ADDRESSING THE NATURE OF SCIENCE IN AN INTRODUCTORY BOTANY LABORATORY COURSE

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Abstract

This paper presents the results of an attempt to both address the nature of science in an introductory botany laboratory course and quantify the changes of the students' understanding of the nature of science. The course used primary literature in addition to traditional laboratory assignments to discuss the nature of science. The students were given a pre and post course survey which included open-ended responses as well as Likert items. This paper will present the results of the Likert items only.

Introduction

Science education in the United States has been the subject of many recent reviews and recommendations (AAAS, 1993; NRC, 1996, Rutherford & Ahlgren, 1990). Many of these documents express the need for more attention to both the nature of science (NOS) and the processes of science. The National Science Education Standards (1996) have had wide reaching implications for the K-12 education in the United States. However, its guidelines and vision have not moved as rapidly into college science courses. More recently, the National Research Council called for a drastic change in the undergraduate education of future researchers (NRC, 2003). Many of the changes in Bio 2010 (NRC, 2003) mirror changes suggested by Science for All Americans including more investigative laboratories.

Northeastern State University, located in Tahlequah, Oklahoma, primarily serves students from a rural, socio-economically depressed area. NSU underwent a recent NCATE program review. Our self-study revealed that teacher candidate courses did not explicitly teach the NOS. In addition, during the review process we were also unable to document the extent to which pre-service students understand the NOS. All biology majors are required to take a senior seminar course. This course is required by the Oklahoma State Regents for Higher Education as a way to assess the biology major. One of the consistent outcomes of the course reveals a lack of understanding of the process of science by our majors.

According to Siebert and McIntosh, "the pre-service courses and the future teachers they serve will, in large part, determine the nation's comfort with, knowledge about, and interest in science." General Botany Laboratory is a course taken by both secondary science education majors as well as biology majors. Because all science education majors will take this course, it was selected as pilot course for including NOS explicit instruction.

This paper presents some of the results of an on-going process to modify an introductory botany lab course that addresses NOS instruction and science process instruction. The results presented in this paper will focus on the NOS aspect of the changes. The purpose of this study was three-fold:

- Incorporate modifications into an existing course to increase understanding of specific NOS concepts.
- Quantify the changes that occurred in undergraduates' understanding of the NOS after taking the laboratory course.
- Refine an instrument that could quantify those changes.

Subjects

The students in this course were all undergraduates. The majority of the students were biology majors; Secondary science education majors and chemistry majors made up a minority of the class. The biology undergraduate degree requires general botany as a part of the biology core of course. Students in this course generally have previously taken a general zoology course. While general botany lab is listed as a freshmen-level course, the majority of the students do not take the course as freshmen.

Methods

Several instruments have been developed to assess the NOS knowledge of undergraduate students (Aikenhead, G.S., & Ryan, A.G.; Lederman, et.al 2002). Each of these existing instruments has strengths and weaknesses. We chose to utilize an instrument in development, the *Student Understanding of Scientific Inquiry* (SUSI), for several reasons. The SUSI (Appendix A) is in the process of development, and we are collaborating with researchers in other areas of the U.S. as well as other countries. The refinement of the SUSI is in collaboration with Ling Liang, La Salle University, Philadelphia, PA; Sufen Chen, Tsing Hua University, Taiwan; Osman Nafiz Kaya, First Universtiy, Elazig, Turkey; Xian Chen, Nanjing Normal University, Nanjing, P.R.China; and Jazlin Ebenezer, Wayne State University, Detroit, MI (Liang et al., 2005). The SUSI utilizes both Likert scale questions as well as open-ended responses. The instructor explained the purpose of the survey and students were asked to voluntarily participate. The SUSI was administered on the first day of the course and then again during the last week of the semester. Only SUSI forms that had 100% of the answers completed were used for this analysis. This analysis is limited to the mean scores for the Likert items. Mean responses were compared using a paired t-test.

During the spring of 2005, the botany laboratory course differed in several ways from previous semesters. Throughout the course scientific literature was emphasized. Appropriate papers from scientific journals were assigned as reading material and then analyzed and critiqued in class discussions. The inclusion of class critiques of primary literature required that several traditional laboratories exercises be deleted from the course. The students were asked to identify the questions posed by the researchers, evaluate the methods chosen to answer the question, discuss the results and place the research in a broader context. Journals that were used in the course included: The *American Journal of Botany, Ecology, Southwestern Naturalist, Nature* and *Oikos*. Each primary literature article was selected because the paper addressed a specific tenet of NOS (Lederman 1992). Table 1 lists the NOS topic areas and the corresponding primary literature used in the modified course.

