Partnering Engineering Graduate Students and Secondary Science Teachers to Teach Water Quality

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Abstract - **This paper discusses several lessons concerning drinking water treatment both locally and internationally, that were developed through the collaborative efforts of Project STEP and RET. These lessons were implemented in eight environmental science classes by two STEP Fellows and one secondary science RET teacher. Locally, students explored drinking water treatment in Cincinnati and the processes that treatment plants perform. Internationally, students explored drinking water issues in South Africa as well as participated in a UC Research project that brought drinking water treatment to a small village in Tanzania. Students discussed issues of water quality and quantity, global water sustainability/reuse, and protection of public health. In addition, students constructed sifting screens which were then transported to Tanzania and used to make a water filter at an elementary school.**

Index Terms – K-12 outreach, partnering engineers and teachers, science education, water quality.

BACKGROUND

Project STEP (Science and Technology Enhancement Program), supported by the University of Cincinnati (UC) and the National Science Foundation (NSF) is a collaborative effort between the College of Engineering, the College of Education, Criminal Justice and Human Services, and Cincinnati Public Schools [1]. This project seeks to educate, nurture, and facilitate university graduate students (Fellows) in the implementation of innovative activities that bring the students' scientific expertise into secondary classrooms while preparing them to become future educators. It just complete its fourth year.

Project RET (Research Experiences for Teachers) supported by UC and NSF provides a unique professional development opportunity for secondary science teachers [2]. RET teachers participate in cutting edge research projects for six-weeks under the guidance and mentorship of university faculty and graduate students. The purpose is to cultivate secondary educators who can confidently implement scientific inquiry, serve as role models through the application of their research expertise, and connect student learning experiences to relevant community issues. It was piloted last year for the first time. This paper discusses five lessons that were developed through the collaborative efforts of Projects STEP and RET which integrate the use of appropriate technology to maximize the quality of publicly supplied drinking water with social justice, both locally and globally. By giving students the design power as an engineer or scientist they have the opportunity to use their knowledge of water in a real-world context.

Water is necessary to all living things. Earth is unique having about seventy percent of its surface area covered with water, thus sustaining life. Of this water, only about three percent is potable. Of this three percent almost two thirds is tied up in glaciers leaving approximately one percent of the Earth's water available for use by living organisms including humans. This amount of available drinking water is further reduced by the introduction of pollutants into our water cycle creating the need for water treatment processes. Drinking water treatment is the process of cleaning water for human consumption and use. Because water is a good solvent, it picks up a large array of natural pollutants. More than two billion people on earth do not have access to potable water, natural or otherwise treated. Water treatment technologies have existed for more than 100 years, but there has been a lack of education dissemination in developing countries, especially in rural areas.

A look at the lack of civil infrastructure facing individuals across the globe quickly makes American students aware of the drastic difference science, engineering, and technology have made in their lives. Through this series of lessons, students recognize the challenge of providing adequate quantities and qualities of water to people in other areas, while acknowledging their fortune to have a seemingly limitless supply of high quality water. These lessons described here served as a vehicle for authentic learning because everyone understands the point of reference for learning – flushing the toilet and drinking water from the tap.

THE WATER CYCLE

A. Description of the lesson

In three (3) 50-minute periods, students explore water usage and its distribution in the world, learn about the Water Cycle, as well as the chemical and physical properties of water. The Water Cycle is a teacher driven lesson that revolves around class discussion, note-taking, calculations, Power Point

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presentations, and demonstrations. Although this lesson is didactic in nature (no true hands-on experiences take place), it actively involves students by teaching the content in a real-world context with visuals, real world examples and demonstrations to create a more engaging atmosphere. This lesson provides students with a backbone to help aid them in future lessons concerning drinking water treatment and filtration. In the real world, engineers and scientists use their knowledge of water to develop solutions to environmental problems such as water pollution, and water quality issues.

