A partnership between a community college biology professor and a local high school teacher was established to engage high school students in authentic microbiology research. High school students isolated actinomycetes from soil samples and tested them for their ability to produce antimicrobial chemicals. They also designed and carried out their own experiments with these isolates. Laboratory reports, written assignments, and quizzes were used to assess the scientific learning of the subject covered by the research project. The students’ attitudes about science and scientific research were assessed using a standardized survey and written reflection questions. In completing this project, the students applied their knowledge of the scientific method and experimental design to address authentic research questions. They also learned several hands-on laboratory skills, including serial dilution, aseptic technique, isolation of pure cultures, Gram staining, microscopy, and antimicrobial testing. Student feedback was overwhelmingly positive—many expressed an increased interest in pursuing a career in science, and most felt that the project helped them gain confidence in their ability to do science. This project illustrates the importance of establishing partnerships between secondary schools and academic institutions to successfully introduce research to younger students.

**Key Words:** microbiology research; Streptomyces; actinomycetes; high school students; authentic research in the high school classroom; high school–college collaborations.

**Introduction**

Several recent reports have addressed the need to reform science education at both the K–12 and the undergraduate level (AAAS, 2011; National Research Council, 2012; NGSS Lead States, 2013), to include a shift from the conventional lecture-model to student-centered activities. Hands-on, inquiry-based learning experiences have been shown to be instrumental in helping students comprehend difficult concepts (National Research Council, 2000; Freeman et al., 2014; Wilder, 2015). Several studies have indicated that engaging students in authentic research activities fosters both academic success and an increased interest in STEM careers. This holds true both at the undergraduate level (Hunter et al., 2007; Lopatto, 2007; Eagan et al., 2013; Cejda et al., 2014; Sell et al., 2018) and at the high school level (Subotnik et al., 2010; Kovarik et al., 2013). Classroom-based research is growing in momentum at the collegiate level, including community colleges, and has been shown to be particularly impactful for minority students (Bangera & Brownell, 2014; Cejda et al., 2014; Staub et al., 2016; National Academies of Sciences, Engineering, and Medicine, 2017).

High school students have also benefited from being engaged in authentic research experiences (Parker, 2005; Kovarik et al., 2013; Santschi et al., 2013; Didden & Edmunds, 2016; Costas et al., 2017). However, many high schools, particularly large schools serving urban populations, are faced with issues of inadequate funding, over-enrollment, lack of laboratory resources, and lack of proper teacher training.

Partnering with academic institutions has helped alleviate some of these barriers. Colleges are often better equipped with resources required for research, and faculty have expertise in obtaining funding and designing experiments that can be done in a high school laboratory. High school teachers are more familiar with the techniques of instruction appropriate to help their students achieve course-specific learning outcomes. College professors and high school teachers can work together to design pedagogical approaches and assessments that are age-appropriate for younger students.

Successful partnerships between academic institutions have been reported (Parker, 2005; Dong et al., 2008; AAAS, 2013; Brown et al., 2014; Houseal et al., 2014; Komoroske et al., 2015; Didden & Edmunds, 2016). The “Barcoding Life’s Matrix”
project described by Santschi et al. (2013) has introduced authentic research to more than a thousand high school students in California. Some partnerships between university and high school faculty have included microbiology-based activities, which are often underrepresented in the high school curriculum (Dong et al., 2008; Costas et al., 2017).

Here, we describe the incorporation of an authentic microbiology research project into a high school classroom as an immersive, yearlong experience by a Queensborough Community College (QCC) biology professor and a high school faculty member at Benjamin Cardozo High School (BCHS). This partnership was established as a way of developing a sustainable model for conducting authentic research involving the isolation and characterization of soil microorganisms and testing them for production of bioactive compounds.

**Background Information about the Research Project**

Misuse and overuse of antibiotics has driven the artificial selection of resistant strains of pathogenic bacteria, creating the need for discovery of new antibacterial compounds (Ventola, 2015). Soil microbiomes are the most common ecosystem surveyed for this purpose, as soils are rich in actinomycetes (including the genus *Streptomyces*) that are known for their production of compounds that possess antibacterial, antifungal, antiparasitic, and antitumor properties (Hug et al., 2018). Scientists are aware that soil microbial biodiversity remains largely unexplored, and there is great potential to unearth novel bioactive compounds from environmental samples.