Table 1:

NOS Topic Areas and the Corresponding Primary Literature Used in the Modified Course.

NOS Topic Area	Selected Primary Literature to Illustrate Topic Area
Tentativeness	Hershey, D.R. (2004). The widespread misconception that the tambalacoque absolutely required the dodo for its seeds to germinate. *Plant Science Bulletin* 50: 105-108.
	Temple, S.A. (1977). Plant-animal mutualism: coevolution with Dodo leads to near extinction of plant. *Science* 187: 885-886
	Witmer, M. C. and Cheke, A. S. (1991). The dodo and the tambalacoque tree: an obligate mutualism reconsidered. *Oikos* 61: 133-137
Empirical Basis	Cahill, J.F., J.P. Castelli & B.B Casper. (2001). The herbivory uncertainity principle: visiting plants can alter herbivory. *Ecology*, 82 (2) 307-312.
Observations	Agrawal, A.A., J.A Rudgers, L.W. Botsford, D. Culter, J. B. Forin, C. J. Lundquist, B. W. Spitzer & A.L. Swan. (2000) Benefits and Constraints on Plant Defense agaist herbivores: Spines influence the legitimate and Illegitimate flower visitors of

	yellow star thistle, Gentaurea solstitialis L. (Asteracere*).* *The Southwestern Naturalist* 45 (1):1-5.
Subjectivity	None
Creativity	Richards, J.H. (2001*).* Bladder Function in Utricularia purpurea (Lentibulariaceae): Is Carnivory Important? *American Journal of Botany*. 88 (1) 170-76.
Social	Wan Shiquang, T. Yuan, S. Bowdish, L. Wallace, S. Russell, and Y. Luo (2002) Response of an allergenic species, <u>Ambrosia psilostachya</u> (Asteraceae), to experimental warming and clipping: Implications for public health. *American Journal of Botany* 89 (11) 1843-1846.
Scientific theories	None
Multiple methods	None

For example, the *Ambrosia* paper emphasized social activity aspect of science due to the public health concern of allergenic plants as a reason for the research (Wan, 2002). The tentative nature of scientific knowledge was demonstrated in a study about *Utricularia*, an aquatic plant. Students in the course were asked to conduct an Internet search for general information about bladderworts. After the entire class had determined that bladderworts were carnivorous plants, a paper that challenged that view was assigned (Richards, 2001). The course ended with a much-cited paper from *Nature*, which concluded that the demise of the dodo bird was responsible for the concurrent demise of the tambalacoque tree (Temple, 1977). Students were asked to critique the dodo bird paper in terms of NOS tenets. After much discussion in lab, two subsequent papers, both of which critiqued the original paper by Temple, were distributed (Hershey 2004, and Wilmer 1991). The students then compared their critiques of the dodo bird paper with two published critiques.

The course also devoted more time to student-developed experiments. Some of the experiments were completed. Other experiments were designed and then critiqued by peers, but were not actually conducted. Before the published bladderwort paper was distributed in class, the students divided into groups and designed an experiment to verify the carnivorous nature of bladderworts. Each experimental design was critiqued by another group of students. While the experimental designs were modified after peer review, the students did not conduct the actual experiment. The students did however, design and carry out an experiment to look at the effect of environmental gradients on stomata density. Peers in the lab critiqued each experimental design. The designs were modified based on the critiques and then the experiments were conducted.

Results

Preliminary analysis of the pre and post survey data did not indicate consistent improvement (Table 2). Three areas of NOS did not show any significant difference in the pre- and post- course scores. Neither the nature of scientific theories nor the discovery versus invention of scientific theories was explicitly discussed in the course and no primary journal articles discussing that area were used in the course. No change is student understanding is predictable. However, the durable/tentative nature was explicitly discussed during the course yet this area had no significant difference in the scores. The only area of NOS that showed significant improvement was the influence of society and culture on science. This tenet of NOS was illustrated by the ragweed paper which clearly stated in the introduction that this botanical study was important due to the severity and implications of human ragweed allergies. A lengthy discussion of the nature of science knowledge accompanied the dodo bird paper and subsequent critiques of the original paper. Survey scores pertinent to this topic significantly decreased on the post-course surveys. The use of creativity and imagination in science also had a significant decrease in post-course survey scores. Several factors may be involved in the uneven results. First, the sample size was small. An unusually high number of students withdrew from the two sections of labs. Not all of the students chose to participate in the study. Some of the students that did participate did not complete all sections both the pre and post surveys; incomplete surveys were not used in the analysis. Secondly, the wording of some questions may have been confusing to the students. Third, some students may have not have taken the survey seriously since a grade could not be assigned to the survey, and therefore the students' responses may be suspect. Finally, tenets of NOS may not have been explicitly addressed in enough depth to affect the students' initial concepts. The pedagogical strategies assumed that the in-depth reading and discussion of the primary literature, along with experimental design exercises, would improve the students' understanding of NOS. The Likert items analysis does not support that assumption.

