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"Examining Student Understanding of the Nature of Science In Relation to Frequency of Exposure to Biotechnology Inquiry"

Abstract:

Student understanding of the Nature of Science is closely tied to experiences in the classroom and the purpose of this study is to examine that understanding in relation to the frequency of exposure to biotechnology inquiry using two week intervals. Students will begin their inquiry on the first day of class and will conduct various biotechnology inquiry activities throughout the semester including virtual, hands-on, historical and philosophical. Student understanding will be measured and recorded through pre- and post-testing as well as journaling.

Rationale:

Teaching the Nature of Science has been an ongoing challenge for me and various of my colleagues. I have tried many approaches in the classroom and have brought my industry experience as well with little success. After reviewing the literature, I am enlightened by a three-step method for teaching students the Nature of Science. First, students should be introduced to inquiry as early as possible through a high interest, context-based activity. Second, this interest and motivation must be sustained through ongoing inquiry with explicit instruction on the nature of science. Third, students must be given time to reflect on their learning and practice individually resolving their understanding of the nature of science. My goal is to accomplish these high interest activities through the use of biotechnology.

The Nature of Science can be taught with varying instructional styles therefore a review of the literature for data-based methods is warranted. Many review articles are easily accessed throughout the last ten years concerning teaching the nature of science, but very few are data driven. Being that the nature of science concerns habits of data collection and analysis to inform decision-making, it seems appropriate to focus this literature review on evidence for successful methods of teaching the concept. Through review, some common methods for teaching NOS materialized and can be summarized as the early introduction of a high interest context-based activity with continuing explicit instruction and reflection throughout the year. This integrative approach is appropriate for a topic that underlies every aspect of science practice and education.

The data-based articles reviewed concerned methods for teaching the nature of science and data collection to determine student understanding before and after instruction. Only half of the articles concerned pre-collegiate students and the other half represented pre-service teachers.

“It seems clear that teachers’ understandings of science as a discipline, and command of science disciplinary content knowledge, need to be established before they enter the K-12 classroom.” (Pasley, Weiss, Shimkus, and Smith 2004) Therefore, with a review of methods the teacher becomes central to suggestions for how best to teach the nature of science. Inexperienced teachers often depend too heavily on the textbook, and “Any change would perhaps require the elaboration of a new paradigm based on history, philosophy and epistemology of science, which in the long run could show to the students that the normal science presented in their textbooks is in most cases quite different from what science is all about.” (Niaz 2008) Yet it is critical to make this change and empower teachers to facilitate rather than direct the learning of NOS. After all, “Teaching an interactive inquiry course requires teachers who believe that students are capable of independent learning give proper guidance and support.” (Lord, Shelly, and Zimmerman 2007) By instructing pre-service teachers using the best methods for teaching NOS, their confidence to teach in this same manner is enhanced and will benefit students.

Agreement exists among all accounts that the introduction to nature of science occurs at the beginning of instruction and is motivational and preferably in context. “Science teachers generally agree that the first few meetings of a science class are crucial in setting the tone for the entire term, and sometimes for all future science courses for those students.” (Hohman, Adams, Taggart, Heinrichs, and Hickman 2006) Just how students are motivated encompasses most of the creative approaches in the literature and the importance of the motivational factor cannot be underscored. “Motivation would be required initially to make students want to participate in learning, and then be needed throughout the whole process until learning is complete. Motivation is therefore an essential pre-requisite and co-requisite for learning.” (Palmer 2009) These initial encounters include demonstrations, quick discovery activities, historical accounts or stories, and even examples of pseudoscience. Their long-term effectiveness went beyond the initial novelty into context for students. “In the ideal, lessons will hook students by addressing something they have wondered about, possibly but not necessarily in a real-world context.” (Pasley, Weiss, Shimkus, and Smith 2004) After gaining student interest, the momentum must be maintained with realistic expectations.

