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Engineering Education Collaboration: Innovative Pedagogical Methods for High School and University Environmentalists

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AC 2010-2129: ENGINEERING EDUCATION COLLABORATION: INNOVATIVE PEDAGOGICAL METHODS FOR HIGH SCHOOL AND UNIVERSITY ENVIRONMENTALISTS

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Abstract

This paper presents an innovative teaching approach, how it is implemented, student response results of the implementation, and the assessment of impact on student learning. The findings are based on surveys given to the students after each lab lesson taught in partnership with university (Project STEP) and community members.

The purpose of this paper is to showcase authentic molecular technology research methods that have been incorporated into a high school level water quality study in cooperation with a watershed restoration program. Typically, water quality studies focus on chemical analysis such as pH, dissolved oxygen, biochemical oxygen demand, orthophosphates, nitrates, temperature, turbidity, macro-invertebrate survey and fecal coliform cultures. This paper shows that by using molecular technology, the source of pollution in the watershed can be determined.

Students in these high school science classes are engaged in authentic experiences to identify and analyze human impact on the environment and local ecosystems. Students also are able to collect and analyze data using computer and molecular technology. With help from the local watershed managers, the AP high school students filter bacteria, isolate their DNA, use the polymerase chain reaction (PCR) to amplify the DNA, and finally use gel electrophoresis to trace the DNA to its source (human, cow or intestinal bacteria). In this way, both AP and Physical Science students can extend the water quality study to trace the pollution to a point source. This is a unique approach to high school science laboratory activities.

All watershed data is collected and organized using Microsoft Excel spreadsheets and graphing software. Students are able to form conclusions using technology that is used in today's workplace. Initial findings regarding student response to this innovative teaching approach indicate that the actual application of molecular technology methods, employed to solve a problem with an unknown conclusion, is very meaningful to students. Unlike other traditional classroom labs, neither the teacher nor the students know what the results of the watershed tests are before-hand. This type of innovative teaching approach, supported by research on inquiry lessons, provides a more memorable experience for the students – actually performing technology that they would otherwise only read about in textbooks and articles. This paper will provide other instructors with a kind of roadmap, but one where there are experiences of many partners and students that highlight both successes and challenges.

Project STEP

The chief goal of this National Science Foundation funded project is to produce scientists, engineers, and secondary mathematics and science educators who are experienced in developing and implementing authentic educational practices. The graduate students, called STEP Fellows, are the main focus of the grant. The STEP Fellows, 15 in the last three years, are trained to bring their complex graduate research to an understandable and interesting K-12 level. This process instills better communication skills in the STEP Fellows and breaks any reservations of working with the K-12 environment once employed as a university faculty member. The secondary goal of Project STEP is to impact student learning by relating STEM content to urban city issues through the use of hands-on, technology-driven, inquiry-based projects that also relate to desired curriculum standards. Students need an understanding of STEM and the reasons to pursue STEM careers; over 3,000 students have been exposed to STEM lessons in the past three years with Project STEP. Teachers of these students are involved in this process as well, and 36 different teachers have participated in the STEP program since 2006. Lastly, Project STEP focuses on the sustainability of the program itself. The university faculty participants, six primary investigators and four coordinators, play a large role in facilitating the promotion of community partnerships with teachers, K-12 students, and Fellows. In this paper, we outline an innovative teaching approach in a high school setting, how it is implemented, student response results of the implementation, and assessment of impact on student learning. The findings are based on surveys given to the students after each lab lesson taught in partnership with university and community members.

Theoretical Framework

We embrace a socio-cultural theory as the framework of this research. We look to the process of learning, not the product constructed as evidence of authentic practice. There is an emphasis on the interaction between learners and learning tasks. Since STEM education is currently in the spotlight, gaining insights into Project STEP's sustainability, using a socio-cultural perspective is important. Working with the urban youth in Cincinnati, Roth and Lee's [1] statement that "a researcher… does not separate the poverty or culture of urban students' home lives from conditions of schooling, consideration of the curriculum, problems of learning, or learning to teach under difficult settings" (p. 218) becomes vitally important. Wertsch [2] also shows the relationship between all aspects of the mind and setting as inseparable in the process of learning. In this way socio-cultural theory is about the whole scene of learning, the process, not the individual pieces or parts in isolation that create the scene. This "whole scene" approach will sharpen our understanding of how STEM research, taught in Project STEP by present day graduate student Fellows (of which most will become future university faculty), can translate and then activate knowledge through Project STEP lessons, students, teachers, and Fellows.

