Proceedings of The National Conference
On Undergraduate Research (NCUR) 2019
Kennesaw State University
Kennesaw, Georgia
April 11-13, 2019

Developing and Assessing an Environmental Science-Based Education Module to Support the Nature of Science and Increase Science Literacy

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Abstract

In today's rapidly evolving career climate, there is an increased need to foster student understanding and appreciation of the scientific method, as well as the higher-order cognitive skills that accompany this process. A partnership with ANP Technologies, a Delaware company that manufactures and produces products relating to environmental monitoring, has led to the development of a classroom-ready educational tool. This module uses a sequence that prompts students to engage, explore, explain, and evaluate while meeting various concepts within the Next Generation Science Standards. Located in Dover, Delaware, Wesley College is a minority-serving liberal arts institution where non-science majors are required to take a topical science course emphasizing scientific literacy. Prior to this project, there was no common instructional tools or assessment between the various class sections. The module developed in this project was piloted in the spring of 2019 along with a post-test to assess module effectiveness and consistency between sections. It was hypothesized that there would be no significant differences between average post-test scores of the different sections following the implementation of the module and that students would achieve proficiency (70% or higher) on at least half of the questions. Results confirmed the consistency between the sections as there were no significant differences in mean post-test score. Students were able to meet threshold on 7 of the 12 questions, suggesting this module could be useful in scientific literacy education.

Keywords: STEM Education, Inquiry-Based Learning, Pesticide Testing

1. Introduction

1.1 Project Background

Wesley College is a minority-serving liberal arts institution in Dover, Delaware with a considerable number of students from populations that traditionally have had limited access to higher education.[1] In the current Core Curriculum, non-science majors must complete a 3-credit science course (SN 100) to introduce students to scientific research and inquiry practices. The topic of this course varies with interest of the instructor, but incorporates common objectives including the use of the scientific method to "formulate questions, conduct a literature review, state a hypothesis, design an appropriate experiment to test the hypothesis, collect and analyze data, draw conclusions, and discuss the relevance of data."[1] This class was also designed for freshman and sophomore students to inspire undeclared students to a pursue career in STEM or have students complete a STEM minor. Since there were no means to assess these outcomes between the topical sections, the goal of this research was to develop a module that emphasizes scientific literacy and has the potential to establish consistency between sections. It was hypothesized that there would be no significant difference in post-test scores between sections following the completion of this common instructional module, and that students would achieve a 70% proficiency threshold on at least half of the questions. Wesley College science majors are required to score a minimum grade of 70% to pass and gain credit for a class. As such, this threshold was selected for the students in the pilots to measure if they had mastered the content. To meet this goal, this module needed to have a solid educational framework.

1.2 Educational Approach

The primary goals of science education in the United States have changed over time. In the mid- to late 1800's, high school classes mirrored college courses, "…these courses stressed science as content, with little attention given to investigation or technology; they rarely reflected on how scientific work is conducted."[2] Events like World War I and World War II influenced science education with the need to stress the practical aspects that apply to everyday life. This was solidified with a 1924 Committee on the Place of Science in Education of the American Association for the Advancement of Science report that "…emphasized the importance of scientific thinking as a goal for science teaching."[2] Reform continued to evolve in response to the Space Race of the 1950s and 1960s, when the United States felt that science education system was falling behind that of the Soviet Union, as students were not interested in science and mathematics[2]. These events sparked the change in view from science as a collection of "knowledge" to a belief that science should be a process that engages students to instill the skills needed to succeed in life. Examples of current learning theories that foster these types of skills include active- and inquiry-based learning which allow students to develop critical thinking while performing experiments that are both interesting and engaging.

Active learning is an instructional approach that engages students in the learning process; this can look like anything from interactive demonstrations to peer instruction. Research shows that this type of learning has a positive impact on student learning and enjoyment[3]. Teachers have sought to develop different ways to utilize active learning in their classrooms. Inquiry-based learning can often be found alongside active learning techniques. Also known as problem-based learning (PBL), it is a type of curriculum design where students are "engaged in the diverse components of problem-solving, interdisciplinary curriculum, open-ended questions, hands-on activities, and group work"[4].