Students’ and pre-service teachers’ first encounter with the nature of science results in a struggle with a multiplicity of concepts. This review highlights realistic expectations and the importance of sustained explicit instruction and reflection on NOS. “During the pilot phases of the course, we were disappointed with students’ abilities to conduct quality research.” (Hohman, Adams, Taggart, Heinrichs, and Hickman 2006) Pre-service teachers were no different than students in the studies as they also lacked experience in applying NOS concepts. “These skills were not of a high standard though – some students had difficulty articulating investigable questions, their observations tended to be superficial, it was sometimes difficult to get them to propose explanations, in most cases their experiments were not fair tests, and their reports were often lacking in clarity – all of which suggested a lack of experience in this type of inquiry lesson.” (Palmer 2009) Following an initial high interest activity with explicit instruction in nature of science will improve students’ skills. Through follow-up inquiry activities with focused reflection, students will begin to view science in reality as opposed to the format of their text and traditional teaching. “It shows the students that scientific theories are not certain, but rather, are subject to change, given new evidence or new interpretation of old evidence. Furthermore, students may realize that facts do not necessarily accumulate linearly and that some discoveries are genuinely revolutionary, completely changing our way of thinking about how nature works.” (Eshach 2009) When their understanding begins to unfold, more controversial topics in science can be approached.

Storytelling came through in the literature review as a rather safe method for introducing more controversial topics. Through an historical and philosophical approach to science, issues such as gender, race, and religion can be studied while leaving students without feeling defensive. One such study laid the ground rules for nature of science then explicitly reviewed each rule in light of various religious stories. “It is clear that there is a danger that our storytelling analogy will enable some students to reject unpopular scientific claims out of hand, but our experience has been that a much, much larger problem is the tendency of students to reject or resist scientific claims because they think they are being presented as absolute truth.” (Bickmore, Thompson, Grandy, and Tomlin 2009) Interestingly, misunderstandings of the nature of science interfered with these students ability to address the issue of religious beliefs and resolve them with respect to their scientific beliefs. Again, storytelling is a method for teaching about the nature of science and should accompany true scientific inquiry activities. “An explicit approach is more effective in improving pre-service teachers’ understanding of NOS than an implicit approach. However, to encourage pre-service teachers to integrate their understanding of NOS with their science instruction, explicit instruction of NOS needs to be conducted in a science context." (Seung, Bryan, and Butler 2009) Allowing students time to learn from explicit instruction and reflect on and integrate this learning is essential. Performing laboratory inquiry is the best method to accomplish this task.

Once an initial understanding of the nature of science has occurred, students should be allowed to conduct experiments using their newly acquired skills. "By performing the labs, the participants focused on how to arrive at and evaluate an answer in a scientific manner, rather than focusing on the answer that is accepted by the scientific community." (Kattoula, Berma, and Martin-Hansen 2009) It should be emphasized that these labs are not dictated by the teacher rather they are created by the student to maintain a high level of interest and promote learning. "The results of this research show that the explicit, reflective process allowed participants to examine their NOS understandings, which thereby fostered changes in their understandings." (Kattoula, Berma, and Martin-Hansen 2009) Students in a study who only performed inquiry experiments without reflection on their application to the nature of science did not perform well on surveys to show their understanding of how science works. "This focus on the development of an idea, rather than on the idea itself, was intended to specifically target student learning about the nature of scientific knowledge and inquiry." (Borda, Kriz, Popejoy, Dickinson, and Olson 2009) It did not. Ongoing inquiry and reflection on the nature of science were shown in the literature to promote understanding following a high interest introductory activity and results were magnified by being presented in context.

A review of the literature has shown that teachers can use the following method for teaching the nature of science: 1) Begin with a high interest activity in context, 2) Immediately follow with explicit instruction on the NOS, and 3) Maintain momentum with ongoing inquiry and reflection. Variations in the types of motivating activities and context-based labs allow for creativity and will ultimately determine the success of this approach. Use of the method is currently prescribed for pre-service teachers as well as students learning science. "Cooper's advice is particularly relevant for science education researchers and science teachers who may not have had the experience of doing high-level scientific research themselves, but who need, nevertheless, to be experts in the process of doing science." (Niaz, Klassen, McMillan, and Metz 2010) While science teachers are learning to apply the nature of science to their lessons, students can be simultaneously learning the tenets of science and applying them to stories and inquiry activities in the classroom. "The results of these investigations confirmed their understanding of these concepts, and that early discussions of the nature of science increased the value of later lessons of scientific topics." (Hohman, Adams, Taggart, Heinrichs, and Hickman 2006) This simple method for implementing the study of NOS in education will enhance every area of science that is explored by equipping students and teachers with scientific habits of mind. Habits are only formed through repetition, so get their attention in context and teach them NOS explicitly then allow them time to work and reflect like real scientists.

