Bridging the Gap: Bringing Professionals into the Classroom to Effectively Teach Environmental Science Concepts

MALLORY WARE, CHRISTIE SMPSON, DELANEY LANN, ERICA LINARD, LAUREN GARCIA CHANCE

ABSTRACT

Hands-on learning is a highly effective teaching method for topics in STEM disciplines. Unfortunately, environmental science teachers sometimes lack the tools to engage their students in hands-on experimentation in real-world research outside of the classroom. Partnerships between science professionals and teachers can help address this disparity, and operating within an established community science program is an excellent way for teachers and professionals to provide K–12 students opportunities for involvement in real-world research. We developed a four-stage program that maximizes the benefits of bringing together members of the professional and academic sectors; the stages include Learn, Collect, Report, and Communicate (LCRC). The goal of this program is to bring science professionals into a K–12 classroom to emphasize the importance of conducting research using the scientific method, to promote responsible community science, improve students’ data literacy and critical thinking skills, and highlight the relevance of science communication. We demonstrate this program with a case study using water quality research in high school AP classes. Evaluations of the case study indicate this framework, and the engagement with science professionals alters students’ perceptions of science and scientists while giving them the skills, knowledge, and confidence to pursue scientific endeavors.

Key Words: Water quality, mentor, scientific process, research, community science.

Introduction

Understanding environmental processes, the benefits provided by healthy ecosystems, and how individual citizens impact the natural world is crucial not only for professionals in scientific fields, but also for members of the general public. Community science, also called citizen science, often refers to research partnerships between scientists and the public, during which data are collected by community members to be analyzed in response to science-based questions (Eitzel et al., 2017). Community science helps engage the public in observing and understanding the ecosystems that surround them, generally for the purpose of collecting data to monitor, for example, any fluctuations in environmental conditions or changes in animal populations (Huang et al., 2018). Due to the hands-on experience provided by participation in community science, introducing students to such programs can help them develop a better understanding of the natural world through active learning. Studies have shown that for students to retain scientific knowledge and understand the scientific method, hands-on experiences and interactions with STEM field partners (e.g., industry, academia) are immensely important (Simmons, 2017). The implementation of community science programs in the classroom creates an environment where students can learn science in a socially and environmentally relevant way.

Furthermore, introducing scientists from industry or higher levels of academia can bring multiple benefits into the K–12 setting. Small lesson modules taught by scientific experts can supplement middle and high school curricula, helping prepare students for standardized or AP exams. In addition, introducing students to a broad range of professional scientists can help combat negative stereotypes (e.g., about age, gender, race, and personality) that often discourage students from pursuing STEM fields or engaging in research. Interactions with a diverse set of scientific professionals have been shown to help change K–12 students’ perceptions of scientists and can additionally enhance their interest in the scientific field (Scherz & Oren, 2006). Implementing a project based on community science programs helps the student truly become involved in a scientific community and foster an identity as an emerging scientist, as well as gain authentic participation in scientific practices (Koomen et al., 2018).

For students to retain scientific knowledge and understand the scientific method, hands-on experiences and interactions with STEM field partners are immensely important.
The uniqueness of the framework used in this case study is that it brings science professionals into the classroom and the field to mentor K–12 students through a four-stage program: Learn, Collect, Report, and Communicate (LCRC). Here, we present a case study using the LCRC active framework in which students (1) learned about the importance of water quality (Learn); (2) conducted field research and collected data from a nearby stream (Collect); (3) analyzed these data and documented their results in a scientific report (Report); and finally (4) communicated their findings at a local science conference (Communicate). This case study followed the water survey methodology of Adopt-A-Stream, a multi-site community science monitoring program in the Southeast. Clemson University graduate students and Clemson Extension Water Resource agents volunteered to mentor students from a local school system and utilized the LCRC program to introduce community science, provide experiential learning, and demonstrate real-life use of scientific concepts to high school students.

