Reaching a Large Urban Undergraduate Population through Microbial Ecology Course-Based Research Experiences

Samantha Parks, Jessica Lee Joyner, and Matthew Nusnbaum

Department of Biology, Georgia State University, Atlanta, GA 30302

Traditional postsecondary education is making progress on embracing the diversity of student backgrounds and experiences while preparing them for the demands of STEM careers. Course-based undergraduate research experiences (CUREs) are effective tools to concurrently achieve many student and faculty goals: facilitating training of students, building career competencies, generating publishable research results and enabling research experiences where students apply their knowledge and interest. Georgia State University is not unique with a high student demand for research experiences and mentors that is greater than traditional research faculty labs can accommodate. Georgia State University is, however, unique in that it is a demographically diverse campus which serves minority and non-traditional students (i.e., second career and veterans) and is also rapidly growing. Therefore, to enhance the microbiology curriculum and facilitate authentic research experiences for the growing number of biology majors, a cluster of course-based research experiences in microbial ecology was developed. A former research lab space was converted to a collaborative teaching lab to serve the growth in course offerings, as well as to accommodate multiple microbial ecology research projects occurring in the same space. The courses offered appeal to students, build on the strengths of faculty experiences, and facilitate collaboration amongst students and with the greater Atlanta community. To ensure that our CUREs are accessible to the diverse students in our department, we addressed a variety of logistical and curricular challenges. Solutions to such challenges align with the goals of the university to offer research and signature experiences to ensure students are included and trained in STEM skills.

INTRODUCTION

As STEM undergraduate enrollment increased, requisite growth to support meaningful STEM research, including available research assistantships in independent faculty mentored research labs, stagnated. Among institutions striving to improve undergraduate education, Georgia State University (GSU) has been recognized for its holistic efforts to seek this improvement, including its focus on innovative teaching (1). Using the focus of such innovative efforts, we established a cluster of microbial ecology labs to increase availability of authentic research experiences, promote community engagement, improve career readiness, and foster the inclusion of the diverse GSU student body within the scientific research culture of the university.

The GSU main campus is in downtown Atlanta, Georgia, enrolling 44,720 students. GSU is a minority-serving institution with a strong non-traditional student representation. In 2018, GSU was ranked #1 nonprofit or public university for conferring both undergraduate and graduate degrees to African-Americans, Asians, and Latinos in the University system of Georgia. In 2019, the incoming freshman class represented 160 nations and territories, with 36% of the incoming class being Black, and the university was ranked the 10th most ethnically diverse university in the United States in 2019 (2, 3). In 2018–2019, there were 2,300 undergraduate Biology majors and only 14 Biology faculty with active research labs. Four of these labs had a prokaryotic focus (4, 5). Such numbers indicate a serious lack of research overall and a particular dearth in areas of microbiology. Currently, biology majors do not have the opportunity to take biology courses until their sophomore year; shortening their exposure to the biological sciences and the breadth of related career opportunities, thereby leading to retention issues in the major, and a potential lack of graduate and career preparedness.

As a component of the Southern Association of Colleges and Schools Commission on Colleges (SACSCOC)
accreditation review process, which occurs every five years, each institution is required to develop a Quality Enhancement Plan (QEP) (6). This QEP is intended to provide a framework by which the institution strives to improve student learning outcomes and/or student success. As a part of the most recent accreditation review, GSU faculty and students identified the College to Career (C2C) initiative as the QEP for the next five years to develop the future of the university (7). The intent is to provide faculty with guidance and support to transform the student learning experience into one that focuses on the knowledge, skills, and abilities for students to be successful in their chosen careers. In accordance with the C2C initiative, our goal is to demonstrate how a cluster of CUREs can be developed on an urban campus to broadly reach students, enhance microbiology research opportunities, and connect with the local community and industries. These programmatic enhancements align with GSU’s new C2C initiative and will, hopefully, allow us to leverage existing relationships and develop new opportunities to bring in resources and continue to grow our impact for our students.