To put the contents of this paper in proper context, it will be appropriate to first briefly describe the teacher training provided to the Fellows as they mature to develop STEM lessons and implement them in secondary school mathematics and science classes. The up-front preparation occurs in "Instructional Planning," a formal three credit hour course offered by the College of Education, taught primarily by the Grant Coordinator (co-author) with support provided for a College of Education faculty member who is a Co-Principal Investigator on the grant. The course addresses a wide range of topics: STEM achievement standards, lesson and unit planning, instructional models of teaching, instructional management, the nature of students, skills of connecting with students at a personal level, understanding student cultures and responding appropriately, and assessment or evaluation of student learning and instructional efforts. The course is scheduled during the summer before the Fellows enter the classrooms, but while they are engaged with upper elementary to high school students in an enrichment summer academy held at UC. When the school year begins, Fellows enroll in another Education course, "Field

Practicum," which is a one credit hour course taken in the fall, winter, and spring quarters. This course supports Fellows as they encounter (frequently) unfamiliar territory upon their entry into the schools. They are required to focus on important aspects of the teaching-learning situation and the culture of the school and students as well as their relationships with the teachers. Structured and focused discussion sessions are managed by the Grant Coordinator. This conversation leads to community building among the group of Fellows, especially since returning Fellows (in their second year) are included. Continued preparation and the refinement of the skills of Fellows for their roles in schools is accomplished through the weekly Field Practicum seminars in the spring quarter where they share and discuss school experiences and collaborate on current and future efforts as a team. These seminars are managed by the Grant Coordinator along with university faculty and guest presenters.

Lesson Creation

Each STEP Fellow creates at least five major STEM lessons, most including several days of teaching, during one academic year. Project STEP lessons are created by the Fellow, but are enhanced by the K-12 teachers, university faculty working with the grant (Principal Investigator or PI and Co-Principal Investigators or Co-PI), grant coordinators, and university faculty working directly with the graduate Fellows on their studies (Research Advisors). The teacher identifies the need for a lesson in the curriculum map for the course, and the Fellow develops the ideas and contents of the lesson in consultation with his/er research advisor and project PI/Co-PIs, which are finally checked for correctness by one of the Co-PIs. Pre- and post-test are part of the lesson development. The teacher leads the effort to develop the post-test for the lesson. A well-defined template is used by the Fellow to create the lesson, which can be disseminated on the project's website soon after its implementation. This template consists of the following blocks: 1) Summary – goal to be achieved by students; 2) Objectives – skills to be acquired by students; 3) Standards to be addressed; and 4) Lesson Information – Grade Level, Subject Area, Duration, Setting, Materials Needed, Background Knowledge, Lesson Plan(s) details, and Additional Resources (learning objects, timelines, assessment rubrics, surveys, etc.). Item 4 includes detailed information provided via hotlinks. The Fellow submits the final lesson to the Grant Coordinator for checking and approval before implementation. On the average it takes about six weeks to develop a lesson before implementation.

Most of the lessons that have been created since 2006 focus on secondary STEM content. The results obtained by reviewing these lessons indicate that 59, 62, 66, and 78% of STEP lessons analyzed contain components of mathematics, engineering, technology, and science, respectively (see Table 1). Interestingly, 97% of lessons at least partially contain components from at least three of these disciplines. When evaluating lessons that definitely contain elements from, science, technology, engineering, and/or math, 82% contain content from at least two of these four STEM areas, suggesting a trend that STEP lessons are interdisciplinary.

More than 97% of lessons address or partially address the use of multiple learning styles, and more than 93% of STEP lessons contain a real-world application. While nearly 60% of lessons deal with societal or social impacts, less than one-third of the STEP lessons focus on connecting the material to potential careers.

Component	% of lessons that addressed this component	% of lessons that partially addressed this component
Science	78.13%	3.13%
Technology	65.63%	25.00%
Engineering	62.50%	34.38%
Math	59.38%	21.88%
Oral assessment	3.13%	3.13%
Written assessment	90.63%	3.13%
Misconceptions	15.63%	18.75%
Review/Essential Questions	31.25%	21.88%
PowerPoint	59.38%	0.00%
Multiple learning styles included	59.38%	37.50%
Pictures and/or diagrams	84.38%	12.50%
Application	93.75%	6.25%
Social impact	59.38%	25.00%
Career connection	34.38%	31.25%

Table 1: Percentage of lesson components.

Of interest is that only 16% of STEP lessons address potential misconceptions associated with lesson content, which may be explained by the evolution of the lesson plan development requirements as Project STEP has itself evolved over the last eight years.