○ Case Study

The “What’s in Our Waters” (WOW) educational outreach program focuses on engaging high school students in water quality research in their local community (https://adobe.ly/2FtrLz3). Water sanitation, affordability, and availability constitute a growing crisis both domestically and internationally (Hutton & Chase, 2016; Mack & Wrase, 2017). Incorporating hands-on learning with water quality lessons helps improve students’ understanding of and appreciation for the environment (Spellerberg et al., 2004). The global importance of water, paired with relatively accessible hands-on opportunities to determine water quality measures, makes water studies an ideal subject to use in teaching students environmental stewardship through the scientific method. In addition, the Adopt-A-Stream program utilized in this project is a well-established community science program in the southeastern region of the United States, allowing mentors to demonstrate the broad range of questions that can be addressed through citizen-collected data. Furthermore, students can utilize statewide data to draw comparisons between different streams.

The WOW program was developed by graduate students at Clemson University and implemented in AP Environmental Science courses in local high schools. The program’s impact and the collected data are useful both for educators working to advance environmental education and for researchers working to increase interest in community science. The content of this program is designed to bring attention to local water resources and alter students’ perceptions of science and scientists. The primary goal of the project is to educate high school students about water quality, proper scientific research methodology, and the importance of science communication. Specifically, the objectives of the program are to:

- convey the relevance of science communication with the public, and
- offer students the opportunity to present findings at a local symposium or conference.

To accomplish these objectives, we used the LCRC framework to maximize the student learning experience. Students are first introduced to community science, watersheds, water quality measures, and field testing through an in-class introduction. The following class period, students are taken to a field site to collect data on local streams. Students are then responsible for developing a collegiate-level lab report based on their findings. Finally, students synthesize their research into a scientific poster presentation and communicate their results at a regional scientific conference. These steps are further elaborated upon in the four LCRC phases (Figure 1). Approximately 108 high school students from three different high schools participated in this program between 2016 and 2018. Following the program, an evaluation survey was administered using quantitative Likert scale rankings and open-ended qualitative responses to gauge student perception and understanding of water quality (Clemson University IRB no. 2016-295).

○ Learn

Professional scientists, called mentors, first engage with students through an in-class instructional period. In the WOW program, these professional scientists are primarily graduate students. However, local extension agents, foresters, or nonprofit employees may be contacted to serve as mentors, depending on the topic of study, their availability, and the specialization needed. During this phase, students are exposed to community science, careers in the environmental sciences, and the processes of building a hypothesis, conducting research, analyzing data, and communicating results. Mentors present this information via a short interactive lecture broken into multiple emphasis areas (see the Supplemental Material for this article, available at https://works.bepress.com/christie-sampson/). The first section begins as an introduction and overview of the program, including who the mentors are, what their career fields look like, and a highlight of mentor experiences or research pertaining to water quality pollutants. The second section is an overview of water quality, including what affects it and how it is monitored. In addition, the mentors discuss the importance of watersheds, the river continuum concept, and stream orders, using local examples. The presentation concludes with details regarding water quality sampling methods that will be used in the data collection phase, including macroinvertebrates, chemical sampling, and bacterial sampling. This overview phase is the foundation upon which the remaining steps in the program build.

Following the presentation, the use of a role-play consulting game, outlined in Sampson et al. (2018), improves students’ critical thinking skills by engaging them in a real-world application of the knowledge just acquired. This role-play scenario teaches students analytical skills in assessing water bodies for water quality impact factors. The students also learn about the field of environmental consulting and the costs associated with conducted water quality tests. This activity assists students in thinking critically and applying their learning in a gaming situation prior to entering the field to conduct research. An observed increase in students’ thought process and hypothesis development while in the field has occurred since incorporating the consulting game.
Collect

This phase of the program introduces the students to fieldwork at a local water body, preferably a stream or creek. Taking students into the field after the in-class lesson gives them a chance to apply the information they have learned in a tangible way. The purpose of this phase is to help students gain a greater understanding of the complex ways in which environmental factors and pollution can directly or indirectly affect aquatic life via effects on water quality. One student claimed that the program “made me see how small differences in the water can have such a large effect on various animals and small organisms.” This phase bases the water quality collection methods and supplies upon a community science program, Adopt-a-Stream, and can be adapted to local or regional water quality testing standards.