Table 2:

Paired t-tests for SUSI Likert items (n=18)

NOS topic	Pre-test mean (std.dev)	Post-test mean (std.dev.)	*t*-test	Significance
Nature of Scientific Knowledge	22.72 (3.478)	19.94 (1.830)	3.693	0.002*
Nature of Scientific Theories	18.22 (1.768)	17.78 (1.830)	0.703	NS
Influence of Society and	17.10	17.78	-2.476	0.024**

Culture on Science	(1.768)	(2.074)		
Imagination and Creativity in Science	13.72 (1.526)	12.22 (2.130)	2.543	0.021*
Durability of Scientific Knowledge	13.67 (1.085)	14.11 (1.183)	-1.458	NS
Discovery versus Invention of Scientific Theories	14.22 (2.390)	14.11 (1.183)	0.223	NS

*Denotes post-course mean lower than pre-course mean;
**Denotes post-course mean higher than pre-course mean.

Implications

There is overwhelming evidence that undergraduate science instruction of NOS is inadequate and changes are required. This project attempted to implement changes in an existing course, as well as document the effects of those changes. This study indicates the need for further examination and analysis of the results we obtained. In conjunction with our collaborators, the SUSI has been revised (Liang et al., 2005). The revision included changes in the wording of some questions, re-alignment of some items, and the deletion of others. The instrument was also renamed the SUSSI (Student Understanding of Science and Scientific Inquiry). Additional course modifications will be incorporated into the spring 2006 sections of general botany lab. NOS topic areas that had a significant decrease in student scores will be emphasized. Additional time will be devoted to NOS instruction. The revised version of the SUSSI will be given as a pre and post survey again. Further research will compare the open-ended responses with the Likert items.

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Wan, Shiquang, T. Yuan, S. Bowdish, L. Wallace, S. Russell, and Y. Luo. (2002) Response of an allergenic species, Ambrosia psilostachya (Asteraceae), to experimental warming and clipping: Implications for public health. *American Journal of Botany* 89 (11) 1843-1846.

Witmer, M. C. and Cheke, A. S. (1991). The dodo and the tambalacoque tree: an obligate mutualism reconsidered*. Oikos* 61: 133-137

Appendix A: SUSI (version used in spring 2005)

ID # _______ Date_______

Student Understanding of Scientific Inquiry Questionnaire

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

SD = Strongly Disagree
D = Disagree more than agree
U = Uncertain or not sure
A = Agree more than disagree
SA = Strongly agree

1. Observations and Inferences					
A. Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	SD	D	U	A	SA
B. Scientists' observations of the same event will be the same because scientists are objective.	SD	D	U	A	SA
C. Scientists' observations of the same event will be the same because observations are facts.	SD	D	U	A	SA
D. Scientists may make different interpretations based on the same observations.	SD	D	U	A	SA
With examples, explain why you think scientist's observations and interpretations are the same OR different.					

2. Nature of Scientific Theories					
A. Scientific theories are subject to on-going testing and revision.	SD	D	U	A	SA
B. Scientific theories	SD	D	U	A	SA
C. Scientific theories may be changed because scientists reinterpret existing observation.	SD	D	U	A	SA
D. Scientific theories based on accurate experimentation will not be changed.	SD	D	U	A	SA
With examples, explain why you think scientific theories change OR do not change over time.					

3. Scientific Laws versus Theories					
A. Scientific theories exist in the natural world and are uncovered through scientific investigations.	SD	D	U	A	SA
B. Unlike theories, scientific laws are not subject to change.	SD	D	U	A	SA
C. Scientific laws are theories that have been proven.	SD	D	U	A	SA
D. Scientific theories explain scientific laws.	SD	D	U	A	SA
With examples, explain the difference between scientific theories and scientific laws.					

4. Social and Cultural Influence on Science					
A. Scientific research is not influenced by society and culture because scientists are trained to conduct "pure", unbiased studies.	SD	D	U	A	SA
B. Cultural values and expectations determine <u>what</u> science is conducted and accepted.	SD	D	U	A	SA
C. Cultural values and expectations determine <u>how</u> science is conducted and accepted.	SD	D	U	A	SA
D. All cultures conduct scientific research the same way because science is universal and independent of society and culture.	SD	D	U	A	SA
With examples, explain how society and culture affect OR do not affect scientific research.					