An Innovative Teaching Approach

Project STEP's Civil and Environmental Engineering Fellow, Gina Lamendella, worked in conjunction with her research advisor, Dr. Dan Oerther, the AP Biology teacher at Norwood High School, Leslie Hadaway, the Physical Science teacher at Norwood High School, Megan Urbaitis, and community leaders on the Mill Creek Restoration Program to create the lesson described below.

The Mill Creek is highly polluted which is negatively affecting the environment and presents a risk to human health. Norwood High School students used chemical, physical and biological methods to measure and analyze different aspects of the water's quality. Students interacted with several water quality professionals at the collegiate and state level, providing students with the opportunity to see potential career paths of environmental scientists and engineers committed to improving and protecting their environment. They also were introduced to careers such as environmental lawyers and policy makers who work to define legislation that ensure water is maintained at an appropriate quality for its identified use. The Clean Water Act, water quality standards and Total Maximum Daily Loads for pollutants were discussed as background to the lesson.

Environmental water quality pertains to water bodies such as lakes, rivers and oceans. Water quality standards vary significantly due to different environmental conditions, ecosystems and intended human uses. Toxic substances and high concentrations of certain microorganisms can present a health hazard for non-drinking purposes such as irrigation, swimming, fishing, rafting, boating and industrial uses. There is some desire among the public to return water bodies to pristine or pre-industrial conditions. Current environmental laws focus on the designation of uses and therefore allow for some water contamination as long as the particular type of contamination is not harmful to the designated uses.

The unit objectives were to allow ninth grade Advanced Physical Science students and eleventh and twelfth grade Advanced Placement (AP) Biology students to understand the importance of monitoring water quality from protection of human health, environmental ecosystems, and economic standpoints. Although individual variations of the lesson were constructed to be age-level and ability-level appropriate, both groups of students traveled to Vorhees Park and Kheener Park within the Mill Creek Watershed to conduct their initial sample collection and water quality testing. Students were asked to define water quality standards, explain traditional and novel methods for analyzing water quality, analyze water quality of the Mill Creek Watershed, and finally assess whether the Vorhees Park and Kheener Park sites at the Mill Creek Watershed are in compliance with water quality standards.

The AP Biology students employed novel molecular biology techniques to identify potential sources of fecal pollution within the local urbanized Mill Creek Watershed and to utilize traditional water quality testing methods to determine the health of this creek. We then used DNA extraction, Polymerase Chain Reaction (PCR), and gel electrophoresis to determine the source of fecal contamination in the watershed. This water quality data could be used by the Mill Creek Restoration Project to better understand and control sources of fecal pollution in the Mill Creek. The AP Biology students also used traditional methods for analyzing water quality, described later in this paper.

The Advanced Physical Science students used physical and chemical principles to measure water quality and categorize water quality based on these parameters. Upon return to the classroom, students utilized Microsoft Excel to tabulate, categorize, average, and graph their water quality data. Additionally, students analyzed and compared water quality data from the Vorhees Park site over the past nine years. Students were engaged in both hands on water quality laboratory exercises, while also utilizing computer technology to analyze their data.

Implementation in AP Biology

Students in AP Biology were prepped on the history of the Mill Creek by Lora Alberto of the Mill Creek Restoration Project. The evolution of the Mill Creek leading up to its current condition was described to students, in addition the multiple factors that cause the pollution. Students were introduced to the fact that the Mill Creek is especially polluted by fecal bacteria. The fecal source of pollution was unknown. There are many sources of pollution that contribute to this multi-use and heavily urbanized watershed, and the fecal material could have originated from any of them. Fecal pollution could contribute to high numbers of pathogenic organisms that can negatively impact human health. Specifically, the creek travels through socio-economically depressed areas where children often play in the creek, even if it is fenced in to prevent human contact with the waterway.

Following this discussion, students visited the Mill Creek and collected water and sediment samples to take back to the classroom. While at the site, students tested three parameters: Chemical assessments (orthophosphate levels, pH, conductivity, dissolved oxygen levels, biological oxygen demand, chemical oxygen demand, and nitrates), physical assessments (temperature, turbidity, and total suspended solids) and biological assessments (fecal coliform counts and benthic macroinvertebrate indicators). Students practiced lab safety and aseptic technique during these activities. Students used the results of these tests to determine the relative health of the waterway.

