDESIRABLE category.

#### *Data Analysis*

To allow for inferential statistics and hypothesis testing, response categories were assigned point values: D = 3, A = 2, U = 1. The conversion to ordinal data allowed for a non-parametric test to determine if there was a difference in student responses between the pre and post course surveys (Conover, 1971; Siegel, 1956). The sign test was used to determine whether the paired median response for each question on the pre-post questionnaire was different among sections of different instructors. The two-tailed sign test allowed for testing the null hypothesis H<sub>0</sub>: The difference in the median of the VOSTS item response categories from pre to post test is zero (it should be noted that the sign test was used when  $N \geq 25$  and the binomial distribution was used when  $N < 25$ ). When  $p > 0.05$ , the null hypothesis was accepted, when  $p \leq 0.05$  the null hypothesis was rejected in favor of the alternate hypothesis H<sub>1</sub>: The difference in VOSTS item response categories from pre to post test is different from zero. For this test, if a student selected a 'U' response on the pre-test but then selected either a 'D' or an 'A' on the post-test, this was considered a positive difference. If a student selected an 'A' on the pre-test and a 'D' on the post-test, this was also considered a positive difference. Responses in the opposite direction were considered a negative difference and any responses

where the student selected the same category choice for the pre and post-test were considered a tie and were not used in calculating the test statistic. The response choices and scoring scheme for VOSTS item #17, which is the focus of this report, is provided in Figure 1.

<p>Scientific ideas develop from hypotheses to theories, and finally if they are good enough, to being scientific laws.</p> <p>Your position, basically: (Please read from A to H, and then choose one.)</p> <p>Hypotheses can lead to theories which can lead to laws:</p> <p>U/1 A. because a hypothesis is tested by experiments, if it proves correct, it becomes a theory. After a theory has been proven true many times by different people and has been around for a long time, it becomes a law.</p> <p>U/1 B. because a hypothesis is tested by experiments, if there is supporting evidence, it's a theory. After a theory has been tested many times and seems to be essentially correct, it's good enough to become a law.</p> <p>U/1 C. because it is a logical way for scientific ideas to develop.</p> <p>A/2 D. Theories can't become laws because they both are different types of ideas. Theories are based on scientific ideas which are less than 100% certain, and so theories can't be proven true. Laws, however, are based on facts only and are 100% sure.</p> <p>D/3 E. Theories can't become laws because they are both different types of ideas. Laws describe things in general. Theories explain these laws. However, with supporting evidence, hypotheses may become theories (explanations) or laws (descriptions).</p> <p>U/1 F. I don't understand.</p> <p>U/1 G. I don't know enough about this subject to make a choice.</p> <p>U/1 H. None of these choices fits my basic viewpoint.</p>
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**Figure 1.** VOSTS item #17 with response choices and scoring scheme.

### *Qualitative Data Collection and Analyses*

*Interviews.* To corroborate student and instructor responses on the VOSTS questionnaire, instructors and students were invited to participate in individual interviews. Of the 25 VOSTS questionnaire items, 11 items were selected as interview questions. These items best incorporated the nine core NOS ideas that the average student should understand (McComas, 2004) and included questionnaire items 6, 10, 11, 13, 14, 16, 17, 18, 21, 24, and 25. All instructors were interviewed individually. Students were purposefully selected based on the results from the quantitative data. We wanted to interview students who had different quantitative outcomes in the same classroom. Therefore, we invited students who had exhibited a lot of positive change, negative change, and no change to participate in individual interviews. The duration of the interviews was approximately 30 minutes in length and was completed in March and April of 2006. In addition to 4 instructors (Instructor B had moved away prior to the interview process), 26 students participated in the interview: 5 from

Instructor A's class; 5 from Instructor B's class; 4 from Instructor C's classes; 7 from Instructor D's classes; and 5 from Instructor E's class. All interviews were audio taped and transcribed by a transcriber.

*Classroom Observations.* The classes, and therefore instructors and students who participated in this study, were not part of a control group experimental design. Instructors were not asked to teach their students in any particular way, and students were not assigned to particular lecture sections. Although the VOSTS survey questionnaire provided quantitative data, which was subjected to inferential statistics, the quantitative data could not provide possible explanations for the results. Therefore qualitative data in the form of classroom observations were important in interpreting the quantitative findings.