The unanswered question for my classes is how frequently to practice inquiry and reflection. I believe most teachers conduct inquiry activities at least every two weeks, so I have chosen this frequency for my initial action research. Students will have a hands-on, virtual, historical or philosophical inquiry activity once every two weeks following an engaging first exposure at the beginning of the year. Each activity will be taught explicitly and students will be given time for reflection. Student understanding of the nature of science will be determined through pre-, mid- and post-assessments as well as weekly journaling.

My action research questions are:

1. Will student understandings of the Nature of Science improve given an initial, context-based inquiry activity followed by ongoing explicit instruction and reflection?

2. Does the frequency of explicit instruction and reflection affect student understandings of the Nature of Science?

3. What is the optimum frequency of explicit instruction and reflection for students' understandings of the Nature of Science?

Action Research Intervention:

To study student understandings of the Nature of Science, an area of inquiry should be chosen that is both challenging and interesting to students. Most individuals are interested in biotechnology and can learn valuable life lessons by following the bench to bedside to bench rationale. By asking relevant questions, students will make their way to the bench where chemistry can be used to improve patient care. By providing my first year Chemistry Honors students with these ongoing biotechnology exposures, I hope to peak their interest in chemistry and teach them how the Nature of Science is used in all aspects of translational research.

Connections to Bench to Bedside Summer Institute:

After spending time with the staff and scientists at UF, I have many stories to share with students concerning the types of inquiry I want them to participate in. I will describe the many aspects of translational research and have access to the equipment and expertise for performing biotechnology inquiry activities with students. Given the curriculum constraints for Chemistry I Honors, biotechnology will be interwoven into the required activities for the course as high interest applications of basic science. A tentative schedule of activities follows with one highlighted lesson plan attached.

Date	***Activity***	***Objective***
8/5/2010	Pre-Assessment VNOS (form B)	Determine student understandings of the Nature of Science using a recognized data collection instrument.
8/6/2010	Initial high-interest, context-based inquiry activity “New Society”	“New Society” activity introduces inquiry as students work like scientists to discover a new society before starting safety training.
8/20/2010	Inquiry and lab skills introductory experiment “Mixture Separation”	“Mixture Separation” applies physical concepts and allows formative assessment of student laboratory skills to inform instruction prior to full safety training.
9/3/2010	Initial high-interest, context-based inquiry lab “Polymers and Toy Balls”	“Polymers and Toy Balls” gets students excited about the applications of chemistry to the art of play. Manufacture and testing of their toy balls introduces the concepts of science and engineering.
9/17/2010	Introduction to techniques for exploring the unseen through “Wave Particle Duality” inquiry and “Flame Test Analysis” lab	“Wave Particle Duality” and “Flame Test Analysis” introduce students to the micro-world of chemistry as they practice discovery of the unseen and use modeling techniques.
10/1/2010	Experience with “Hydrated Crystals Lab” and return to applications of “Recrystallization and X-Ray Diffraction”	“Hydrated Crystals Lab” for determination of the formula for a hydrate followed by “Recrystallization and X-Ray Diffraction” applications of this purification technique.

10/15/2010	Reinforcement “Empirical Formula Lab” coupled with an empirical evidence inquiry activity Bioethics Module 1 of 4 for the academic year	“Empirical Formula Lab” reinforces concepts of molecular analysis coupled with “Empirical Evidence” Inquiry activity “Bioethics Module 1 – Concepts and Skills” for compare and contrast and to explicitly teach discussion with NOS habits of mind.
10/29/2010	Laboratory analysis technique to determine “Activities of Metals” with inquiry activity.	“Activities of Metals” laboratory analysis techniques followed by application lesson concerning heavy metal poisoning.
11/12/2010	Introduction to conservation of mass through inquiry “Mole Ratio” lab and the story of Antoine Lavoisier	“Mole Ratio” inquiry lab introduces key concept of conservation in science is enhanced with a history and philosophy of science story concerning the father of chemistry – Lavoisier.
12/3/2010	Technique of “Gravimetric Analysis” mastered then contrasted with the biotech “DNA Extraction” technique	“Gravimetric Analysis” chemical lab followed by “DNA Extraction” biotechnology lab to illustrate similarities and differences in these two disciplines.
12/10/2010	Mid-Assessment VNOS (form B) and Bioethics Module 3 activity	Assess student understandings of the Nature of Science using a proved data collection instrument. Bioethics Module 3 – The Case of Organ Transplantation as informal assessment of student abilities to discuss using NOS concepts
1/7/2011	Observe a “Heating Curve for Water” to dispel misconceptions and apply new knowledge to controversial topic.	“Heating Curve for Water” dispels student misconceptions through hands-on activity then extension into the Origins of Life on Earth Webcast and discussion.
1/21/2011	Biotechnology skill “Gel Electrophoresis of Dyes” and “Tie Dye” organic dyes activity.	“Gel Electrophoresis of Dyes” introduces skills in biotechnology followed by chemistry of fiber reactive dyes activity through high interest Tie Dye T-shirts.
2/4/2011	Learn separation techniques of “Chromatography” and applications of Proteomics to	“Chromatography” chlorophyll lab shows basic separation techniques; Enhancement review of “Pharmaceutical Proteomics”