Although isolation of unique *Streptomyces* from soil samples is often done using large-scale, complex procedures (Kealey et al., 2017), there are also relatively simple and straightforward procedures that can be readily taught to high school students. Biology teachers who are not familiar with microbiological techniques can easily learn the techniques with some basic training. These procedures are relatively low-cost and do not require expensive equipment or materials.

**Methods**

This project received QCC IRB Exemption status 695738-1 and approval from the New York City Department of Education’s Institutional Review Board (study no. 1143). The high school students’ parents were given permission slips to sign that explained the project. Student data were reported in aggregate form without personal identifiers.

**Description of Partner Institutions**

Queensborough Community College, part of the City University of New York (CUNY), is located in Bayside, Queens. QCC’s biology department houses an extensive array of laboratory equipment for many types of research, and the department has established a thriving research environment, with several faculty members who have external funding for their projects. Each year, many QCC students are engaged in research one-on-one with faculty mentors. More recently, faculty have engaged students in authentic research as part of a laboratory classroom experience (https://www.qcc.cuny.edu/ur).

Benjamin Cardozo High School (https://www.cardozohigh.com), a community school with ~3500 students in grades 9–12, is renowned for its academic excellence and extensive support system designed to ensure that all students succeed. BCHS houses many special programs, including the DaVinci Science/Math Research Institute, in which students (~120 students per grade, or ~480 total) take four years of honors and AP math and science courses. Students enrolled in this program have the opportunity to take a yearlong biology research course (BioResearch) in which they develop hypotheses and design and carry out scientific experiments based on these hypotheses. The high school typically offers one or two sections and enrolls approximately 30–70 students in this course each year.

**Project Overview**

The project was conducted by students enrolled in BCHS’s BioResearch classes in the 2015–16 and 2016–17 school years. The soil samples used in this project were collected from three areas within New York City as part of a CUNY grant-funded research project (Soil Joint Seed Project, principal investigator M. Trujillo, personal communication). The three areas chosen represent soils that are heavily contaminated (Newtown Creek), a relatively pristine area within the New York Botanical Gardens (Thain Forest), and an area of intermediate human influence (Central Park). The larger aims of this project were to (1) detect differences in microbial community composition in these three distinct areas and (2) determine patterns of antibiotic and heavy-metal resistance genes through molecular analysis.

The procedures used to isolate actinomycetes from soils and screen them for antibacterial activity are described in Supplemental Material Appendix A. Gram staining and microscopy protocols were adapted from McLaughlin and Petersen (2016) and were provided to the high school teacher and reviewed ahead of time as needed. The students were instructed on how to work safely with BSL-2 microorganisms based on the American Society for Microbiology’s (2012) *Guidelines for Biosafety in Teaching Laboratories* and were carefully monitored and supervised by the high school teacher and the professor at all times. Since the high school was not equipped with a working autoclave, all contaminated materials were brought back to QCC for autoclaving before disposal, and laboratory benches were wiped down with either a bleach solution (1:10 dilution) or 70% ethanol following all lab work. Only the high school teacher and professor handled liquid cultures and worked with the Bunsen burner.

The high school teacher and professor met several times (total time: five to six hours) before the project began to plan lessons and prepare for the activities. This preparation included deciding on the overarching learning outcomes and objectives; defining the division of responsibilities and roles; discussing available materials, facilities, and support; and figuring out the logistics of when and how to carry out the experiments. The high school teacher spent about one to two hours per week outside of class time to prepare for the activities and design related assignments and assessments.

The professor also met with the students several times to provide an overview of the project. The students were taught procedures by both their teacher and the professor – during the hands-on activities in year 1, the professor met with the class once or twice a week. The students kept detailed notes of all the procedures in a laboratory notebook that was collected and graded periodically. The high
school teacher graded all student assignments, quizzes, and exams and provided data to the professor in aggregate form.