The BIO 1101 course content is somewhat prescribed by the program coordinator, hence certain topics must be addressed by all instructors. After that, if time permits, instructors may include other topics of their choice. From the list of required topics, Mendelian Genetics, DNA Structure, and Microevolution were selected to be video recorded. These three lecture topics were selected because their content includes discussions of the contribution of several scientists to the development and growth of scientific knowledge within that topic. For this reason, we believed that these topics would naturally present opportunities to incorporate the nine core NOS ideas in class. The first author went to each instructor's lecture for as many days it took them to address each topic and video recorded the session from the back of the room. Since the purpose of the classroom observations was to explain the quantitative findings, the video footage of lectures was transcribed into a written script that could be used as the actual qualitative data. This resulted in 21.5 hours of video footage. The purpose of the lecture video footage was to provide methodological triangulation (Patton, 2002). The actual language that the instructors used when presenting the three lecture topics served as qualitative data that provided triangulation for student choice of responses to specific items on the VOSTS questionnaire when students explained their choices during the interviews.

#### *Data Analysis*

Transcripts of interviews were already broken down by VOSTS items and students' responses provided further insight as to their conceptions of each item. Transcripts of the video footage were read and re-read in order to identify themes and patterns in the language used by the instructors when they taught the particular topics. Specifically, the presentation of science content was coded as it pertained to each of the VOSTS items reported in the Results section. For example for VOSTS item 17 (Figure 1), when an instructor discussed hypothesis, theory, or law, the language used was designated with a particular color representing that item that could then be used to add insight to the quantitative findings. The triangulation of the quantitative and qualitative data constituted a form of comparative analysis, which increases confidence in whatever conclusions are drawn (Patton, 2002).

## **Results**

### *Choice of Vosts Items for Analysis*

Only six of the VOSTS items—14, 16, 17, 18, 21, and 24—were selected for additional analysis. These six items were selected not necessarily due to statistically significant findings, but because of the significance of the questions. All six selected items are from the conceptual scheme regarding the nature of scientific knowledge. Students' conceptions about the nature of scientific knowledge are of particular importance because these conceptions influence students' learning strategies (Edmondson & Novak, 1993). These items relate directly with



the core NOS ideas (McComas, 2004) and were also included as interview questions. Thus, the quantitative results on these items can be corroborated by qualitative data. Of these six items, results for only item 17 are presented here because this item relates to the most crucial aspect of the nature of scientific knowledge, namely the relationship between hypotheses, theories and laws. For reference, instructor responses on this item are presented in Table 1.

**Table 1.** *Instructors' category conceptions for VOSTS item 17.*

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<i>Instructor</i>	<i>Response Category</i>
A	A
B	A
C	U
D	D
E	U

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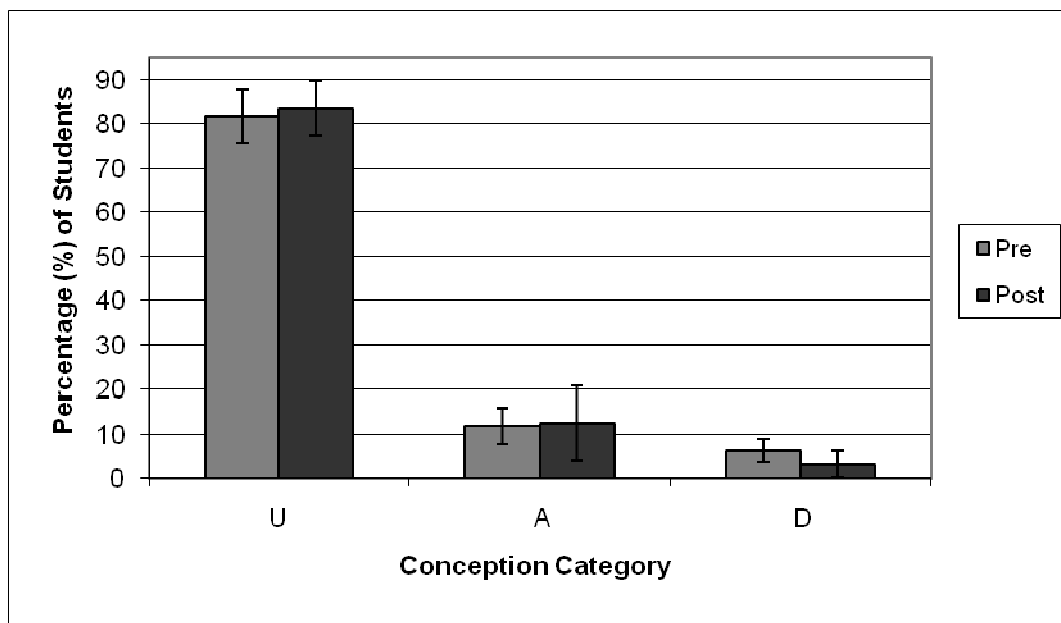
#### Analysis of Vosts Items 17