Students are split into small groups of three to five, with one mentor or instructor available to work with the group for the entirety of the field activity. Mentors work with students to develop hypotheses regarding the data students can collect. This practice helps provide focus and guidance as the students (1) conduct a macroinvertebrate survey, (2) test various water chemistry parameters, and (3) collect samples for bacterial counts (Table 1). Guidelines and procedures for each of these tests as outlined by South Carolina Adopt-a-Stream (Callahan et al., 2017) can be found in the Supplemental Material. Additional water quality tests can be utilized to supplement classroom learning, such as tests for nitrogen, phosphorus, and other pollutants. Depending on available funding, the number of water quality tests and the types of materials and equipment used for the tests can be modified (e.g., using low-cost testing kits instead of high-end testing equipment, or even accessing free data from sources such as the Adopt-a-Stream website). A list of the materials used during this case study can be found in the Supplemental Material.

No particular order needs to be followed in which students collect data, although it is ideal to start students downstream and work upstream to prevent downstream disturbance of collection sites.

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**Figure 1.** A four-step framework was utilized that included the phases Learn, Collect, Report, and Communicate (LCRC) to maximize student learning. Steps for each phase and expected outcomes are included.

**Table 1. Layout of tests conducted as part of the Adopt-a-Stream program, with estimated time allotment and explanation of tests.**

<table>
<thead>
<tr>
<th>Test</th>
<th>Time Allotment</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water chemistry</td>
<td>30–45 minutes</td>
<td>Measurements of parameters including oxygen, temperature (air and water), pH, and electrical conductivity</td>
</tr>
<tr>
<td>Bacterial</td>
<td>15–20 minutes</td>
<td>Plating of collected water samples for detection of E. coli; incubation period of 24 hours needed following plating</td>
</tr>
<tr>
<td>Macroinvertebrates</td>
<td>45–75 minutes</td>
<td>Collection of macroinvertebrates from the water source through leaf packs, streambed disturbance, or kicknets, followed by identification using published macroinvertebrate keys</td>
</tr>
</tbody>
</table>
While students should autonomously conduct all tests, mentor assistance in understanding interactions or observed trends highlight relationships between the chemical, biological, and environmental parameters involved. When the field portion of this program (Collect) follows shortly after the in-class phase (Learn; i.e., within a two-week period), a higher retention of information in the students has been noted and appears to reduce student confusion, decrease the time needed for preparation, and increase the efficacy of the activity.

○ Report

It is essential for students to understand scientific writing as a core science communication practice. Hand et al. (2007) found that writing scientific articles improved content knowledge in the natural sciences for 10th-grade students. For this case study, students are provided a rubric (Supplemental Material) utilized within undergraduate ecology laboratories to frame their written reports. This rubric includes aspects such as background information on why the experiment was conducted, a hypothesis, experimental variables, materials and methods, data analysis, and conclusion. To conduct the data analysis, students are provided a data set from their field collection. If possible, additional data are provided for the collection site across time or similar local collection sites during the same period for comparison. Students are given an introduction to data analysis by their course teacher and then are asked to determine how the data are related to their hypothesis. Students often present findings in graphs and tables with written explanations. This step requires students to reflect upon materials and methods they used to conduct their experiment, as well as begin to form data and conclusions to either corroborate or negate their hypothesis. The reporting phase helps develop students’ data literacy and serves as a vital record they will utilize to communicate their work during the final phase of the program.

○ Communicate

The final activity in the WOW program, and the end stage of the LCRC framework, is focused on working with students to develop effective communication skills and preparing them to present their research at a local scientific conference. First, mentors return once more to the classroom to provide a short lecture on how to create a scientific poster and what to expect when presenting in a poster session at a conference. Then students break into teams of three to five (generally carried over from the previous stages) and, drawing from the compilation of reports written by each individual student, work with a mentor to develop a scientific poster. The program encourages students to produce posters similar to those found at a collegiate level, including explaining the motivation for their research, the hypothesis developed by the group, the methods used to test their question, and the results of their study (Figure 2). Initially, the students are given a template for the poster format (Supplemental Material), but they are encouraged to modify it to convey their findings best. After developing a rough outline for each section during the in-class portion, teams revise the poster using input from both their mentor and their teacher. The mentor also discusses potential questions the students might receive from people attending the conference and best practices and strategies for presenting their research as a team. While attendance at a scientific conference is preferred, classroom poster presentations with the mentors acting as judges may be done as well. If desired, feedback and incentivization can be provided through a judging rubric (Supplemental Material).