In year 1 (2015–16), the BioResearch students at BCHS (two classes; total of 54 students) were given soil samples from each of the three sampling areas described above. From these soils, they prepared serial dilutions of their samples and plated these dilutions on actinomycete isolation agar plates containing 50 µg/mL cycloheximide and 50 µg/mL nystatin (antifungal agents). Plates were wrapped in parafilm and incubated at room temperature for 7–10 days or until colonies appeared. The students counted the total number of colonies and selected one or two colonies per plate to further purify and study. The students then re-streaked these colonies onto fresh actinomycete isolation agar or soy-flour mannitol agar. After pure cultures were obtained, the students prepared slides for Gram staining and microscopic analysis. They also prepared additional plates that were used to screen the isolates for their ability to produce antibacterial compounds. After such pure cultures were obtained, the students prepared slides for Gram staining and microscopic analysis. They also prepared additional plates that were used to screen the isolates for their ability to produce antibacterial compounds that inhibit the growth of three types of bacteria (Escherichia coli, Micrococcus luteus, and Mycobacterium smegmatis; chosen to represent the Gram-negative, Gram-positive, and acid-fast cell wall, respectively). After incubation, the students determined which of their actinomycete strains were producing compounds that inhibited the growth of other bacteria.

Throughout the school year, the students reviewed primary literature and obtained extensive background information about actinomycetes and antibiotics (some examples of the assignments used to reinforce learning are given in Supplemental Material Appendix B). Based on this information and their isolation and screening experiments, the students worked in groups to develop their own research questions. They then designed and carried out experiments to test their hypotheses (examples listed in Supplemental Material Appendix C) and wrote laboratory reports based on their research.

In year 2 (2016–17), a new cohort of BioResearch students (one class of 34 students) worked with a subset of previous isolates. They confirmed the production of bioactive compounds by repeating the screening tests. They also learned Gram staining and microscopy and designed and carried out their own experiments. Since the students were working with putative actinomycetes that had been previously isolated and purified, the year 2 project took up considerably less time and required fewer visits from the professor, as the teacher was now well versed in the methods needed and was able to explain most aspects of the project on his own. The professor still met with the class on occasion (about once or twice a month) to help supervise the microbial work, as well as to explain the origin of the soil samples and other aspects of the project in detail.

**Pedagogical Approaches**

Several pedagogical techniques were used to introduce and reinforce the biological concepts behind the research. All lessons were planned and implemented by the high school teacher with input and guidance from the professor as needed. Some examples of the assignments related to the project included the following:

(1) Online Kahoot quizzes (https://kahoot.com) were developed by the teacher and implemented during class time – this allowed the students to test their knowledge of the research topic in a fun and engaging way. Two sample quizzes with correct responses are provided in Supplemental Material Appendices D and E.

(2) Using an in-class writing prompt, “I am a Streptomyces spore,” the students were asked to trace the steps of the life cycle of this organism.

(3) The students completed a group project in which they read primary literature about Streptomyces and other actinomycetes and gave oral presentations in front of their classmates as if they were the researchers.

(4) The students prepared news reports on their research, some of which were published in the school newspaper.

(5) The students presented their research plans in a mini-symposium in class and received feedback from their peers.

(6) Using “flipped classroom” techniques, short “clip lectures” were assigned covering topics such as “How do bacteria develop resistance to antibiotics?” The students then shared what they had learned from these clips with their classmates, and the teacher reinforced the learning, focusing on classwork and problem solving.

**Assessment**

The project was assessed in the following ways:

(1) Prior to beginning the research, the students participated in the Classroom Undergraduate Research Experience (CURE) pre-survey (https://www.grinnell.edu/academics/courses-programs/cla/assessment/cure-survey). This survey is designed to assess several self-reported gains of students in undergraduate research courses (Lopatto & Tobias, 2010) and has been widely used to assess research experiences of both high school and college students (Auchincloss et al., 2014). The students were asked to disregard any questions that did not pertain to them as high school students. The CURE posttest was taken at the end of the research project. Self-reported gains were summarized by the administrators of the survey and results were sent to the professor.

(2) The students were asked to answer eight written reflection questions after the research experience was completed (Supplemental Material Appendix F).

(3) Student learning objectives for the BioResearch course were assessed by grading of laboratory notebooks, in-class and homework assignments, quizzes, and a laboratory report.

(4) Examples of quizzes completed by students in Kahoot are given in Supplemental Material Appendices D and E; Supplemental Material Appendix G shows the grading rubric for laboratory reports.

**Results**

**Highlights of Research Projects**

Year 1 students successfully isolated 27 pure cultures of actinomycete strains. Of these, 13 demonstrated the ability to inhibit the growth of other strains of bacteria. The students’ original research experiments also yielded some very interesting results, as summarized below.

