Promoting STEM Learning through a Multidisciplinary SENCER Framework at a Minority-Serving Institution

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Abstract

The Prospect Park Biodiversity Project was a SENCER collaboration project between the Departments of Biological Sciences, Chemistry, and Mathematics at the New York City College of Technology. The goal of this project was to enhance students' participation and learning in STEM disciplines through a civically engaged framework. The project utilized the eco-complexity of Prospect Park Lake in Brooklyn, New York for an interdisciplinary study on the water quality. The project, which involved ten students and four faculty mentors, integrated microbiology, chemistry, and mathematics perspectives using active-learning pedagogies, including hands-on exploration and collaborative learning.

Introduction

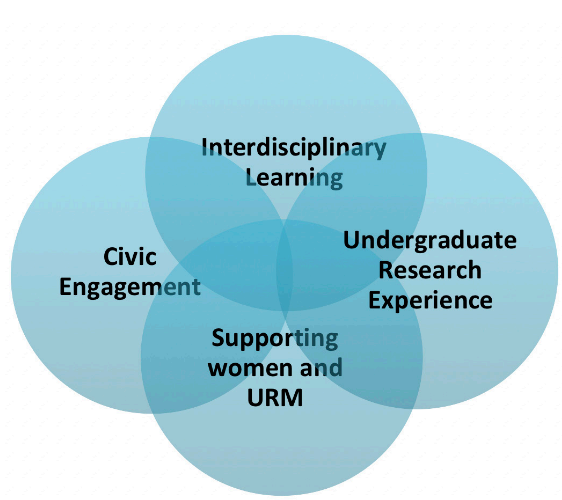
The Prospect Park Biodiversity project was initiated by four faculty—a microbiologist, a biochemist, and two mathematicians—at the New York City College of Technology (City Tech). Located in downtown Brooklyn, City Tech is a public, open access, non-residential, minority-serving institution. With students representing the demographics of Brooklyn and the Metropolitan New York

City area, it is one of the most racially and ethnically diverse higher education institutions. The intention of the project was to promote STEM learning among women and underrepresented minority students through an interdisciplinary collaboration in a SENCER (Science Education for New Civic Engagements and Responsibilities) framework (Figure 1). The main goals were to accomplish the following:

1. To promote STEM learning through a hands-on collaborative interdisciplinary experience.
2. To create an undergraduate research experience for students.
3. To heighten students' awareness of community resources and their civic responsibilities.
4. To encourage STEM learning and research among women and underrepresented minority students.

According to Heidi Jacobs' manual, "interdisciplinary" is defined as a "knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience." She recognized the growing need for interdisciplinary content and emphasized "linkages" and "relevance" rather than fragmentation or polarity in curriculum design (Jacobs, 1989). Studies have shown that an interdisciplinary framework for teaching encourages cognitive thinking and real life problem-solving (Husni & Rouadi, 2016; Cowden & Santiago, 2016). Pedagogy in Action, a project of the Science Education Resource Center (SERC) and the National Science Digital Library (NSDL) that shares and disseminates pedagogical practices, points out that interdisciplinary teaching helps foster the development of self-efficacy and multi-dimensional thinking, such as recognizing bias and understanding moral and ethical considerations (Pedagogy in Action, 2021). Shifting away from the traditional discipline-focused learning, today's education values interdisciplinary learning in multi-perspective contexts and the transferability of skills across disciplinary boundaries (Murray, Atkinson, Gilbert, & Kruchten, 2014).

FIGURE 1. Supporting and Integrating Active STEM Learning



Research also shows that active-learning pedagogy enhances the success of underrepresented minority students in STEM. Ballen, Wieman, Salehi, Searle, and Zamudio (2018) found that active-learning pedagogy (ALP) disproportionately positively benefited underrepresented minority (URM) students in science classes. While the non-URM (white and Asian) students showed little or no difference in course performance using ALP compared with the traditional lecture, the URM students showed an increase in science self-efficacy and sense of social belonging in classes that employed ALP, resulting in better grades and academic performance for URM students (Ballen et al., 2018). For active-learning pedagogies, Cattaneo (2017) used key words such as discovery-based, project-based, learner-centered, interdisciplinary, collaborative, etc., all considered high-impact STEM education practices for promoting deeper understanding and critical thinking, and for building STEM identity and belonging (Betz, King, Grauer, & Montelone, 2021; Kuh, 2016; Repko, 2006; Singer, Montgomery, & Schmoll, 2020).