○ Discussion

Student receptivity to the WOW program and the LCRC structure has been positive, with high levels of student engagement and input. One student commented during an open-response question that “it’s a strong, hands-on way to get high schoolers into science.” Exposure to science during high school is critical because that is when decisions to pursue STEM are made and college-prerequisite math and science courses are taken. Bottia et al. (2018) found that greater exposure to various STEM courses and experiences in high school increased the likelihood of students declaring a STEM major in college. In particular, for this case study, the field experience was very important to the students and most likely attributed to their changes in water quality understanding. One student remarked of the activity, “I like that we did hands-on activities with [mentors] who are really interested in the field,” while another reported that “I saw myself as a scientist because I was collecting data and figuring out answers from that data.”

Students gained more than just knowledge of water quality and environmental science through participation in the WOW program. Hall et al. (2011) found that what school personnel knew about given career fields was one of the most significant factors influencing the degree program pursued by the student, but that approximately one-third of science teachers did not feel that they were knowledgeable about careers in the science field. Bringing mentors into the classroom to interact with students may help address this deficit. Engagement with the graduate student mentors increased students’ perceptions of college and higher education; among the 108 participants, 65% felt that the mentors helped them better understand the college experience and 74% believed that the mentors encouraged them to pursue science at a higher level. One student remarked that the program “talked about college more, it was probably the most I’ve heard about [college] in a while.”

Furthermore, we found that the unintentionally high number of female mentors in the program had a positive effect as well, with a female student responding, “I liked seeing how many females were in the field.” Female students who have female teachers or mentors have been shown to have a more positive attitude toward science (Tsuji & Ziegler, 1990) and to perform better (Dee, 2007). Also, supporting female students during their secondary education as well as providing opportunities for them to engage in science outside of the traditional school setting has been shown to positively impact their success in STEM fields (Kim et al., 2018). Therefore, we encourage the recruitment of as many female mentors as possible when implementing the program.

This program was developed to align with the core competency requirements outlined in the AP Environmental Science guidelines (Table 2). The success of WOW has led AP Environmental Science teachers from nearby schools to request implementation of the program in their courses. A teacher engaged in the program noted that
students better comprehend the impact of their actions on the downstream watershed when following the four-phase program process than through traditional lecture-style teaching alone. Among the 108 participants, 83.8% noted that they became more conscientious about their individual impact as well as the human population's impact on water quality, 81.4% felt that the hands-on fieldwork helped them better understand what was taught in the classroom, and 45.3% would take personal action following the program to preserve water quality.

**Conclusion**

The LCRC framework, combining hands-on learning with opportunities to engage with professional scientists, has impacts on students’ understanding of the environment and the research process as well as providing experiences that can lead to higher enrollment and retention in the field of science. While we used the topic of water quality as a model for the LCRC program, investigations of other fields (e.g., species distribution, the spread of invasive species, fire ecology) are also possible. Creating partnerships with local community science projects can provide excellent opportunities for K–12 students to engage with research, especially under the guidance of a mentor.

**Modifications**

This program was designed for use in an AP Environmental Science course but can be modified for middle school students or for use in a university setting. In our case study, we were able to associate each program section with one or more of the defined AP competencies, allowing teachers to easily include this program in their yearly lesson plans. The interdisciplinary program is adaptable to the needs of individual classrooms and can be tailored as needed, based on locality and available resources. Opportunities include the following:

- Emphasis on the scientific process, proper research methods, and science communication can be reduced or increased.
- If student access to local surface water is not possible, water samples and macroinvertebrates can be brought into the classroom to provide testing.
- The focus of the four phases can be directed to a specific topic or lesson as needed by the instructor (i.e., agriculture impacts, land-use change, aquatic communities).
While we used the topic of water quality as a model for the LCRC program, investigations into other fields and citizen science programs (e.g., ornithology and “Celebrate Urban Birds,” weather and “Citizen Science Condition Monitoring”) are also possible. Mentorship can be achieved in a variety of ways. Consider partnerships with nonprofits, universities, governmental bodies, and other local organizations. While this case study focused on water quality and taking students to the field, there are many online citizen science programs that can be adapted to fit the LCRC framework. The program eBirds (http://ebirds.org) is an excellent example of a citizen science program that teachers could use within the LCRC framework to either gather data in the field or download them from the eBird database, thereby reducing costs.