	Pharmaceuticals	applications.
2/18/2011	Learn "Titration" lab technique then apply this new skill to the problem of Vitamin C deficiency	"Titrations" skills lab followed by the analysis of ascorbic acid in vitamin C tablet or selected juices – implications of vitamin C deficiency past and present.
3/4/2011	Solve the problem of "How Blood Maintains pH" using student designed demonstration then explore Bioethics Module 5	"How Blood Maintains pH" student demonstration followed by an exploration of Bioethics Module 5 – The Power and Peril of Human Experimentation with explicit instruction in discussing with NOS habits of mind.
3/18/2011	Basic skills and analysis introductory "Calorimetry" lab then student designed calorimetry lab application	"Calorimetry and Hess's Law Lab" for basic skills and analysis, then "Energy in Foods" student designed calorimetry lab as biotechnology application – comparing natural vs. genetically engineered foods
4/8/2011	Application of "Beer's Law" using the CBL and experiment into a local gulf waters problem	"Beer's Law" CBL Lab introduction with application to photosynthesis in gulf waters during algal blooms.
4/22/2011	Analysis of weak biological acids "Measuring Ka for Acetic Acid Titration" and journal review of weak acids in biofuels	"Measuring Ka for Acetic Acid" provides an understanding of weak biological acids then review of a journal article concerning the role of weak acids in biofuel production.
5/6/2011	Post-Assessment VNOS (form B) and Bioethics Module 3 activity	Final assessment of students understandings of the Nature of Science; discussion of Bioethics Module 3 – Ethical Issues in Genetic Testing as informal analysis of student discourse in NOS issues.

To foster ongoing interest and retention of biotechnology inquiry, students who continue through my 3 year program will be involved in continuing activities. After an introduction in Chemistry I Honors, students will explore more of the chemical applications to biotechnology during Advanced Placement Chemistry including forensic investigations and exposure to environmental quality testing and remediation specifically as it relates to green chemistry initiatives. During their senior year, Advanced Placement Biology students will actively seek out biotechnology experiences by participating in the Mission Biotech gaming program, visiting with doctors and clinicians, and addressing the use of biotechnology in patient care specifically the area of genetic engineering. The goals of this 3 year plan are to equip students with a broad understanding of the implications of biotechnology in their personal and professional lives.

Data Collection and Analysis:

A standard data collection instrument for measuring student understandings of the Nature of Science (NOS) will be used as well as informal discussion of topics in bioethics with assessment of student abilities to apply NOS habits of mind. I like the mixed quantitative and qualitative data which will allow a cold analysis of our success and at the same time a window into student perceptions and applications of the inquiry activities. I have decided to use the VNOS Views of Nature of Science (form B) which is open ended. Students will be given the assessment pre-, mid- and post-term. A rubric for grading responses will be developed and attached with the data. The informal discussions will center around four modules in bioethics that allow for student reflection and open discourse of their positions on controversial topics. A rubric for their recorded responses will also be developed to allow for data analysis.

Literature Cited:

See Attached

Budget and Budget Justification:

Budget items for my action research include materials for copying and administering the test, journaling and lab materials for the inquiry activities.

Item	**Description**	**Qty**	**Cost**
Copy Paper	Case of white copy paper for student assessments and activity handouts	1	25.00
Equipment	Hot plates for DNA Extraction Lab	4	500.00
Consumables	Agarose gel and pipette tips	4 sets	75.00
Total:			600.00

Permissions:

I have obtained permission from my principal and district to participate in this program and complete an action research plan. I also obtain release forms from all of my students at the beginning of each school year for using their images and work in my studies. In addition, I plan to send a letter to parents explaining my research and asking their permission to include their student anonymously in the study. I will include an option on each questionnaire for students to answer yes or no about including their answers in the study.

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