The lesson is structured around three themes: What if the Earth didn't recycle? (2) The Water ReCycler; and (3) What's so great about water? Activities include teacher-led demonstrations; reading activities, a Power Point presentation, a sublimation demonstration, an exploratory lab, active discussions, mathematics applications and the completion of graphic organizers and interactive worksheets.

B. Objectives of the lesson

The objectives of the lesson were for students to be able to:

- ***Understand*** how the water use and pollution of humans affects the equilibrium of the water cycle.
- ***Illustrate*** how uses of water resources at local, state, regional, national and global levels affect quality of life.
- ***Construct***, ***interpret*** and ***apply*** physical and conceptual models that represent or explain the distribution of water, the water cycle and water.
- ***Utilize*** mathematical models to predict and analyze water usage on Earth.
- ***Analyze*** how materials from human societies (e.g. radioactive waste and air pollution) affect the water cycle on Earth.
- ***Explain*** how human behavior affects the basic processes of natural ecosystems and the quality of the atmosphere, hydrosphere and lithosphere.
- ***Show*** how populations can increase through linear or exponential growth with corresponding effects on resource use and environmental pollution.
- ***Summarize*** data and construct a reasonable argument based on those data and other known information concerning New Orleans and the water cycle.
- ***Explain*** that the electric force between the nucleus and the electrons hold an atom together. Relate that on a large scale, electric forces hold solid and liquid materials together (e.g. salt crystals in water).
- ***Demonstrate*** that the pH scale (0-14) is used to measure acidity and classify substances or solutions as acidic, basic or neutral.
- ***Explain*** how atoms join with one another in various combinations in distinct molecules or in repeating crystal patterns.

C. Relationship to Standards

This lesson was designed to meet standards set by the Ohio Department of Education [3] which are aligned with national education standards. The Water Cycle lesson meets the following science standards for grades 9-10 (Benchmarks indicated in parentheses). Life Science (G), Physical Science (B), Science and Technology (B) and Scientific Inquiry (A). This activity also meets the following science standards for grades 11-12. Earth and Space Science (C), Life Science (E), Physical Science (A) and Scientific Inquiry (A).

D. Outcomes

Assessment of student learning included formative assessments, a comprehensive quiz that encompassed the content of the lesson, an engagement observation study of one of the classes, as well as a student feedback survey.

Formative assessments were conducted during each class through observations of student engagement and participation in class discussions. Questioning techniques and student comments were used throughout this lesson to make it a more engaging and knowledge-rich activity. Students found the mathematics section of the activity to be very challenging. The students observed do not see the connection between mathematics and science. This disconnect challenged the students mathematical ability. But, the students were able to persevere and succeed on this mathematical section through modeling the math procedures needed and through excessive questions by the students.

50% of students' whose grades were collected for this activity had improved quiz scores. Average quiz score for this activity was 69%. When comparing this quiz score to other similar quizzes conducted in this class, there was a two percentage increase in average quiz scores. It is important to note that in one class, male students had an average quiz score of 73%, an eleven percent improvement in comparison to their other class quizzes. In addition, 75% percent of students with 1st quarter grades in the D and C range had improved quiz scores. Thus, it can be concluded that the interactive teaching style of the Water Cycle activity not only improved quiz scores, but also helped struggling students achieve.

An engagement survey was conducted by the STEP fellow during day three of this activity. It is evident from the results of this study that the this lesson was a success in terms of engagement. During the 35 minutes of actual instruction and discussion that occurred in the class, only three students were seen to be exhibiting off-task, non-engaged behavior.

At the conclusion of this activity students provided feedback regarding the impact of the lesson on their learning. 75% of the students that participated in this activity felt that they had learned a lot. 43% reported that the water cycle activity increased their interest in engineering. Most importantly, 82% of the students reported increased confidence in their ability to learn science. When asked what they liked most about the activity, one student stated "I think it was a fun way of learning." Another student stated "it taught me a lot of things about water, like how much is in the whole world and etc. " A third student stated that they liked "learning more about the water cycle and how it's important in our lives." When asked what they liked least about the activity, several students reported that they did not like the writing and the mathematical calculations required.