VOSTS item 17 explicitly deals with NOS core component #4: laws and theories are related but distinct kinds of scientific knowledge (Figure 1). The results for this item were selected because this was the only question for which the majority of students held an undesirable conception on the pre-test. In addition, transcriptions of lectures from Mendelian genetics provided some insight into the misconception that there is a hierarchy in the development of scientific ideas.

The vast majority of students selected undesirable conceptions on both the pre- and post-tests (Figure 2). Student conceptions stayed the same as the majority of the students selected the same category conception on both the pre and post-test (Table 2). Instructor D was the only instructor to hold a desirable conception (Table 1). In this instructor's class, just as many students moved in a positive direction as in a negative direction, from pre- to post-test, although more students held desirable conceptions on the post-test than on the pre-test. While the results do not indicate any trends of statistical significance overall, there were more negative differences than positive differences. Thus, 3% of the students finished the course with the desirable conception that theories and laws are distinct kinds of knowledge compared to 6% that entered the course with such conception (Table 2, Figure 2). Eighty-four percent of the participants finished the course with the misconception that scientific idea development occurs as a hierarchy and that a theory is not as valid as a law because a theory does not have as much "proof" as a law.

**Table 2.** Instructor influence on student responses for item 17 on post-course questionnaire compared to pre-course questionnaire with *p* value for the sign test.

Instructor	Negative (-) differences	Positive differences	(+) Ties	<i>P</i>
A	1	2	32	1.000
B	10	7	26	0.629
C	12	8	52	0.503
D	9	9	68	1.000
E	10	7	45	0.629
<b>Total</b>	<b>42</b>	<b>33</b>	<b>223</b>	<b>0.356</b>



**Figure 2.** Percentage of students that selected each category conception on pre and post-course questionnaires for item 17, *N*=298. Error bars represent standard deviation.

The qualitative data from the Mendelian genetics lectures provides insight into the high percentage of students that finished the course with undesirable conceptions about scientific ideas. Instructor D was the only instructor to correctly and consistently refer to the scientific outcome of Mendel’s work as laws: the Law of Segregation and the Law of Independent Assortment. Instructors A and C consistently referred to these same concepts but referred to them as theories and hypotheses respectively. Both Instructors B and E were inconsistent and excerpts from their lectures illustrate this inconsistency.

Instructor B: So the 1st law or the 1st theory that Mendel came up with he called the Law of Segregation ...so now through his experiments so far we've done a monohybrid cross and a test cross both to support his Theory of Segregation... So from the data he collected he formed a theory, Theory of Segregation, now people call it the Law of Segregation of alleles.

Instructor E: ...and that held up every time he did a cross, a test cross, uh, now if you do this lots and lots of time and you don't get any conflicting data and you start to have some confidence in your hypothesis and so his hypothesis or his law sometimes, uhm, we'll see it's the Theory of Segregation...So that's the Law of, Mendel's 1st Law or the Law of Segregation or the Theory of Segregation in genetics.

Both Instructors B and E used theory and law interchangeably during the Mendelian genetics lecture. In addition, Instructor B implied a hierarchal development of scientific ideas. Instructors varying use of words for the same concept demonstrates not only a lack of understanding on the Instructor's part but also an inconsistent and misleading use of terminology when discussing scientific ideas with their students.

Interview transcripts confirm the quantitative result that students retain the misconception that scientific idea development is hierarchal.