The SENCER framework was chosen because we believe in SENCER's mission of connecting STEM learning to real-world problems and the issues of local, national, and global importance as well as teaching students about their civic responsibilities (SENCER). The site of our study was Prospect Park, which was selected not only for its vast biodiversity and eco-complexity, but also for its vital role in the life and vigor of the community as "Brooklyn's Backyard." With 10 million visits a year, the Park provides events, concerts, and recreational and educational programs to help promote healthy, balanced living for its community. With one lake, the Park supports wildlife habitat of over a hundred species of birds and other fauna and offers resting, feeding, and breeding grounds for migratory birds (Prospect Park Alliance, n.d.).

Project Design

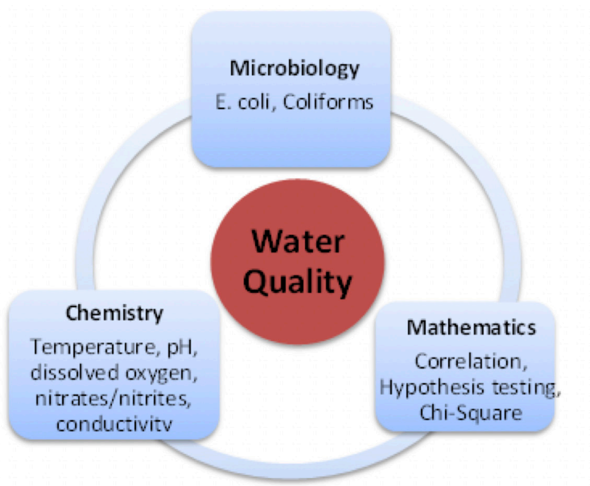
The four faculty designed an interdisciplinary project involving students from the following three courses: Microbiology (BIO3302), General Chemistry 2 (CHEM 1210), and Statistics (MAT 1372). Students selected for the project would also enroll in the Honors and Emerging Scholars Programs, undergraduate research programs at City Tech. Of the ten undergraduate students, seven (70%) were female, seven (70%) were identified as underrepresented minority; five (50%) were female in the underrepresented minority group. Altogether, nine (90%) of the ten participants were either female or underrepresented minority students. They came from various STEM and health majors including Biomedical Informatics, Chemical Technology, Computer Science, Computer Engineering, Liberal Arts and Sciences, and Nursing. The project had three main components:

1. Disciplined specific research with the faculty mentor: Students worked individually with the faculty mentor of their discipline to review literature and study the background of the project.
2. Group work and interdisciplinary activities: Students and faculty from all three disciplines worked collaboratively in team meetings, laboratory experiments, field trips, etc.
3. Project presentations and conference participation: Students were encouraged to disseminate their research results at local and national venues. This is integral to STEM identity building.

The project attempted to investigate the key question "What is the water quality in Prospect Park Lake?" The project activities were hands-on and exploratory, and encompass the scientific process from the microbiology, chemistry, and mathematics perspectives. The students worked as a team throughout the whole project. They went on field trips to Prospect Park, made observations of the park habitat, and collected water samples from the lake. A map of Prospect Park Lake is provided in Figure 2, showing the water collection sites numbered 1–5 in red. These accessibility sites were defined by the Prospect Park Alliance. Next, 50-ml water samples were collected in sterile tubes from the five sites in the lake. To avoid bacterial growth, the water samples were stored at 4°C in a cooler. After water collection, the team of students reconvened in the laboratory and performed chemical and microbial analysis (Figures 3 and 4).

FIGURE 2. Map of Prospect Lake (Copyright Brooklyn Public Library; Center for Brooklyn History) and Images from Water Collection Sites

FIGURE 3. Integration of Data from Chemistry, Microbiology and Mathematics



The Microbiology Perspective

As a result of an extensive literature search, students found that one of the most-used parameters to monitor environmental water quality is the level of enteric bacteria (coliforms), usually occurring in the intestines of humans, animals, and birds. The presence of coliforms, such as *Escherichia coli (E. coli)* and *Enterobacter spp.* is an indicator of fecal contamination (Coulliette, Money, Serre, & Noble, 2009; Tortora & Funke, 2013). This could be of serious concern because the higher levels of coliforms show potential presence of pathogens (bacteria, viruses, etc.) and other pollutants (Bergman, Nyberg, Huovinen, Paakkari, Hakanen, & the Finnish Study Group for Antimicrobial Resistance, 2009).