The fellow reported that although the lesson was didactic in nature, the active discussions, presentations and demonstrations appeared to have a positive impact on the students' engagement, enthusiasm and learning during the activity.

WATER POLLUTION

A. Description of the lesson

Students play the role of environmental engineers working for the Cincinnati Environmental Protection Agency (EPA). In a classroom scenario, an oil company has a disastrous oil spill on the Ohio River in which it is the job of the students to develop an Oil Removal Plan to remove all of the oil in the river. Students design and implement a scale model oil removal plan. Students explore water pollution issues specifically related to the Ohio River, as well the Exxon Valdez Oil spill. In addition, students learn about real-world remediation techniques and environmental issues associated with oil spills.

During three (3) 50-minutes periods, student groups filled the role of environmental engineers to design an efficient and inexpensive oil removal plan; implement the oil removal plan on a scale model oil spill; learned about the disastrous affects of oil spills as well as real world remediation techniques.

B. Objectives of the lesson

The objectives of the lesson were for students to be able to:

- ***Design*** an oil removal plan to effectively and efficiently remove the oil from Harry Voll Oil Incorporated's oil spill. This design must use the "removal materials" provided in class.
- ***Apply*** their knowledge of the properties of water and oil to design their oil removal plan.
- ***Implement*** their team's oil removal plan using a scale model.
- ***Apply*** knowledge of real-world remediation techniques to the *Bengal's Oily Mess.*
- ***Recall*** what oil is used for as well as what causes oil spills.
- ***Describe*** the effects of oil spills on the environment and wildlife.
- ***Justify*** who they think is responsible for paying for the oil spill remediation.

C. Relationship to Standards

The Water Pollution lesson meets the following science standards for grades 11-12. Earth and Space Sciences (C and F), Scientific Ways of Knowing (C). In addition, this lesson meets the following technology standards for grades 11-12. Technology and Society Interaction (A), Design (A and B).

D. Outcomes

Students were assessed using the Water Pollution activity handout which measured the students understanding of the content learned. In addition, formative assessments of student learning and a student feedback survey were conducted to assess the engagement of students during the activity.

The average handout grade for this activity was 73%. 54% of the students assessed scored at or above the class average. Many of the students that scored below this average turned in incomplete handouts due to absenteeism. Absenteeism was a major issue during the implementation of this activity and had a negative impact on several students' grades.

Formative assessments of student learning were conducted through student observations. Student groups were very active during the oil removal implementation. Engagement waned during the reading portion of this activity. Typically, groups containing male students were more eager in the implementation of their oil removal plans. When one group experienced a minor "oil removal explosion", they simply laughed and started over. Conversely, female students demonstrated more interest in the design of their oil removal plans and selection of their oil removal materials.

At the conclusion of this activity students provided feedback regarding the impact of the lesson on their learning. 53% of the participants in this activity felt they had learned a lot. 44% reported the water pollution activity increased their interest in engineering. Most importantly, 85% reported increased confidence in their ability to learn science. When asked what they liked most about the activity, one student stated "The thing I liked most about this activity was the problem solving." Another student stated that they liked the activity because they got to "act like environmental engineers." A third student commented that they enjoyed "making a mess." When asked what they liked least about the activity, a majority of the complaints revolved around the physical labor of having to write the procedures for their oil removal plan.

DRINKING WATER TREATMENT

A. Description of the lesson

This is a 3-4 day (50 minute) lesson where students learn about drinking water treatment in Cincinnati and the processes that water treatment plants undertake in order to maintain high water quality standards for its consumers. In addition, students perform the main steps of the water treatment process (aeration, coagulation/flocculation, sedimentation, filtration and disinfection) in a hands-on, student group activity and analyze the effectiveness of the process through qualitative analyses of water before and after treatment.

B. Objectives of the lesson

The objectives of the lesson were for students to be able to:

- ***Recall*** the locations, water sources, distribution of service, and volume of water treated at the two (2) water treatment plants located in Cincinnati.
- ***Describe*** the steps of the drinking water treatment process.
- ***Understand*** the significance of each step in the treatment process.
- ***Implement*** and ***identify*** the major components of the water treatment process.
- ***Analyze*** the aesthetics (appearance, color, odor, etc.) of treated and untreated water.