A's Student: I'm going to lean more to how many times it's been proven. If it's been proven so many times and hasn't been able to be disproven then, I mean, it becomes a law.

B's Student: I don't think that it should, uhm, because like a theory you know isn't 100% true and I don't know, I don't know, everything that we're taught in science is a theory and they've been teaching it for so long and it just seems like that if that were true it would have already become a law.

E's Student: ...I think like, with hypotheses they have to be tested a lot, like experimented and experimented and have all of the supporting evidence gathered together in order to make it a theory so after its been proven true for so many times then I think yes it's a hierarchy but once it's proven by experiments it's a theory and then once that theory becomes absolutely true then it's a law.

From the observed class lectures, Instructor C was the only one to explicitly discuss theories with his students. The excerpt below is from his lecture on microevolution.

Remember how we spoke about theories aren't hypotheses, they're basically these unifying principles that are supported by everything that we know about the field of biology and so that's why biologists get really irate when people want to not allow it to be taught because it's basically the fiber that holds everything that we know about biology together and so that's why it's really important and actually why I'm teaching it right at the very end of the semester is because we will be able to see that everything that we learned this semester goes into supporting this theory.

Interview data from one of Instructor C's students illustrates the above conception of theories. Although the student seems to understand the confusion between scientific theories

and the day to day use of the word theory, this student still holds the common misconception that laws are absolute.

C's Student: Well, you always hear that the theory of evolution is just a theory, but when scientists think of the word theory it's as if theory means law to the scientist and theory is hypothesis to the lay person. Like, oh it's just a theory, like it's just something like a hypothesis, but scientific theory is much more concrete with strong evidence and it's just a theory, laws are supposed to be 100% concrete stable...theories you can change around, I don't know, I'm not really sure anymore.

A student from Instructor D's class also demonstrates a more contemporary conception of theories but still displays remnants of traditional thought.

D's Student: That a law is not something that you can create, there is no transition from a theory to a law, a law is just, just usually observed but it just is. Theories are, you know, you go through the whole scientific method and you, it comes from a hypothesis but it can never be fully proven, not 110% a theory can't, ...it is still a good way of explaining something...usually theories try to interpret laws, while maybe they work together maybe.

A pattern emerged when students were asked where they had developed their conceptions about scientific ideas.

A's Student: I mean going all the way back to middle school and high school. A scientific law is much more above a theory.

C's Student: That's just what I've always gathered from what I have heard in all my science classes.

D's Student: ...it's the way my teachers have always taught it since, you know I actually started paying attention in science classes like 9th grade you know, you see, you test your hypotheses and that becomes a theory that you can base other things off of and then we learned about laws which are proven and unquestionable.

E's Student: I actually think more of high school sciences because we talked about that a law comes from a theory which comes from a hypothesis.

Students' traditional conceptions regarding scientific ideas are established and even students with more contemporary conceptions still display confusion. These misconceptions are most likely a result of years of science education that has presented scientific ideas as a hierarchy and the BIO 1101 course did not significantly influence students to think otherwise.

## **Discussion**

### *Interpretation of Results*

The BIO 1101 course was taught as an introductory course covering the breadth of the discipline and is content driven. Overall, the course did not significantly influence students towards contemporary conceptions of NOS. For the most part, the results from this study concur with the findings of previous studies.

The fact that 82% of the students in this study entered the course with undesirable conceptions about scientific ideas sustains 30 years of previous research on this item (Lederman, 1992). A high percentage of students' believing that scientific ideas develop as a simplistic hierarchal relationship has been found by many researchers using a variety of different instruments (Ryan & Aikenhead, 1992; Blanco & Niaz, 1997; Dagher et al., 2004; Edmondson & Novak, 1993; Meyling, 1997; Rubba & Anderson, 1978). This misconception signifies that students do not view theories as frameworks but rather as proven hypotheses (Sandoval & Morrison, 2003; Smith & Wenk, 2006). In addition this hierarchal misconception is associated with the idea that laws are absolute and the only valid scientific knowledge because they have been proven true (Dagher & Boujaoude, 2005; Edmondson & Novak, 1993). Student interviews corroborate Meyling's conclusion (1997, p. 401) that their conceptions of the "tentative character of theories is not founded on epistemological reasons but on deficient experimental evidence." The lack of change of student conceptions is most likely a result of two factors. First, student interviews confirm findings that students have been bombarded in previous science classes that scientific knowledge development is a hierarchy (Dagher et al., 2004). Second, instructors' portrayal of hypotheses, theories, and laws were often inconsistent or incorrect helping to perpetuate this notion of hierarchy. Only one instructor was observed explicitly differentiating a theory from a hypothesis for his students. Student interviews reveal that even those who held the desirable conception choice articulated either some level of confusion or remnants of traditional conceptions. Further cementing this view in students' minds, McComas (2003) found that none of the biology textbooks he reviewed (including college level texts) provided an acceptable view of theories or laws. Unfortunately, the notion of hierarchy between theories and laws give rise to the often heard phrase "it's only a theory" especially from those who wish to discredit the theory of evolution. The BIO 1101 course investigated in this project did not help students reject this hierarchal misconception.