### Table 2. Relating AP Standards to concepts present in this program.

<table>
<thead>
<tr>
<th>AP Standard</th>
<th>Concept Present in the Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Earth Systems and Resources</td>
<td>Surface water issues and possible sources of water quality degradation (including pollution, erosion, climate change, and human impacts) are explored.</td>
</tr>
<tr>
<td>C. Global Water Resources and Use</td>
<td>One way to assess water quality is to look at macroinvertebrates, a keystone species in aquatic biomes. Species diversity is used to determine water quality scores. Aquatic systems provide countless ecosystem services.</td>
</tr>
<tr>
<td>D. Soil and Soil Dynamics</td>
<td>Human populations require more natural resources as they grow, which can contribute to habitat destruction and resource depletion.</td>
</tr>
<tr>
<td>II. The Living World</td>
<td></td>
</tr>
<tr>
<td>A. Ecosystem Structure</td>
<td></td>
</tr>
<tr>
<td>C. Ecosystem Diversity</td>
<td></td>
</tr>
<tr>
<td>III. Population</td>
<td></td>
</tr>
<tr>
<td>B. Human Population</td>
<td></td>
</tr>
<tr>
<td>3. Impacts of population growth</td>
<td></td>
</tr>
<tr>
<td>IV. Land and Water Use</td>
<td>Increasing amounts of agriculture lead to increased water demand and possible water contamination, such as by nitrogen and phosphorus, pesticides, and herbicides.</td>
</tr>
<tr>
<td>A. Agriculture</td>
<td>Different land-use types impact watershed health. Variations in chemical, bacterial, and biological characteristics of surface water are related to land use. The contribution of various land uses to pollutants of concern is addressed.</td>
</tr>
<tr>
<td>1. Feeding a growing population</td>
<td></td>
</tr>
<tr>
<td>IV. Land and Water Use</td>
<td></td>
</tr>
<tr>
<td>D. Other Land Use</td>
<td></td>
</tr>
<tr>
<td>1. Urban land development</td>
<td></td>
</tr>
<tr>
<td>2. Transportation infrastructure</td>
<td></td>
</tr>
<tr>
<td>3. Public and federal lands</td>
<td></td>
</tr>
<tr>
<td>VI. Pollution</td>
<td>Discussion of sources, causes and effects, and eutrophication. Tests are designed to gain understanding of water quality and work to maintain quality in the future through environmental advocacy.</td>
</tr>
<tr>
<td>A. Pollution Types</td>
<td></td>
</tr>
<tr>
<td>3. Water pollution</td>
<td></td>
</tr>
<tr>
<td>VI. Pollution</td>
<td>Water pollution can negatively impact human, animal, and/or plant health. Water quality understanding, including E. coli risks, is pertinent for human safety.</td>
</tr>
<tr>
<td>B. Impacts on the Environment &amp; Human Health</td>
<td></td>
</tr>
<tr>
<td>1. Hazards to human health</td>
<td></td>
</tr>
<tr>
<td>2. Hazardous chemicals in the environment</td>
<td></td>
</tr>
<tr>
<td>VI. Global Change</td>
<td>Water quality, especially when influenced by pollution, can impact aquatic ecosystems and biodiversity. Correlation between water quality and biodiversity emphasize the need for conservation.</td>
</tr>
<tr>
<td>C. Loss of Biodiversity</td>
<td></td>
</tr>
<tr>
<td>Laboratory and Field Investigations</td>
<td>Students learn about the environment through firsthand observation, data collection, and communication of the results.</td>
</tr>
</tbody>
</table>

- **Supplemental Material**
  Supplemental material is available at https://works.bepress.com/christie-sampson/.

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References


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