Based upon the need for research-based career competencies, including microbiology (8), a cluster of four microbial ecology (ME) CUREs was developed (Table 1). The CUREs create an inclusive opportunity through a collaborative space and complementary topics based on instructor research strengths (9). Labs include computer and bench work, with all benchwork following BSL2 Laboratory Safety Guidelines due to the presence of unknown microorganisms. Overall, CUREs improve student access to research opportunities and persistence in STEM; additionally, they incorporate outreach and interdisciplinary studies (10–16). CURE students are motivated to develop novel research questions, conduct basic microbiology lab processes, analyze and interpret data, and communicate scientific findings through written and oral presentations to their peers and the broader university community (17, 18). Interpersonal skills are strengthened through peer review and collaboration. In some cases, aspects of the methodology are prescribed and consistent across projects to emphasize key skill development. In these contexts, students still have broad flexibility in their tested variable(s) and the project’s specific application. Learning outcomes and assessment are generally similar amongst the CUREs (Table 2), with a combination of formative and summative assessments via organic and scheduled lab discussions, interim and final reports, journal club, and campus- and department-wide presentations. While students can only take one CURE each semester, they can take additional ME CUREs, in any order.

Winogradsky columns

The Winogradsky course (19) invites students to investigate soil microbial communities and the response to naturally sourced antimicrobial compounds. Key questions investigated by this lab involve the impact of essential oils, spices, and herbs upon the efficacy of antibiotics used to challenge microbial isolates. Students use locally sourced soil to develop Winogradsky Columns that challenge soil bacteria with varied spices, herbs, and essential oils that have reported antimicrobial capabilities. Students choose the compounds for challenging their Winogradsky columns with a consideration of their varied cultural and ethnic backgrounds. They are asked to consider what natural antimicrobial compounds have previously been introduced to through family, news, culture, or other venues. These considerations promote cultural awareness and an inclusive lab environment. Once the compound is selected, it is vetted for relevance and appropriateness. Students then develop the columns and isolate and characterize bacteria, including assaying the antimicrobial sensitivity profiles, biofilm capacity, minimum inhibitory concentration of the compound of interest, and phylogeny of the isolates. While similar selective enrichment and Winogradsky columns may be used in other university (GSU and beyond) undergraduate research labs, the focus on natural antimicrobial compounds with significance to the GSU student body is unique. The inclusion of scientific research from countries that more commonly use such natural antimicrobials, as well as discussing how compounds such as black seed oil, basil, garlic, peppermint, and turmeric are used worldwide, facilitates an understanding of varied cultural norms.

Bits and code of life

The Bits and Code of Life, or metagenomic data analysis course, was developed in response to the need for students to be trained in the processing and analysis of the data rapidly accumulating from the plethora of metagenomic projects (20, 21). An existing bacteria community dataset (16S rRNA sequenced with Illumina MiSeq), focused on the bacterial communities of the urban environment, is provided for students to use as the primary resource for their independent projects. Given the urban context that is the daily life of GSU students, this course encourages them to consider and expand upon their experiences as they explore the microbial ecology of their environment. Students ask novel questions that include their interest and interaction with the urban environment, enhancing their understanding of microbial ecology as both participants and researchers in an urban context.

The course includes the challenge of learning the language and process behind the common bioinformatic tools as well as microbial ecology, building from methods and content of similar courses or modules that incorporate bioinformatics (22–24). This process has been shown to provide students essential skills for careers such as a physician or lab technician (24). They exercise their newfound skills in writing computer scripts and using existing bioinformatic programs and processes. The course uses free or open access programs (e.g., Virtual Box, QIIME [25, 26], R [27]) to facilitate translation of course activities to graduate...
| CURE                                      | Principal Investigator | Goals                                                                 | Common Lab Methods                                                                 |
|------------------------------------------|------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Winogradsky column (BSL2; unknown soil microorganisms) | Samantha Parks         | 1. Students use locally-sourced soil to develop Winogradsky columns that challenge soil bacteria with varied spices, herbs, and essential oils that have reported antimicrobial capabilities.  
2. Students choose compounds for challenging their columns with a consideration of their varied cultural and ethnic backgrounds.  
3. Students use such compounds to facilitate column development, bacterial isolation and characterization, and antimicrobial assays. | 1. Streak and spread plating  
2. Bacterial isolation  
3. 16S rDNA PCR amplification and sequencing  
4. Staining and microscopy  
5. Kirby-Bauer testing  
6. Minimum inhibitory concentrations |
| Bits and Code of Life (metagenomic data analysis)  (no wet lab component) | Jessica Joyner         | 1. Learn the computer language and analysis process behind the common bioinformatic tools.  
2. Understand the urban microbial ecology and influences on microbial populations and human health.  
3. Analyze metagenomic datasets to describe the urban microbiome. | Investigate 16S rRNA community dataset  
Analyze metagenomic data using new bioinformatic tools |
| Urban Water Quality (BSL2; unknown water microorganisms) | Jessica Joyner         | 1. Students select a local source for water, based on their interests.  
2. Students investigate and monitor the water quality along with citizen scientist program.  
3. Evaluate which monitoring and detection method best addresses their question. | 1. Culture-based detection: IDEXX & Plate cultures  
2. Molecular-based detection: PCR & qPCR |
| Fermentation Ecology (BSL2; unknown microorganisms in kombucha) | Matthew Nusbaum        | 1. Using kombucha, the lightly effervescent product of sweetened tea fermentation by a symbiotic consortium of bacteria and yeasts, students are able to ask who is in the consortium, their roles during the fermentation cycle and how they are affected by varied treatments.  
2. Students are asked to identify treatments of interest, defend their selections and investigate pertinent hypotheses regarding the treatment effects on the microbial community.  
3. Students are encouraged to think about what they know about the health benefits of fermented foods, as well as common, commercial kombucha flavorings. | 1. Streak and spread plating  
2. Bacterial isolation  
3. 16S rRNA PCR amplification and sequencing  
4. Staining and microscopy  
5. Kirby-Bauer testing  
6. CO₂ monitoring  
7. pH monitoring |