**Effect of light vs. dark**

Almost all strains tested grew better in the dark; they also exhibited greater production of antimicrobial compounds.
Effect of pesticides
Students reported that although pesticides inhibited the growth of some of their isolates, some were not affected, and a few even grew better in the presence of the pesticide. All three pesticides tested (Raid Ant and Roach Spray, Raid House and Garden Spray, and Hot Shot Fogger) seemed to be most effective against isolates from Central Park and Thain Forest; Newtown Creek isolates were least affected, and some students noted that these isolates increased their pigment production in the presence of pesticides.

Effect of heavy metals
Among the heavy metals tested (copper, iron, and lead), copper had the greatest inhibitory effect on actinomycete growth, whereas iron improved the growth of some. Several isolates exhibited changes in pigment production and appearance of growth when exposed to heavy metals. As with the pesticides, Newtown Creek samples seemed to be least affected by the presence of heavy metals.

Competition
Several strains of actinomycetes had inhibitory effects on other strains. Growing the organisms together on the same Petri dish also resulted in changes in phenotype (some took on a more mucoid growth, or produced more or less pigment).

Assessment of Research Experience

CURE survey results
Students’ self-reported gains in several aspects of course elements and learning. For most questions, their gains were comparable or exceeded the average gains reported for all students taking the survey (~10,000 high school and college students). Some notable gains are shown in Table 1.

Students’ attitudes about science were also measured by the CURE survey; BCHS students had mean scores comparable or slightly higher than the mean for all students. The creators of the survey identified five questions related to engagement that have been shown to correlate with higher reported learning gains and a higher likelihood of majoring in science. The BCHS student scores for these questions are shown in Table 2. Post-survey results assessing the overall impact of the research experience are shown in Table 3. BCHS students typically had higher mean scores than the mean for all respondents.

Student reflections
Reflection questions revealed the impact of the research experience on students in their own words. A summary of these reflections is presented below. The vast majority of students (~90%) enjoyed the research experience and reported that the hands-on experience helped them learn about science better.

A few common themes emerged in response to the question “What was your favorite part of this project and why?” Several students wrote about how much they enjoyed the hands-on experiments and learning actual laboratory techniques. Many really appreciated the opportunity to create and carry out their own experiments. Several wrote that it gave them the opportunity to interact with their teacher and fellow students more than they have in other classes. Students often mentioned that they felt accomplished and proud, and that they appreciated learning from their mistakes. Among the experiments, they particularly enjoyed the Gram staining/microscopy components, as well as testing for antimicrobial activity. These two activities are very visual and the results were very clear to understand.

Another reflection question asked, “Do you think this experience helped you understand how science/science research works?” Ninety-two percent answered yes. Specific student comments included that completing the project increased their respect for scientists and their understanding of the rigor of scientific research. Many also commented on the need to work cooperatively, be patient, and have strong time-management skills. Others mentioned that the project made them realize that “science is not just boring textbook work” and that “there is so much more to learn.”

The students were also asked, “What problems did you encounter? What did you do to overcome them?” Many students mentioned

Table 1. A sample of CURE survey results for self-reported gains. Asterisks indicate results in which BCHS student scores were higher than the average reported for all survey respondents. Results are reported as means based on a scale of 1–5, with 5 being the greatest gain.

| Self-Reported Gain                                      | BCHS Students Year 1, Year 2 | All Respondents Year 1, Year 2 |
|---------------------------------------------------------|------------------------------|-------------------------------|
| Work on a lab or project where no one knows the outcome | 3.55*, 3.78*                 | 3.35, 3.51                    |
| Maintain a laboratory notebook                          | 3.57*, 4.10*                 | 3.47, 3.63                    |
| Work in small groups                                    | 4.09*, 4.30*                 | 3.90, 3.98                    |
| Become responsible for part of a project                | 3.77, 3.89                   | 3.92, 4.03                    |
| Critique work of other students                        | 3.41*, 3.83*                 | 3.31, 3.38                    |
| Collect data                                            | 3.98*, 3.85                   | 3.89, 4.05                    |
| Analyze data                                           | 4.00, 3.70                    | 4.01, 4.12                    |
| Skill in interpretation of results                     | 3.71*, 3.75*                 | 3.60, 3.72                    |
| Learning laboratory techniques                          | 3.98*, 4.11*                 | 3.71, 3.89                    |
| Ability to analyze data and other information           | 3.81*, 4.10*                 | 3.75, 3.88                    |
| Clarification of a career path                          | 3.13*, 3.65*                 | 3.08, 3.20                    |
specific mistakes they had made in the procedures that they were usually able to correct. Several stated that the experience helped them become more organized and work more carefully to avoid those mistakes. Some also struggled with designing manageable experiments, dealing with the scientific jargon they encountered, and finding sufficient background information needed for their assignments. These problems were overcome primarily by seeking help from their teacher. Many felt they would never be able to master the techniques used, including microscopy, Gram staining, and spreading the bacteria properly on the agar plates. However, most felt that by asking for help and by continued practice they were able to improve their hands-on skills. Many students commented on feeling rushed by the short class period, and some felt they did not have enough supplies for some of the experiments. They overcame these issues by learning to manage their time better and learning to conserve materials by making fewer mistakes.