To improve student understanding of the scientific process, the Next Generation Science Standards (NGSS) were developed with a more integrative approach to teaching science. This project was spearheaded by a collaboration between the National Resource Council, the National Teachers Association, Achieve, and the American Association for the Advancement of Science and was freely published online in 2013[5]. The objective of the Next Generation Science Standards is to have students develop the traditional in-depth understanding of content, while also developing communication and problem-solving skills[5]. Scientific literacy has become increasingly important in today's current political climate. A scientifically literate person is one who can ask questions; can read, understand, and discuss articles that are scientific in nature; and can evaluate the quality of scientific evidence and data that is presented within an article[6]. These traits are beneficial in the workplace and for creating a collective society that can make informed decisions.

There have been concerns about the implementation of the standards for several reasons. For some groups of educators, the transition to active- and inquiry-based learning can be difficult. These are teachers who have only experienced traditional lecture methods of teaching, which reflects in their teaching styles. A reluctance to design new lesson plans is common in these environments. Additionally, the vast majority of undergraduate college and high school students have not yet had the opportunity to participate in the new NGSS curriculum. It can be difficult for students who have never experienced active learning to participate in these new types of learning environments which demand reasoning and thought.

The largest barrier to widespread adoption is the financial burden that the materials for these new learning styles require. At this time, there is no federal funding or grants tied to the adoption of the NGSS, so schools are left to find their own resources to incorporate learning styles promoted in the Standards[5]. To help create scientifically literate students, more education modules need to be designed around the Next Generation Science Standards. These modules should be relatively low in cost, allowing greater dispersal of these products to all school settings.

The goal of this project was to design and implement an educational module based on food-safety and pesticide testing that promotes scientific literacy and an appreciation of science. The module utilized the low-cost NIDS ACE Rapid Pesticide Test by ANP Technologies, a Delaware-based company. This commercially available test has no prior use in education but could be a marketable curriculum product for low-income, minority-serving schools. The results provided a better understanding of the concepts that should be emphasized within the next module as well as ways for improving the corresponding assessment instrument, which will be piloted in the fall semester of 2019. The author also looked for additional factors outside of content and module design that influenced its' efficacy.

2. Methodology

2.1. Curriculum Building Coursework

The author enrolled in a three-credit graduate-level Curriculum Building class to become familiar with science standards, learning theories and techniques, and the design of educational materials. In the course, the author was tasked with investigating the Next Generation Science Standards in-depth, analyzing existing curriculum products at various grade levels, designing a sample curriculum, and critiquing peer-designed curricula. The professor of this class asked the author to create a sample environmental science curriculum in a way that is user-friendly for all teachers, especially those without science backgrounds, as this class contained mostly non-science pre-service teachers.

2.2. ANP Technology Kits

ANP Technologies is a world leader in developing innovative nanotechnologies, as well as a premier provider of nanobiotechnology-based products for biological defense, medical diagnostics, and food safety testing[7]. The ACE III test detects organophosphate and carbamate pesticides and toxic metals that may contaminate fruits and vegetables. To understand how the ANP product worked, the author, research assistant, mentors, and staff from ANP Technologies met for an afternoon training session. ANP staff described how the test works and provided a demonstration with practice for students and faculty. The NIDS ACE III Rapid Pesticide Test is a prepackaged kit that includes a disposable pipette and a 2-well test strip and retails for $6.99.

2.3. Module Design

The author developed an educational module that aligns itself with the Next Generation Science Standards, striving for a five-day sequence assuming a class time of fifty minutes per session. Sample standard alignments will include practices and core ideas like asking questions and defining problems; obtaining-, evaluating-, and communicating information; planning and carrying out investigations; analyzing and interpreting data; and engaging in argument from evidence[5]. A common theme that arose during the analysis of the Next Generation Science Standards was the use of a series known as the BSCS 5 E Instructional Model. First used in the 1980s, the Biological Sciences Curriculum Study's model consists of the following stages: engage, explore, elaborate, explain, and evaluate[8]. The author decided to utilize this sequence in the module design. A brief overview is given below.