Unfortunately misconceptions about scientific ideas compounded with misconceptions of the scientific method make it easier for students to dismiss the theory of evolution and many other aspects of biology. Sandoval and Morrison (2003) concluded that for some students a simple step-by-step scientific method promoted the conception of theories as proven hypotheses as opposed to encompassing more than hypotheses. Dagher and Boujaoude (2005) found that many biology majors expressed the view that evolution is only a theory as opposed to a fact because it was missing one or more steps of the scientific method. For these students the theory of evolution is missing the experimentation stage of the scientific method therefore it lacks the hard evidence to make it credible. What started as a simple list of characteristics associated with scientific research has accidentally turned into a definite step-wise process of how all scientists work (McComas, 1997). This misconception has dire consequences for scientific knowledge that does not follow these exact steps. If Dobzhansky (1973) is correct and, "nothing in biology makes sense except in the light of evolution," this combination of misconceptions could negatively affect students' abilities to understand biology. In addition, these misconceptions help explain why after more than 150 years since the publication of Darwin's *On the Origin of Species*, debates about teaching the theory of evolution and the inclusion of alternate non-scientific theories in science classes still occur.

### *Implications*

The results of this study are consistent with earlier research findings. Previous studies have shown that implicit reiterations of history are not enough to influence students' conceptions and that explicit discussion of NOS with content are necessary to encourage change in conceptions of NOS (Abd-El-Khalick & Lederman, 2000; Meyling, 1997; Schwartz & Lederman, 2002). The qualitative data from this study support these conclusions. It seems



that when there was some sort of influence on students for a particular item, either their instructor was observed explicitly mentioning the item or students' interviews revealed that the item was explicitly mentioned. Of particular concern are students' and instructors' conceptions of theories. Unfortunately it seems that many of the items that the students have misconceptions about are related to the misconceptions that they have of scientific theories.

A study by Dagher and Boujaoude (2005) found that misconceptions about theory led biology majors to make false conclusions and compromised their ability to reason about the theory of evolution. In the study three types of evidence were presented to students to provide support for the theory of evolution: circumstantial; direct; and historical. Three types of evidence were considered direct: observational; experimental; and practical. Although a variety of things were presented as evidence supporting the theory of evolution, students' misconceptions about theory made it easy for them to dismiss the theory. Several different misconceptions were responsible for student reasons for dismissing the theory. For some students the nondirect evidence wasn't seen as corroborative evidence that strengthens the theory but is seen as soft evidence that weakens it. As mentioned earlier, for some students a law was considered the only reliable form of scientific knowledge and for others the theory of evolution did not follow the scientific method. The authors concluded that an explicit approach incorporating theories and content was needed to improve students' conceptions of NOS. All the student misconceptions about theories mentioned above were also mentioned by students in the current study. In addition, instructors in this study discussed all three types of evidence with their students in class, but very little explicit discussion of theories was observed. Although students were not directly asked about the theory of evolution, considering their misconceptions about theories and based on the research done with biology majors, it is likely that many students in the BIO 1101 course would lack the ability to reason about the theory of evolution. In addition, student understanding of biology may be compromised by these misconceptions because the theory of evolution is one of the most important products of modern biology and lies at the heart of understanding how science functions (McComas, 2003). Not surprising is the lack of improvement in students' conceptions of NOS and the potential impact on their scientific literacy in the biology course. Content oriented courses have been found to be in opposition to scientific literacy (DeBoer, 2000; Johnson & Pigliucci, 2004). College departments can design their own curriculum (unlike schools where the curriculum is often prescribed by the state), therefore there are better opportunities to influence students' conceptions of NOS at the college level if the curriculum is specifically designed to do so. However, changing student conceptions of NOS is obviously easier said than done. In spite of the fact that the contemporary views of NOS have been around for almost 40 years, students and instructors still hold many misconceptions about it. Therefore, students are going to enter the BIO 1101 course with misconceptions. On the other hand, it is still possible to influence college students' conceptions (Edmondson & Novak, 1993; Lord & Marino, 1993). This is supported by Miller (2004) who found that students who take college level science courses are not only more scientifically literate, they are more comfortable with science as well. The language used by instructors during science instruction is important (Lederman, 1999; Munby, 1976; Zeidler & Lederman, 1989). Explicit discussions of NOS are better able to influence student conceptions of NOS than implicit language (Abd-El-Khalick & Lederman, 2000; Lederman, 1999; Southerland, Gess-Newsome, & Johnston, 2003). The results of this study support the explicit approach as students often referenced explicit discussions from class for influencing their conceptions. If the goal of science education is to improve scientific literacy, then instructors of general education science courses should stop focusing only on teaching and learning discreet topics of the discipline and design these courses in such a way that students encounter, experience, and understand the contemporary nature of science.