When asked to comment on the negative aspects of the research experience, some students did consider the project very time-consuming and somewhat tedious. Some also expressed the frustration of scientific researchers, including the limits of funding resources. A few specifically mentioned that they did not like the smell of the microorganisms, and some wished they had covered more topics than microbiology.

Despite these challenges, most student comments were very positive. Some notable examples: “I felt like a real cool scientist,” “made me feel like an actual microbiologist,” “the things we did felt like such a privilege,” “no boring worksheets,” “the less lecture and more hands-on science is, the more us teenagers are able to appreciate it,” and “being a scientist is strenuous but it pays off in the end.” Almost all the students believed that they had gained a better understanding of the roles and responsibilities of a scientist. Many wrote that they now had more confidence in their scientific ability and were considering majoring in a STEM field after completing the course. Even students who stated that they were not interested in pursuing science as a career still reported having gained a better understanding and appreciation of scientific research.

### Assessment of Learning Outcomes

Several of the student learning outcomes for this course were assessed by a written lab report; results for year 1 are shown in Table 4. The students received an average grade of 44/50 points on their lab reports.

### Table 2. Sample of CURE survey results for attitudes about science. Asterisks indicate values that are higher than the average reported for all survey respondents. Results are reported as means based on a scale of 1–5, with 5 being the greatest gain.

| CURE Survey Statement | BCHS Students Year 1, Year 2 | All Respondents Year 1, Year 2 |
|------------------------|-------------------------------|-------------------------------|
| Even if I forget the facts, I’ll still be able to use thinking skills learned in science. | 4.00, 3.89 | 4.21, 4.20 |
| The process of writing in science is helpful for understanding scientific ideas. | 3.90, 4.05 | 3.99, 4.04 |
| I get personal satisfaction when I solve a scientific problem by figuring it out myself. | 4.17, 4.40* | 4.21, 4.21 |
| I can do well in science courses. | 4.02, 4.00 | 4.03, 4.06 |
| Explaining science ideas to others has helped me understand the ideas better. | 3.95, 4.00 | 4.11, 4.12 |

### Table 3. Overall assessment of the research experience. Asterisks denote values that are higher than the average reported for all survey respondents. Results are reported as means based on a scale of 1–5, with 5 being the greatest gain.

| CURE Survey Statement | BCHS Students Year 1, Year 2 | All Respondents Year 1, Year 2 |
|------------------------|-------------------------------|-------------------------------|
| This course was a good way of learning about the subject. | 4.21* | 4.12 |
| This course was a good way of learning about the process of scientific research. | 4.25* | 4.20 |
| This course had a positive effect on my interest in science. | 3.85 | 3.97 |
| I was able to ask questions in this class and get helpful responses. | 3.75 | 4.17 |

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Table 4. Year 1 (2015–16) student learning outcomes assessed by laboratory report (N = 54 students).