Day One sets the stage for the entire exercise by prompting students to think about where their food comes from, focusing on the concept of food miles and carbon footprints, as well as how agriculture has industrialized over time. Day Two examines how pesticides are used and how they can be harmful to both the environment and human health. Day Three and Day Four challenge the students to design and carry out an experiment to test for pesticides on fruits and vegetables. Day Five prompts students to summarize their findings and then engage in argument from the collected evidence to make decisions about pesticides.

2.4. Post-Test Construction

The author oversaw a freshman research assistant in the Environmental Science program who developed a post-test that could evaluate student learning from the module. The test was created by rewriting questions from existing educational tools to evaluate student understanding of the nature of science[9,10]. The use of this instrument with undergraduate students was approved by the Wesley College Institutional Review Board (IRB).

2.5. Module Execution

The module was piloted in three sections of SN100, Frontiers of Science, and two sections of BI100, Introductory Biology, at Wesley College in the spring of 2019. SN100 topics vary depending on the instructor's interests; classes offered this semester included Diabetes, Cancer, and Climate Change. Introductory Biology is offered for non-science majors to gain an understanding of the fundamental facts of modern biology and introduce them to a lab environment.

Before the pilot, the author met with each instructor to set a timeline and schedule for each class. Two of the three SN sections, Diabetes and Cancer, only had two 1.25-hour class periods available. A condensed module was designed based on the instructor's specific needs and the best way to connect the module to their individual class topics. This condensed module was also used in one three-hour lab period for the BI100 sections. The third section of SN100, Climate Change, was able to complete the full five-day module. Students in all sections, despite differences in time commitment, designed and executed a research experiment using the NIDS ACE III test kit, as this is the most emphasized portion of the module. Each professor introduced the module to their class; the author assisted as needed. All materials were provided to the instructor. Professors were given the option of how, if at all, they wanted to assess their students' participation. The Diabetes section and the two BI100 sections elected not to grade or incentive their students, while the Climate Change and Cancer sections did.

2.6. Statistical Analysis of Assessment

The post-tests from these pilots were graded and the total score for each student was recorded in Excel; means were calculated by section. A one-tailed t-test assuming unequal variances was performed between the sections. Additionally, student answers on each question were coded into Excel as one or zero, depicting if they had or had not gotten the question correct. The percentage of students who correctly answered each question was calculated for the whole group.

3. Results & Analysis

3.1. Analysis of Scientific Literacy

Sixty-two students in the SN100 and BI100 sections completed the post-test.

Table 1. Mean total post-test score per section

Section	**Post-Test (%)**
SN 100 (Diabetes)	58
SN 100 (Cancer)	63
SN 100 (Climate Change)	69
BI 100 Introduction to Biology	69

Despite differences in time and incentive, there were no significant differences in mean total score between the sections. Students in the Climate Change section who received a grade for their test score and had the longest duration of exposure achieved the same average score (69%) as the Introductory Biology sections who received no incentive and shorter exposure time.

Table 2. Mean percentage of students to correctly identify variables and answer scientific method questions on post-test

	Post-Test (%)	Meets Threshold?
Scenario Identification		
Dependent Variable	57.1	NO
Independent Variable	51.8	NO
Control Group	76.8	YES
Experimental Group	66.1	NO
Constant Variables	66.1	NO
Conclusion and Explanation	87.5	YES
Multiple Choice + True/False Response		
Theories can be changed by new evidence	91.1	YES
The results of experiments can be shared	78.6	YES
The Scientific Method is a series of logical steps followed in solving a problem	87.5	YES
Dependent Variables change in response to the manipulated variable	91.1	YES
Controlled experiments are those in which only one variable is manipulated at a time	89.3	YES
A hypothesis is a potential explanation for observations that can be tested	32.1	NO

Students were able to meet the 70% threshold in 7 of 12 questions. They were best able to comprehend both the ongoing nature of scientific theories and the concept of the dependent variable changing in relation to the manipulated variable. Students were also able to define the scientific method, identify control groups, and understand the concept of a controlled experiment at an acceptable level. Students struggled the most in their ability to define a hypothesis, as only a third of students answered correctly; most students misconceived a theory for a hypothesis. Students also had difficulty identifying dependent and independent variables in a given experiment.