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## APPENDIX A

### Stems of VOSTS items used as numbered in the questionnaire but classified by components of NOS.

#### Nature of Scientific Knowledge:

1. Defining science is difficult because science is complex and does many things. But MAINLY science is:
13. Scientific observations made by competent scientists will usually be different if the scientists believe different theories.
14. Many scientific models used in research laboratories (such as the model of heat, the neuron, DNA, or the atom) are copies of reality.
15. When scientists classify something (for example, a plant according to its species, an element according to the periodic table, energy according to its source, a star according to its size), scientists are classifying nature according to *the way nature really is*; any other way would simply be wrong.
16. Even when scientific investigations are done correctly, the knowledge that scientists discover from those investigations may change in the future.
17. Scientific ideas develop from *hypotheses* to *theories*, and finally if they are good enough, to being scientific *laws*.
18. When scientists investigate, it is said that they follow the scientific method. The scientific method is:
19. Even when making predictions based on accurate knowledge, scientists and engineers can tell us only what *probably* might happen. They cannot tell what will happen for certain.
20. If scientists find that people working with asbestos have twice as much chance of getting lung cancer as the average person, this must mean that asbestos causes lung cancer.
21. Science rests on the assumption that the natural world can *not* be altered by a supernatural being (for example, a deity).
22. For this statement, assume that a gold miner “discovers” gold while an artist “invents” a sculpture. Some people think that scientists *discover* scientific LAWS. Others think that scientists *invent* them. What do you think?
23. For this statement, assume that a gold miner “discovers” gold while an artist “invents” a sculpture. Some people think that scientists *discover* scientific HYPOTHESES. Others think that scientists *invent* them. What do you think?
24. For this statement, assume that a gold miner “discovers” gold while an artist “invents” a sculpture. Some people think that scientists *discover* scientific THEORIES. Others think that scientists *invent* them. What do you think?
25. Scientists in different fields look at the same thing from very different points of view (for example, H<sup>+</sup> causes chemists to think of acidity and physicists to think of protons). This makes it difficult for scientists in different fields to understand each others’ work.

#### Characteristics of Scientists

2. Most American scientists are motivated to work hard. The MAIN reason behind their *personal* motivation for doing science is:
3. The best scientists are always open-minded, logical, unbiased and objective in their work. These personal characteristics are needed for doing the best science.
4. A scientist’s religious views will NOT make a difference to the scientific discoveries he or she makes.