| Lab Report Section | Learning Outcome Assessed                                                                 | Number of Students Receiving Point Values of: |
|---------------------|------------------------------------------------------------------------------------------|-----------------------------------------------|
|                     |                                                                                          | 9–10  | 7–8  | 5–6  | 3–4  | 0–2  |
| Introduction (8 points maximum) | • Apply knowledge of biological concepts and the scientific method to formulate questions and hypotheses for their research project. | N/A   | 35   | 17   | 1    | 1    |
| Hypothesis (8 points maximum)    |                                                                                          | N/A   | 27   | 21   | 5    | 1    |
| Methods (8 points maximum)       | • Apply knowledge of the scientific method to design experiments with appropriate controls and replicates. | N/A   | 50   | 2    | 2    | 0    |
| Results (10 points maximum)      | • Demonstrate the ability to accurately record and display experimental results.          | 46    | 6    | 2    | 0    | 0    |
| Conclusion (8 points maximum)    | • Demonstrate the ability to analyze their experimental results and draw appropriate conclusions. | 0     | 43   | 10   | 0    | 1    |
| Discussion (8 points maximum)    | • Articulate the details of their own research project and the significance of this research in the context of advancing biological knowledge. • Understand the limitations of their experimental design, and suggest possible improvements and/or follow-up experiments. | N/A   | 22   | 20   | 7    | 5    |

(scores ranged from 31 to 50). Year 2 students submitted group reports; scores ranged from 43 to 49 points, and the average grade was 47/50.

The students were also assessed by Kahoot quizzes (examples are given in Supplemental Material Appendices D and E) before and after completion of the hands-on activities. Year 1 student averages improved from 61.73% to 77.54% on the “Crazy for Streptomyces” quiz and from 42.86% to 73.33% on the microscopy/staining quiz.

**Overall Student Assessment**

After completing hands-on activities, the BioResearch students showed an overall ~25% improvement in their understanding of several of the concepts taught. These results are based on (1) assessment quizzes given on the same topics before and after the related experiments were performed and (2) the high school teacher’s assessment of their overall understanding of the material based on class discussions, exams, and periodic grading of the laboratory notebook. Students reported that the hands-on activities really helped them understand the material.

Based on assessment of overall class performance, >90% of the BioResearch students showed mastery of the material related to the research taught in the class, and ~80% could successfully formulate a hypothesis and carry out a simple research project based on their own questions and background information.

- **Discussion**

The results of our two-year study with BCHS students support the growing body of evidence that engaging students in inquiry-based activities, including authentic research in the classroom, leads to increased student engagement and increased interest in pursuing STEM fields. The BCHS students’ CURE survey results (Tables 1–3) and reflections demonstrate their appreciation for the hands-on learning experience – the students’ scores were comparable to those of all respondents for many of the survey questions. Survey results for the overall assessment of the research experience are particularly noteworthy – the BCHS students’ scores were higher than those of all survey respondents for most questions (Table 3). Graded assignments indicate that engaging in hands-on research enhanced their academic performance and helped most students achieve the defined learning outcomes. Most students received very good to excellent grades on their laboratory reports; scores were particularly strong for the methods and results sections of the reports (Table 4).

After completing this project, students demonstrated a much stronger understanding of the process of scientific research, including literature research, planning experiments, and data collection, as evidenced by their laboratory notebooks and in-class discussions. Their gains in understanding the importance of including controls in the experiments they proposed were particularly impressive. After reading, discussing, and presenting articles on Streptomyces, it was
clear that the students learned a great deal about how to organize and present experimental data. They also learned how to quantify and tabulate their results to facilitate interpretation and analysis, as shown in their lab reports.

In addition to noteworthy advances in understanding scientific methodology, students also demonstrated significant gains in comprehending the biological concepts pertaining to the research project. Before the onset of the project, most of these students had never even heard of *Streptomyces* or actinomycetes and were unaware that soil microorganisms are the source of most of our natural antibiotics. After participating in hands-on research with these organisms, students demonstrated a substantial increase in their understanding of the complex life cycle of *Streptomyces* and other, similar microorganisms. The experiments performed also led to a deeper understanding of the importance of the production of secondary metabolites with antimicrobial activity. Prior to this class, most had very little experience with microscopy and had only observed larger eukaryotic organisms. Preparing their own Gram-stained slides offered the students their first experience with bacterial smear preparation, staining, and use of the oil immersion lens to view prokaryotic cells.

There were some other positive benefits of the project: several students (~20%) informed their teacher that they were planning to apply for summer internships. Most said they were inspired by the class research experience and felt less intimidated by the idea of doing science research. In addition, many students reported that participation motivated them to take advanced science classes (such as AP Chemistry) to prepare for a future STEM-related career.