In our research, following collection of water samples, the students performed tenfold serial dilutions, and 1 ml from each dilution was inoculated, using nutrient agar and MacConkey agar plates (Gavalas & Cook, 2015). Nutrient agar is a general-purpose medium, supporting growth of wide range of microorganisms. MacConkey agar is a selective and differentiating medium for cultivation of coliforms (*E. coli and Enterobacter spp.*) After incubation at 37°C for 48–72 hours, the number of bacteria was determined by the colony forming units (CFU) assay. The colonies were counted manually, and the results shown as the number of CFU in 100 ml of water. Additionally, Simmons Citrate agar was used to differentiate between *E. coli* and *Enterobacter spp.*

The Chemistry Perspective

The chemistry perspective focused on examining water quality in terms of dissolved oxygen, conductivity, concentration of nitrates and nitrites, pH, and hardness of water. Chemical analysis was performed on the water samples in the following manner: a) a Fischer Scientific Traceable Conductivity Meter was used to measure the conductivity; b) the dissolved oxygen (DO) was measured using the Winkler Method (data are reported as an average of three trials); and c) LaMotte multi-factor test strips were used to measure the water pH and nitrate or nitrite levels. All analyses were done at room temperature. Distilled water was used as reference sample (where the dissolved oxygen levels were recorded to be 6.6 ppm and the conductivity 2.3 μS/cm [microSiemans/cm], both acceptable values).

The Mathematics Perspective

The mathematics perspective provided students with the tools to examine the experimental data, think critically, and make scientific connections between the data and the water quality. Students used Excel spread sheets for data analysis. Students learned to formulate alternative and null hypotheses based on practical problems and assessed the data critically using chi-squared test and correlation coefficient.

Results and Discussion

The Prospect Park Lake provides a wide variety of habitats with multiple wildlife species. The results from our water sample analysis are presented in Table 1. The students identified the potential sources of fecal contamination to be domestic dogs and wildlife. A variety of birds were observed along the lake (specifically at sites 1, 4, and 5), such as ducks, geese, and swans (members of Anatidae family). It has been shown that some birds can excrete high amounts of coliforms, which may be a potential risk for pathogens. An earlier study has demonstrated that the density of aquatic birds affects the total number of bacteria in lakes, as birds are a natural source of coliforms, including E. coli (Hoyer, Donze, Schulz, Willis, & Canfield, 2006).

TABLE 1. Microbiology and Chemistry Quantitative Data from the Water Analysis

Site # of water sample	Temperature at collection site (° Celsius)	Total number of bacteria (CFU/100ml)	Number of coliforms (CFU/100ml)	Dissolved oxygen (ppm)	Conductivity (μS/cm)	pH
1	17	1,000,000	12,500	8.0	87.4	7.5
2	15	1,100,000	10,500	5.1	85.7	7.4
3	16	2,300,000	21,500	5.4	103.6	7.3
4	14	350,000	8,500	7.3	110.4	7.2
5	19	600,000	5,500	7.5	114.1	7.3

Reference Sample: Distilled water (dissolved oxygen levels 6.6 ppm; conductivity 2.3 μS/cm; pH 7). Estimated Nitrate/Nitrite: 0 (same for collected water samples)

Furthermore, the students observed the presence of multiple freshwater turtles at site 3, which most likely contributed to the highest numbers of total bacteria and coliforms at that site. Another factor resulting in the large number of bacteria at sites 2 and 3 could be the water stagnation, with lack of aeration and water currents, and the fact that these sites of the lake are very narrow. In contrast, the low number of total bacteria and coliforms at sites 4 and 5 could be explained by the water dynamics and free flow, as well as the location of the sites at the widest part of the lake. Other potential factors that affect the total number of bacteria are the temperature and weather conditions. Our results indicate that the sites in which the number of coliforms was higher are the areas with significant concentration of wildlife. Thus, it seems that the water contamination is due to the inhabitants of Prospect Park Lake. Moreover, the samples obtained from sites 4 and 5, which are from the area used for recreation purposes such as fishing and boating, showed the lowest bacterial levels. The numbers of coliforms at all sites of the lake, however, were above the safety standards established for boating and fishing (1000 CFU/100ml) by the U.S. Environmental Protection Agency (EPA) (2017).

Conductivity and dissolved oxygen are two important water quality parameters. Conductivity measures the ability of a solution (such as water) to conduct electricity and can be correlated to salinity level. Higher conductivity values indicate more dissolved ions (which are necessary to conduct electricity) such as phosphate or chloride anions, or calcium or sodium cations (EPA, 2012a). Prospect Park Lake appears to be on the lower end of conductivity; lakes and river water in the U.S. are typically 50–1500 μS/cm (EPA, 2012a). The level of dissolved oxygen in water is temperature dependent. Colder water typically has higher levels of dissolved oxygen (EPA, 2012b). Stagnant water contains less dissolved oxygen. This was observed in sites 2 and 3, as the water was stagnant. These two sites also had the lowest dissolved oxygen levels. According to the United States Geological Survey (USGS) (2018), as organic matter decomposes, "bacteria in water can consume oxygen," which may also point to why the