Once back in the classroom, AP Biology students filtered the bacteria from the water samples using a suction pump and filter paper. There were two students teams – one team worked on the bacteria concentrated from water samples and the other team worked with bacteria collected from sediments samples. The collected bacteria were then chemically analyzed and their DNA was collected using centrifugation. Four different primer sets were used that targeted the 16S rRNA gene of *Bacteroidales* bacterial populations. The DNA primers were specific to general *Bacteroidales*, cow (ruminant), human, and pig *Bacteroidales.* Use of these four primers allowed students to pinpoint the source of the fecal coliform pollution of the Mill Creek. Polymerase Chain Reaction was performed for each of the four DNA primer sets. The PCR products were loaded into agarose gels which were prepared ahead of time and gel electrophoresis was used to visualize the presence or absence of general and host specific fecal pollution. Confirmation of primer inserts was made using a photograph of the final gel electrophoresis product. It was determined that the fecal coliform bacteria were most likely derived from human sources.

Implementation in Physical Science

Ninth grade students in Advanced Physical Science were also briefed on the history and evolution of the Mill Creek by the Mill Creek Restoration Project's Lora Alberto prior to visiting the Vorhees Park site. Students were also given a brief introduction to water quality standards, water quality parameters they would be testing, reasons for testing each parameter, basics of fecal source tracking, DNA extraction, PCR, and gel electrophoresis. Upon reaching the site, students (in small groups; 3-4 students) rotated to various water quality stations. Water quality testing parameters included pH, dissolved oxygen levels, nitrate levels, temperature, phosphate levels, and turbidity. Using a Hach Test Kit or similar is appropriate for these tests. Each group performed each test at least once, creating four replicates as a class for each water quality parameter. Students recorded all necessary data to take back to classroom to organize and analyze, allowing the students to work through the scientific method.

Once back at school, each group reported their data to their entire class, so that all classmates were able to record the same data into Microsoft Excel data sheets. Students were also given water quality data from the Mill Creek Watershed from year 2000 to present by using the online "Surfing Your Watershed" software. Students then learned how to average their replicates for each water quality parameter tested. For many students, this was their first time using this software and teachers made a point to explain how powerful this software is in terms of data management and graphical analysis. Students also learned how to transform dissolved oxygen (mg/L) to percent saturation so that they could compare it to a given dissolved oxygen graph.

Finally, students were able to use the average of each water quality indicator to determine water quality category for each parameter into (i.e. nitrate levels are considered in the fair water quality category) (Figure 2).

Fecal Coliforms	Excellent (<50 colonies)	good (51-200 colonies)	fair (201-1,000 colonies)	poor (>1,000 colonies)
pH	Excellent (6.5-7.5)	good 6.0-6.4 or 7.6-8.0	fair (5.5-5.9 or 8.1-8.5)	poor (<5.5 or >8.5)
Nitrate (mg/L)	Excellent (0-1.0)	good (1.1-3.0)	fair (3.1-5.0)	poor (>5.0)
Phosphate (mg/L)	Excellent (0-1.0)	good (1.1-4.0)	fair (4.1-9.9)	poor (>10)
Turbidity (JTU)	Excellent (0-10)	good (10.1-40)	fair (40.1-150)	poor (>150)
Dissolved Oxygen (% Saturation)	Excellent (91-110)	good (71-90)	fair (51-70)	poor (<50)

Figure 1: Student-generated water quality classification for physical, chemical, and biological parameters measured in Vorhees Park.

Once a conclusion had been made, students discussed which water quality measurements were of excellent, good, fair, and poor water quality; the site evolution over the past nine years (has this site of the Mill Creek improved over time); ways in which water quality could be improved at this site; in which years were certain water quality parameters the highest; what caused for higher water quality parameters; the implications of having poor water quality; and what we could do to improve water quality at this site. The discussion allowed students to realize that many of us tend to take water quality for granted in the United States because many people don't understand why it is important to monitor and protect our water resources. Students learned that more than one billion people worldwide don't have access to clean water. They also learned about the detrimental impacts of poor water quality on human health, the economy, fishing, and recreation.

Student Responses

Students in both classes were engrossed in testing these parameters on site: pH, dissolved oxygen, biological oxygen demand, nitrates, orthophosphates, temperature change, turbidity, macroinvertebrates, and fecal coliforms. It was rainy on the day of testing, and had been raining for several days. This was positive for sample collection because increased stormwater runoff was released into the creek, giving students a good opportunity to test for sources of pollution. Several hours were spent in the on-site testing, followed by several hours back at the lab.

Students were able to see the entire process from start to finish. There were no substitute items, unlike in lab kits where students often use synthesized materials to mimic the real thing. The fact that their results would be of benefit to the Mill Creek Restoration Project made a difference to them, and gave them a purpose aside from earning a grade.