C. Relationship to Standards

This lesson meets the following science standards for grades 11-12. Earth and Space Sciences (C), Life Science (F and G), Science and Technology (Benchmark A), and Scientific Inquiry (A, B and C). In addition, this lesson meets the following technology standards for grades 11-12. Technology and Society Interaction (B) and Design (A).

D. Outcomes

Several student assessments took place during the duration of this activity to determine the lesson's impact on student learning and engagement. Student knowledge concerning the content of this activity was assessed through observations of student participation and engagement, a vocabulary quiz that covered the major concepts of the activity, the completion of the activity handout, as well as a student feedback survey.

Formative assessments were conducted through observations of student engagement and participation. During the duration of the activity, students were engaged. Students actively participated in class discussions, asked lots of questions, and were talking on topic while they were working on the laboratory experiment. In addition, some of the more passive, quiet students in the class actively participated in the class discussions and were more willing to offer their answers to questions posed by the teacher. No free time during the activity further increased the engagement of the students.

The student average on the Drinking Water Treatment vocabulary test was 83%. Many students that normally struggle on vocabulary tests did exceptionally well on the quiz. Many only missed one vocabulary term. Student average on the activity handout was 95%. The lowest grade on the activity handout was an 85%. These high scores may indicate the need to reevaluate the difficulty level of the handout as well as the grading standards used to evaluate it. The high scores achieved by the students indicate that the students successfully completed the handouts. Students worked exceptionally hard on this activity and deserved the high grades for their participation and effort.

At the conclusion of this activity students provided feedback regarding the impact of the lesson on their learning. 77% of the students that participated in this activity felt that they had learned a lot. 35% reported that the drinking water treatment activity increased their interest in engineering. Most importantly, 82% reported increased confidence in their ability to learn science. When asked what they liked most about the activity, one student stated "I liked the participation. I got to do a lot of hands-on (activities) which made a big difference in my learning process." Another student stated that they liked the activity because of the real-life "significance" of the topic being studied. When asked what they liked least about the activity, a majority of the complaints revolved around the homemade dirty water that was used in their drinking water treatment simulation. They didn't like the look or smell of it.

WATER QUALITY

A. Description of the lesson

Taught in five (5) 50-minute periods, students learn about drinking water quality standards and regulations and the governmental agencies that enforce them. Students also learn what water quality is, how it is measured, why we have water quality standards, and what affects water quality. Students are subjected to a brief history of the Mill Creek, a local water system in the Cincinnati area that has experienced severe pollution problems as well as the restoration/education project that has been instituted to help clean it. In addition, students learn about the 9 water quality standards the Mill Creek Restoration project uses. In small groups, students then perform 4 water monitoring tests (turbidity, dissolved oxygen, pH and temperature) on a local stream and rate the quality of the water in that stream by analyzing the data from the tests. By placing the students in the shoes of a scientist, students have the opportunity to use their knowledge of water, water pollution, and testing techniques in a real-world context.

B. Objectives of the lesson

The objectives of this lesson were for students to be able to:

- ***Summarize*** the importance of the CWA and SDWA.
- ***Summarize*** the history and purpose of the Mill Creek Restoration Project
- ***Explain*** water quality.
- ***Identify*** components of water quality.
- ***Apply*** and ***perform*** water quality testing techniques and calculations.
- ***Analyze*** water quality testing data.

C. Relationship to Standards

This lesson met science standards for Earth and Space Sciences (C), Life Sciences (B), Science and Technology (A), and Scientific Inquiry (A, B, and C).

D. Outcomes

Students were assessed using the Water Quality activity handout and vocabulary quiz which measured the students understanding of the content learned. In addition, formative assessments of learning and a feedback survey were conducted to assess the engagement of students during the activity.