FIGURE 4. Selected Images of Faculty and Students at Collection Sites and Performing Laboratory Analyses

levels of bacteria at sites 2 and 3 are high and dissolved oxygen levels relatively low, as well as to their moderately strong negative correlation coefficients (see mathematical analysis below). On the other hand, most enteric bacteria (coliforms) are facultative anaerobes. In the presence of oxygen, they perform oxidative metabolism (respiration), whereas if dissolved oxygen levels are low, they switch to fermentation and still survive. As noted previously, the high bacterial counts at site 1 could be attributed to birds along the lake. For aquatic life (i.e., fish) to be sustained, the dissolved oxygen level in water should be above 5 ppm. Overall, the water quality of Prospect Park Lake (based on dissolved oxygen level) shows potential to support some aquatic life.

The undergraduate students made use of Excel spread sheets to record, organize, and analyze data. Students were tasked with finding the correlation between several parameters using correlation coefficients. The correlation coefficient, r, takes on a value between –1 and +1; an r value close to 1 implies a strong positive correlation between two parameters, an r value close to –1 implies a strong negative correlation, and an r value close to zero implies weak or no correlation. We found a moderate negative correlation between the total number of bacteria with dissolved oxygen (r=-0.64353) and the number of coliforms with dissolved oxygen (r=-0.52226); a correlation between bacteria and dissolved oxygen is expected as explained in the paragraph above. Comparisons of other parameters yielded insignificant correlations. A chi-squared test on the number of coliforms revealed statistically significant variations in coliform counts between various sites for all sample data (p-value < 0.0001), meaning that the variations in the coliform counts were too large to have occurred by chance alone. Other factors such as animal activities and water conditions (stagnation or open lake) may have contributed to the coliform counts, as previously discussed.

This project led to two poster presentations at City Tech's Semi-Annual Poster Sessions for Honors and Emerging Scholars, two oral presentations and a poster presentation at the Mathematical Association of America (MAA) Metropolitan New York Section Annual Conference, an oral presentation at the SENCER Regional Conference hosted by City Tech, a poster presentation at SENCER Summer Institute (SSI) and a student publication in the City Tech Writer (our college journal for exemplary student writing) (Gavalas & Cook, 2015).

A highlight and an eye-opening event for the students was the SENCER Summer Institute. Here are comments by students reflecting their experience:

> *My SSI trip was one of highlights of my summer. And it was my first time attending an out-of-state conference. Although my team and I were the youngest participants, I really enjoyed showing the audience our poster. Many of them commended us for our work.… I watched many presentations by other attendees and even got to learn interesting facts about the National Park Service. It was amazing to hear what they do to preserve our country's national parks.*

> *My peers and I had the opportunity to meet the other attendees, and learned about the topics of their projects.… I had an amazing time, thank you Professors for the opportunity.*

> *My group and I presented our poster and communicated with attendees of various backgrounds. It was interesting to see the poster presentations that (other) professors and students worked on.*

Conclusion

Collaboratively, faculty members from biology, chemistry, and mathematics designed an interdisciplinary SENCER project on Prospect Park biodiversity. Our investigation revealed that the coliforms in Prospect Park Lake exceeded the safety standards for secondary human contact (boating and fishing) (1000 CFU/100ml) established by the U.S. Environmental Protection Agency (EPA, 2017). The water quality in the lake is considered "threatened" (e.g., supports recreational use but exhibits a deteriorating trend) because of contamination with coliforms and other pollutants. In the last decade, the Prospect Park Alliance worked diligently to engage the community, expand its volunteer force, and secure funds for restoration and environment protection projects. We recognize the importance of their work and how much more still needs to be done.

In addition to the SENCER framework, the project achieved its four goals: (1) The project activities were interdisciplinary, collaborative, and hands-on. All students regardless of disciplines were engaged in the activities; computer science and engineering students learned about biodiversity and performed laboratory tests alongside biology and chemistry students; biology and chemistry students learned to formulate and test scientific hypotheses using Excel alongside computer science students. (2) All students were required to enroll in the undergraduate research program and worked with faculty mentors an average of two hours per week. Research activities included one-on-one research with the faculty mentor as well as joint work with all faculty and students in the team. (3) All students had to read literature regarding water quality and its importance before starting the activities. In addition, all students worked collaboratively to prepare posters and presentations, resulting in seven presentations and one student publication. (4) Nine of the ten participants were women or underrepresented minority students in STEM or in a health major. All participants successfully completed the program. Faculty and students shared the sentiment and appreciation for the richness and meaningfulness of the experience. Future work may include an expansion or repetition on a regular basis for the benefits of civic engagement and educational values.

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