4. Discussion

No significant differences were found in average post-test score between sections, supporting the hypothesis that the different sections of SN 100 are consistent in their ability to answer questions about the scientific process following the module; this suggests that common class objectives are being met. Students were also able to achieve proficiency in 7 of the 12 questions, supporting the hypothesis that students would reach acceptable performance on at least half of the questions. As students could not meet the threshold in identifying variables and on the difference between a theory and a hypothesis, future work will revise the module to dedicate more time exploring the topic of hypothesis testing to address this common misconception. To improve student ability to identify variables, the module will be adapted to have students share their experimental design plans so their peers can provide feedback.

The author observed that students became most engaged when they were allowed to work together in groups to design and carry out their own experiments. Students utilized their creativity to design experiments that compared fruits grown in different geographic regions of the United States and from other countries, fruits labeled as organic to those deemed non-organic, and fruits that have been cleaned using different washing techniques. Once provided with their selected materials, the groups were excited to get out of their chairs and use the ANP kits to answer their questions.

Additional work will take what was learned in this experiment to revise the testing instrument by adding additional questions to evaluate the comprehension of theory and hypothesis, as well as several pesticide and food mile content questions to gauge student engagement on Day One of the module. Demographic questions will be included to seek trends between genders, races, and first-generation college students. The reconstructed test will be utilized before and after the module to measure improvement in test scores, as well as student opinions toward science.

The importance of class time management was observed. In sections with the shortest instructional time, conducting the experiment ran longer than expected, leaving students with only a few minutes to complete the post-test. This could mean that students rushed through the questions instead of taking their time to answer. To allow students ample time to work through the questions, the pre- and post-test will not be incorporated into the time requirements of the module, but rather will be given on the first day of the course (to establish a baseline) and a week following the treatment. The post-test will also be given during the last week of class to observe the effects of the module over time.

The revised module and assessment instrument will be used in the SN 100 sections during the fall semester of 2019 at Wesley College. To better refine experimental design, one section of SN 100 will serve as a control group. They will take part in the pre- and post-tests but will not receive the module. This will allow the author to compare changes in scientific literacy from a population who participated in the active- and inquiry-based learning techniques present in the module with one who participated in traditional learning to evaluate the efficacy of the module.

Taking what was learned in this educational trial and after making the proper alterations, this module has the potential to provide a consistent means to evaluate the core scientific principles intended to be taught in the SN 100 courses at Wesley College. Additionally, this exercise will offer an opportunity for all students in SN 100 to participate in an inquiry-based scientific experiment, which can be difficult with the topical nature of the class. Based on the findings of the Fall 2019 pre- and post-test study, this learning method and content could have the potential to become a tool to increase scientific literacy within the SN 100 classes and in other academic settings.

5. Acknowledgements

The author wishes to express her appreciation to Dr. William Kroen and Dr. Stephanie Stotts who served as mentors for this study, Cassandra Miller for her research assistance, and Greg Witham of ANP Technologies for his cooperation. She would also like to recognize the significance of a Delaware Biotechnology Institute's Delaware Bioscience Center for Advanced Technology/Applied Research Collaborations grant, without which this collaboration would not have happened.

Wesley College acknowledges support from an NSF-EPSCoR award (OIA-1757353, Grant No. IIA-1301765), an NSF (DUE) S-STEM grant 1355554 (Wesley College Cannon Scholar program), the State of Delaware, and the Delaware INBRE program, supported by a grant from the National Institute of General Medical Sciences – NIGMS (P20 GM103446) from the National Institutes of Health and the State of Delaware. The opinions and views expressed in this article are those of the authors and do not necessarily reflect the opinions and views of any of the federal and state funding agencies.

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