Students in the AP Biology course were introduced to laboratory equipment that they usually only hear about and do not get to use. Filtration with a vacuum pump and side-arm erhlenmeyer flask was used to separate the bacteria from the water and the sediment. A lysis procedure was used to break open the bacterial cells to release the DNA. Centrifugation was used to isolate the DNA from the cell fragments from bacteria contained in the water and sediment samples. A PCR machine was used to replicate targeted DNA segments. Students used a gel electrophoresis apparatus to separate segments of DNA. These experiences are rare at the high school level and are a result of being able to work with scientists outside of the school setting.

Following the laboratory work, AP Biology students created a poster of their work, summarizing their assessment of the water quality of the Mill Creek Watershed. They also presented their findings to the National Science Foundation and sent their results to the Mill Creek Restoration Project.

Results of the Implementation

Students determined that the quality of water at Mill Creek was very poor due to an extreme excess of fecal coliform bacteria from human sources. Dissolved oxygen, pH, nitrate levels, turbidity, orthophosphates, and macroinvertebrates were all categorized as good. The temperature was excellent and the biological oxygen demand was fair. The level of fecal coliform colonies was classified as poor due to the high levels in the creek on the day of testing.

This unit covered water quality standards and traditional physical, chemical, and biological testing methods that are used to assess the quality of our waters. The lesson gave students a better understanding of the challenges environmental scientists, engineers, and policy makers face when trying to improve and protect our nation's water quality for public and ecosystem health. This unit integrated fundamental physical, chemical, and microbiological principles with molecular technology, which provided an opportunity for high school students to understand how an interdisciplinary approach to research is essential in solving complex environmental problems.

Student Impact

The results of pre and post testing of students show that student knowledge of laboratory methods, general knowledge of environmental pollution and water quality and career opportunities increased significantly (Figures 2 and 3).

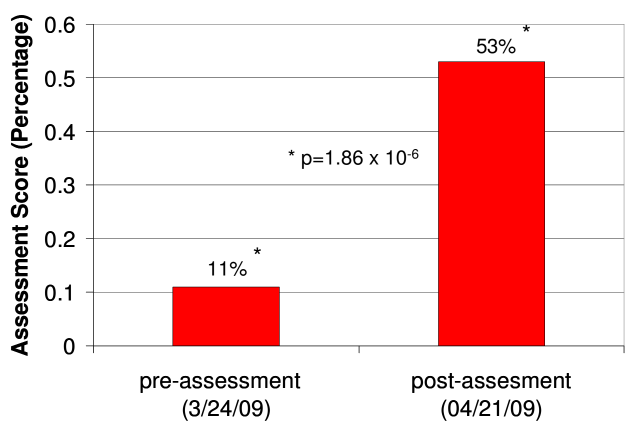

Figure 2: Pre- and post-assessment results for AP Biology class.
*** Indicates statistical significance (p-value < 0.05) using a Student's T-test.**

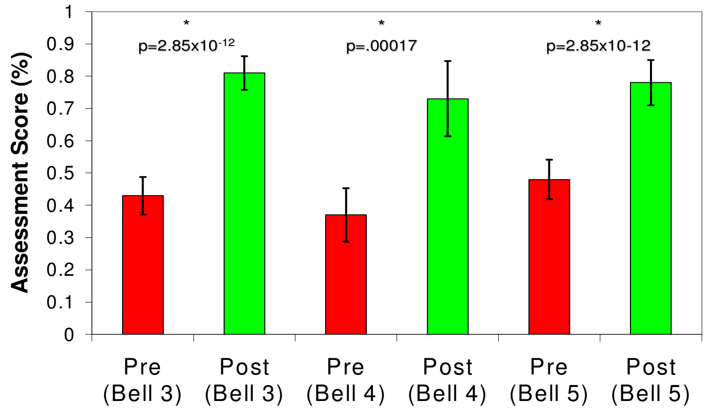

Figure 3: Pre- and post-assessment results from three Physical Science classes. * Indicates statistical significance (p-value < 0.05) using a Student's T-test.

The AP Biology students had the opportunity to present their findings to a National Science Foundation Program Director and that experience required confidence, dependability and leadership qualities. Students gained an awareness of human affect on the environment and how difficult it is to reverse the incurred damages. Students learned how to use the scientific method and apply it to a real-world situation in their area, which is priceless. All classes showed an increase of at least 40% between their pre and post-test assessments.

Acknowledgement

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