The actinomycetes project described here also has the potential to be expanded to other classes. For example, the BioResearch teacher also teaches AP Chemistry and has piloted the chromatographic study of some of the bioactive compounds in the required chromatography lab. This exemplifies a way to incorporate authentic research into a class with an established curriculum without sacrificing course content.

The Small World Initiative (Caruso et al., 2016) has introduced citizen science as a way of involving undergraduates (including non-science majors) in antibiotic discovery and has created a database on the antimicrobial activity of the isolates collected. Our project has demonstrated the efficacy of extending this type of research experience to high schoolers as well.

We engaged an entire class in research opportunities within a yearlong BioResearch class. While not all high schools may offer such a class, the research project could be adapted to be incorporated into upper-level elective classes, including AP Biology, Microbiology, and Environmental Science. For example, studies of actinomycete isolates can be linked to several AP Biology topics, including environmental effects on phenotype, biodiversity, and community ecology. AP Environmental Science topics such as terrestrial biomes and soil composition and properties could also be enhanced by hands-on studies of these microorganisms. Scale can also be adjusted by starting out with previously isolated actinomycetes or eliminating some of the experiments. Spores from actinomycete isolates can be stored as frozen stocks when not in use to minimize the amount of microbiological media needed to keep the strains growing (Shepherd et al., 2010).

This collaboration provides a unique and valuable opportunity for high school students to apply their knowledge of research and the scientific method to contribute to an actual biological research project while working in conjunction with college professors and students. Students become familiar with the tools and procedures used by professional biology researchers. BCHS faculty have the opportunity to develop advanced research skills that can be continued and expanded in the high school classroom in future years. Such collaborations also offer the benefit of potentially generating new information for the scientific community and providing pilot data for researchers to further develop projects into larger-scale, long-term research.

In completing this project, BCHS students learned about and performed many commonly used laboratory techniques and applied the scientific method to design and implement original experiments based on their own ideas. The hands-on, student-driven approach to learning helped students better understand and appreciate the scientific process and the roles of the scientist.

Motivated high school students may choose to pursue research in biological sciences and other disciplines outside of school time (as after-school, weekend, or summer experiences). However, high school students may not choose to engage in research for a number of reasons: they may have other family or school obligations, worry about the loss of time away from their studies, or not be aware of opportunities. Students may also shy away from research because they do not believe that they have the required skills. Research conducted in a classroom-based setting circumvents many of these obstacles and engages a much higher number of students.

In summary, partnerships between high school and college faculty that engage high school students in authentic research in a classroom setting can offer solutions to many of the issues facing educators today. They can address the call to engage young students in inquiry-based activities, increase their awareness and interest in pursuing STEM fields, and expose greater numbers of students to scientific research.

**Supplemental Material**

The following appendices are available as Supplemental Material with the online version of this article:

- Appendix A: Protocols for Preparing Soil Suspensions/Isolation of Actinomycetes and Testing for Antibacterial Activity
- Appendix B: Additional Assignments Used to Reinforce Student Learning
- Appendix C: Examples of Student Hypotheses (from Year 1 Cohort)
- Appendix D: Crazy for Streptomyces Quiz (Used in Kahoot)
- Appendix E: Gram Stain/Microscopy Quiz (Used in Kahoot)
- Appendix F: Reflection Questions Given after Completion of the Project
- Appendix G: Rubric for *Streptomyces* Laboratory Reports

**Acknowledgments**

This project was funded by the American Society of Biochemistry and Molecular Biology through a Hands-on Opportunities to Promote Engagement in Sciences (HOPES) seed grant for academic years 2015–16 and 2016–17. The authors wish to acknowledge the support of Dr. Omar Sharafeddin (Assistant Principal of Science, BCHS). We also wish to thank Dr. Monica Trujillo (Associate Professor, QCC).
for providing the soil samples as well as guidance and support, Ms. Laura Rachiele (College Laboratory Technician, QCC) for her generous assistance with preparing media and other materials, and Adolfo Coyotl (QCC student) for assistance with the maintenance of the cultures.

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JOAN PETERSEN is an Associate Professor in the Department of Biological Sciences and Geology, Queensborough Community College, Bayside, NY 11364; e-mail: jtpetersen@qcc.cuny.edu. PATRICK CHAN is a Teacher in the Science Department at Benjamin N. Cardozo High School, Bayside, NY 11364; e-mail: pchan@schools.nyc.gov.