5. Imagination and Creativity in Scientific Investigations					
A. Scientists use their imagination and creativity when they collect data.	SD	D	U	A	SA
B. Scientists use their imagination and creativity when they analyze and interpret data.	SD	D	U	A	SA
C. Scientists do not use their imagination and creativity because these conflict with their logical reasoning.	SD	D	U	A	SA
D. Scientists do not use their imagination and creativity because these can interfere with objectivity.	SD	D	U	A	SA
With examples, explain why scientists use OR do not use imagination and creativity.					

6. Scientific Investigation					
A. Scientists use a variety of methods to produce fruitful results	SD	D	U	A	SA
B. Scientists follow the same step-by-step scientific method.	SD	D	U	A	SA
C. When scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
D. Experiments are not the only means used in the development of scientific knowledge.	SD	D	U	A	SA
With examples, explain whether scientists follow a single, universal scientific method OR use different methods.					

Part II: Please circle you response(s) to each item below.

1. Gender: A) Male B) Female

2. Age group:
   A) under 18 C) 25-40
   B) 18-24 D) Over 40

3. Your current level of study:
   A) High School
   B) First Year in College/Freshman
   C) Second year in College/Sophomore
   D) Third year in College/Junior
   E) Fourth Year in College/Senior
   F) Graduate Student
   G) Other

4. With which of the following groups do you self-identify? Mark all that apply (optional).
   A) African-American/Black
   B) Latino/Hispanic
   C) American Indian/Alaska Native
   D) Asian/Pacific Islander
   E) Caucasian/White

5. What is your most likely concentration/major? Mark all that apply.
   A) Natural Science: a. Physics b. Chemistry c. Biology d. Earth/Space Sciences
   B) Elementary Education (K-6 or K-8)
   C) Early Childhood Education (PK-3)
   D) Special Education
   E) Secondary Science Education (6-12)
   F) Other:________
   G) Undecided

6. Which of the following coursed have you taken in <u>high school</u>? Mark all that apply.
   A) Earth Science
   B) Biology
   C) Chemistry
   D) Physics
   E) Physical Science
   F) General Science
   G) Advanced Biology
   H) Advanced Chemistry
   I) Advanced Physics
   J) Other: _____________
   K) Other: _____________
   L) Other:_____________

7. Have you ever taken the following two courses at the <u>college level</u>?
   History of Science A) yes B) no
   Philosophy of Science C) yes D) no

8. How many science courses at the college level have you completed so far?
   A) 0 D) 3 G) 6
   B) 1 E) 4 H) 7
   C) 2 F) 5 I) >7

Appendix B

Taxonomy of Views about Nature of Scientific Knowledge (NSTA, 2000; AAAS, 1993; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) Revised July 2005

Aspect	Explanation/Description	Items
Tentativeness	Scientific knowledge is simultaneously reliable and tentative. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes.	1A(-); 1E (+); 1G(-); 2A (+); 2G(-); 5A (+); 5B (+); 5C(+); 5D (-);
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world. Science aims to be testable.	1F(+), 5A (+), 5B(+)
Observations and inferences	Science is based on both observations and inferences. Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extensions of those senses) and about which observers can reach consensus with relative ease. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.	2B(+); 9A(+); 9B(+); 9C(-); 9D(-); 9E(+);
Subjectivity/objectivity	Science aims to be objective and precise, but subjectivity in science is unavoidable. The development of questions, investigations, and interpretations of data are to some extent influenced by the existing state of scientific knowledge and the researcher's personal factors and social background.	2A (+); 2B(+); 2C(+); 2D(+); 2E(+); 2F(+); 2G (-);
Creativity/rationality	Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world. Scientists use their imagination and creativity throughout their scientific investigations.	1I (+); 4A(+); 4B(+); 4C(+); 4D(+); 4E(-); 4F(-); 10D(+);
Social and cultural embeddedness	Science is part of social and cultural traditions. People from all culture contribute to science. Science requires accurate record keeping and peer review and aims to be replicable. As a human endeavor, science is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.	1D(+); 1H (+); 3A (+); 3B(+); 3C(+); 3D(-); 3E(-); 3F(-);
Scientific theories and laws	Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Scientific theories are inferred explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories.	6A (-);; 7A(-); 7B(-);8A (-); 8B (-); 8C(+); 8D(-); 8E(+)
Multiple methods of scientific investigations	There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is gained in a variety of ways including observation, analysis, speculation, library investigation and experimentation.	1C(-); 3D(-); 10A(-); 10B (-);10E(+); 10F(-)

Items with a (+) denote a correct score as either "Strongly Agree or Agree"; items with (-) denote a correct score as either "Strongly Disagree or Disagree".