Observations of students showed high levels of enthusiasm and engagement throughout this activity. They were more than willing to put on rubber boots and actually get into the stream to do their water quality tests. One student in particular, a normally shy and quiet individual came out of his shell during this activity. The STEP fellow reported in a weekly report that “I was so happy when I left that day because I felt like I made a difference.” Students got to experience water quality testing in a real-world context, which defiantly impacted their engagement and learning. Average on the Drinking Water Treatment vocabulary test was 83%. Average on the activity handout was 87%. These high scores indicate elevated levels of learning and engagement during the activity.

At the conclusion of this activity students provided feedback regarding the impact of the lesson on their learning. 53% of the students that participated in this activity felt that they had learned a lot. 29% reported that the water quality activity increased their interest in engineering. Most importantly, 73% of the students reported increased confidence in their ability to learn science. When asked what they liked most about the activity, one student stated “I liked that we got to go outside and actually test different things (water quality parameters).” Another student stated that they liked that the activity was “interactive.” Overall, students enjoyed the outside experience. What they didn’t enjoy was the mud they had to walk through to get to the stream.

WATER FILTERS

A. Description of this lesson

Students follow the engineering design process to create a functional water filter using common every day items provided to them in their science classroom or provided by the students themselves. By placing the students in the shoes of an environmental engineer, students have the opportunity to use their knowledge of water filtration in a real-world context. Students also are given the opportunity to use critical thinking skills and apply their knowledge in the creation of an actual water filter. This lesson occurs in five (5) 50-minute periods.

Students learned about global issues concerning drinking water and a research project at the University of Cincinnati to develop a water filter for a school in Roche, Tanzania. They participated in a “filter round robin” in which they performed qualitative analyses on seven different filter materials that they could potentially use in their filter designs. Then, students worked in collaborative groups to design, construct and test their water filter. Tests of the water filters’ effectiveness included pH, turbidity, presence of pathogens, and dissolved oxygen tests of each groups filtered water. Students compared the results of the effluent water with those obtained from the influent water. Students analyzed the water quality data and the filter designs of other student groups in order to redesign their water filters to improve its effectiveness.

B. Objectives of the lesson

The objectives of this lesson were for students to be able to:

- ***Design*** a filter to purify polluted drinking water using the principles of engineering design.
- ***Utilize*** chemical and biological techniques to test the quality of water produced by their filter.
- ***Analyze*** data from the tests performed on their filter and draw conclusions about the efficiency of the filter they designed.
- ***Compare*** the results of the water quality produced by their filter with the results of water quality produced by other filter designs.

C. Relationship to Standards

This lesson meets the following science standards for grades 11-12. Life Science (F), Earth and Space Science (C), Science and Technology (A), Scientific Inquiry (A), and Scientific Ways of Knowing (A and C). In addition, this lesson meets the following technology standards for grades 11-12. Nature of Technology (A, B, and C) and Design (A and B).

D. Outcomes

Activity outcomes were assessed through observations of student engagement, formative assessments of their learning and a student feedback survey.

The Water Filter activity was well received by the students. They were engaged and asked lots of questions throughout the activity. Filter round robin groups engaged in active debates and held educated conversations about the different filter materials they were testing. Students also engaged in conversations about the most effective use of materials, an important concept in the field of engineering. One group was so excited about the activity that they asked to stay during their lunch period to make further inquiries about the effectiveness of each of the filter materials. Student groups took great pride in their filter designs. The Fellow made the following comment in a weekly report, “I still can’t believe how excited they (the students) all were about it (the Filter activity.” During the construction phase of the activity, students got very competitive, and could not wait to test their filter. Testing day was a day of excitement for most groups and disappointment for others. When groups drastically improved the water’s turbidity, they were very excited. When groups did not improve the water’s quality (their resulting filter water was still brown) disappointment could be seen in their faces. Although some groups did not succeed in improving the quality of their water sample, they were successful in redesigning their filters. In engineering, testing and redesign are major components of the design process. If the students could realize what they did wrong and how they could improve their filters the next time they achieved the objective set out for them in this activity.