#### Social Construction of Scientific Knowledge

5. Loyalties affect how scientists do their work. When scientists work together for a company, *their loyalty to the ideals of science* (open-mindedness, honesty, sharing results with others, etc.) is replaced by a *loyalty to the company* (for example, the company is always right).
6. When scientists disagree on an issue (for example, whether or not low-level radiation is harmful), they disagree mostly because they do not have all the facts. Such scientific opinion has NOTHING to with moral values (right or wrong conduct) or with personal motives (personal recognition, pleasing employers, or pleasing funding agencies).
7. Scientists publish their discoveries in scientific journals. They do this mainly to achieve credibility in the eyes of other scientists and funding agencies; thus helping their own careers to advance.
8. Scientists compete for research funds and for who will be the first to make a discovery. Sometimes fierce competition causes scientists to act in secrecy, lift ideas from other scientists, and lobby for money. In other words, sometimes scientists break the rules of science (rules such as sharing results, honesty, independence, etc.).
9. A scientist may play tennis, go to parties, or attend conferences with other people. Because these social contacts can influence the scientists work, these social contacts can influence the content of the scientific knowledge he or she discovers.



10. With the same background knowledge, two scientists can develop the same theory independently of each other. The scientist's individuality does NOT influence the content of a theory.
11. Scientists trained in different countries have different ways of looking at a scientific problem. This means that a country's education system or culture can influence the conclusions which scientists reach.
12. BACKGROUND: A team of scientists worked together "in private" in their lab for 3 years and developed a new theory. The team will present their theory to a group of scientists at a science conference and the other team will write a scientific journal article explaining their theory (that is, the team will work "in public" with other scientists). The following statement compares *private* and *public* science.  
STATEMENT: When scientists do their *private* science (for example, when they work in a lab), their thinking is open-minded, logical, unbiased and objective; just as it is when they do their *public* science (for example, when they write an article for presentation).

## APPENDIX B

### STUDENT DEMOGRAPHIC SURVEY QUESTIONS

1. I am a
  - A. freshman
  - B. sophomore
  - C. junior
  - D. senior
  
2. I am
  - A. female
  - B. male
  
3. I had
  - A. no biology in high school
  - B. one year of high school biology
  - C. two years of high school biology
  - D. more than two years of high school biology
  
4. This biology course is
  - A. The only college-level course in science I have taken.
  - B. Not the only college-level course in science I have taken
  
5. I had
  - A. no high school chemistry
  - B. one year of high school chemistry
  - C. two or more years of high school chemistry
  
6. I had
  - A. no high school physics
  - B. one year of high school physics
  - C. more than one year of high school physics
  
7. I am enrolled in this biology course because
  - A. I have to, to fulfill distribution or college requirements
  - B. I have to fulfill the requirements, but I would anyway
  - C. I want to take it, I don't have to
  
8. Are either of your parents research scientists, research technicians, physicians, veterinarians, or otherwise trained, employed or involved in science or science-related fields?
  - A. yes
  - B. no
  
9. Have you ever attended any summer institutes or other science programs which are not formal courses?
  - A. yes, more than once
  - B. yes, once
  - C. no

10. Why did you choose to take biology rather than one of the other sciences, such as chemistry or physics?

- A. because I thought it would be the easiest
- B. because I have even less interest in the other sciences
- C. it fit in my schedule better
- D. biology seems more relevant to my day to day life than the other sciences

11. Most likely my major will be

- A. Art
- B. Anthropology
- C. Business
- D. Computer Science
- E. Education
- F. English or Literature
- G. Foreign Language
- I. Health, Leisure and Exercise Science
- J. History
- K. Math
- L. Music
- M. Philosophy and Religion
- N. Political Science
- O. Science
- P. Sociology
- Q. Theatre and Dance
- R. Other

12. Which of the following best describes your opinion about biology?

- A. It is hard and I hate it
- B. It is hard but I think there are important things to learn
- C. It is not hard, but it is boring
- D. I do not see the importance in it, I will never use it again
- E. I think it is interesting and it is important to understand basic concepts

**APPENDIX C**

**INSTRUCTOR TEACHING EXPERIENCE SURVEY QUESTIONS**

1. How many years have you been teaching?
  - a. 1-3 years
  - b. 4-8 years
  - c. 9-15 years
  - d. 16-20 years
  - e. Over 20 years
  
2. Have you ever had any science education courses or training?
  - A. no
  - B. 1 or 2
  - C. 3 or 4
  - D. More than 4
  
3. Have you ever attended any workshops or meetings regarding science education?
  - A. no
  - B. 1 or 2
  - C. 3 or 4
  - D. More than 4