At the conclusion of this activity students provided feedback regarding the impact of the lesson on their learning. 77% of the students that participated in this activity felt that they had learned a lot. 61% reported that the water quality activity increased their interest in engineering. Most importantly, 88% of the students reported increased confidence in their ability to learn science. When asked what they liked most about the activity, one student stated that "It was fun and it made me think more than usual." Another student stated "I liked that our filter actually worked!!! Haha!" A third student stated that they liked "that we got to develop our own water filter an test our own clean water." Overall, students enjoyed the filter activity and many had a competitive spirit which increased their engagement dramatically.

OUTCOMES FOR ENGINEERS AND TEACHERS

The activities discussed in the article had a positive impact on not only the students, but the STEP Fellows as well. One Fellow stated, "This activity definitely showed me the impact that STEP has had, not only on my students, but on me as well. I am happy that I had the opportunity to do this water module with them. I think that the Tanzania connection and the engineering design of a filter made it that much more powerful for my students and more gratifying for me. I am very thankful that I had the opportunity to incorporate the RET water quality research project into my lessons and that my students were given the opportunity to have Tanzanian pen pals. I feel that the students retained more from this activity because of the "realness" of it and because what they were learning could have a positive impact on people that live in Tanzania. As a Fellow, this activity has provided me with a wealth of knowledge concerning environmental engineering. As a future science educator, I appreciate any and all learning opportunities that I can use to enhance the learning of my students. Project RET and STEP have definitely provided me with priceless knowledge that will aid me in the integration of STEM (Science, Technology, Engineering and Math) education in my future science classrooms."

This project was an excellent vehicle to teach STEM skills to this teacher because the problem required an interdisciplinary approach to the environmental biotechnology and bioprocess engineering. The activities discussed in this article have had huge and lasting impacts on the style and manner in which the teacher approach topics in her Environmental Science class. She is now able, through my participation in both the RET and STEP, to bring real world examples of engineering into the classroom. This has greatly impacted student learning as the students in her class are now able to see a connection to the real world and the reasons they need to learn concepts taught in class. The collaboration with the STEP Fellow in this classroom has resulted in the development of lessons that now incorporate STEM skills into their daily learning. The teacher reports "I am thankful for the opportunity given to me through the RET program to work on the water quality project this past summer. This experience has given me an opportunity to meet and interact with individuals doing research in the field of engineering and has allowed me to further my knowledge of current research. The collaborative effort with the STEP Fellow has continued throughout the school year. I continue to attend the Lab Groups monthly meetings to keep up with new work and research occurring in water quality research. Working with both STEP and RET has increased both my energy and enthusiasm for teaching science and has allowed me to approach topics taught in my Environmental Science class with renewed enthusiasm and a fresh perspective."

SUMMARY

These partnerships benefit students, teachers, and Fellows. By placing students in the shoes of an engineer, students had the opportunity to utilize their knowledge of water in a real-world context. These lessons were received with great enthusiasm and interest. As a result, student confidence in learning science and their interest in engineering were both increased. The teacher reports positive impact of participation on her teaching as well as increased attitude towards and confidence in doing research. Fellows report improved communication skills, teaching proficiency, team building skills, and expanded interest in humanitarian efforts in their perspective communities. Project STEP has been approved for continued funding for five years. Project RET has been approved for full implementation for the next three years.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support provided by NSF Award No. DGE-0139312, and cost sharing funds provided by the Southwest Ohio Center for Excellence in Science and Mathematics Education at University of Cincinnati. Assistance provided by the Cincinnati Section of the American Society of Civil Engineers in organizing the engineering seminars for the teachers is greatly appreciated. We acknowledge and appreciate the teachers, students, Fellows, and graduate research mentors who assisted with these projects as well as the participation of the Village Life OutReach Project.

REFERENCES

[1] Project STEP website, www.eng.uc.edu/STEP, 2006.

[2] Project RET website, www.eng.uc.edu/RET, 2006.

[3] Ohio Resource Center for Mathematics, Science and Reading, www.ohiorc.org, 2006.