or professional positions without the dependency on academic subscriptions to resources. Following the mastery of the traditional process to analyze metagenomic data, students are encouraged to test out new ways to analyze the data, using new processes or tools they create or find. The students then craft presentations to share their new microbial perspective of their environment and campus with other students.

**Urban water quality**

The investigative process for the Urban Water Quality course includes the common methods used by monitoring and regulatory agencies. Urban watersheds are under increasing pressure due to population growth and land development, with a strong impact on the microbial community (28, 29). Students select local water resources to sample, which removes a bias for neighborhoods with greater...
**TABLE 2.**
Microbial Ecology CUREs’ common learning objectives with the associated acquired career skills and example learning assessments (italicized content).

| Learning Objective | Example Career Skill and Assessment | ASM Curriculum Guidelines | NACE Competency |
|--------------------|-------------------------------------|--------------------------|----------------|
| Collaborate to develop authentic research questions and testable hypotheses. | • Science process and writing  
• Group work dynamics  
• Gallery walk to review questions and provide constructive feedback | • Scientific Thinking: 28 – Ability to apply the process of science | • Critical Thinking/Problem Solving  
• Oral/Written communications  
• Teamwork/Collaboration  
• Leadership  
• Professionalism/Work Ethic  
• Global/Intercultural Fluency |
| Demonstrate an understanding of primary literature that informs project background and results interpretation. | • Scientific literacy  
• Partner presentations of primary literature and guided class discussion | • Scientific Thinking: 29 – Ability to use quantitative reasoning | • Critical Thinking/Problem Solving  
• Oral/Written communications  
• Teamwork/Collaboration  
• Digital Technology  
• Career Management |
| Identify and apply appropriate techniques and skills to implement experimental design for data collection. | • Experimental design  
• Vision board of example figures  
• Present and critique data figures from publications | • Microbiology Laboratory Skills: 34 – Use appropriate methods to identify microorganisms  
• Microbiology Laboratory Skills: 35 – Estimate the number of microorganisms in a sample | • Critical Thinking/Problem Solving  
• Oral/Written communications  
• Digital Technology |
| Maintain a precise and relevant laboratory notebook. | • Scientific literacy  
• Periodical submissions with instructor feedback | • Microbiology Laboratory Skills: 38 – Document and report on experimental protocols, results and conclusions. | • Critical Thinking/Problem Solving  
• Oral/Written communications  
• Leadership  
• Professionalism/Work Ethic |
| Accurately represent data and communicate to a general audience in both written and oral format. | • Group work dynamics  
• Iterative development of research poster  
• STEM Conference participation  
• Final report as a scientific publication  
• Final research presentations | • Scientific Thinking: 29 – Ability to use quantitative reasoning  
• Scientific Thinking: 30 – Ability to communicate and collaborate with other disciplines  
• Microbiology Laboratory Skills: 38 – Document and report on experimental protocols, results and conclusions. | • Critical Thinking/Problem Solving  
• Oral/Written communications  
• Teamwork/Collaboration  
• Digital Technology  
• Leadership  
• Professionalism/Work Ethic  
• Career Management |
| Understand microbiota form rich, complex communities. | • Broader impacts of group data  
• ‘Chalk-talk’ about key result | • Microbial Systems: 20 – Microorganisms are ubiquitous and live in diverse and dynamic ecosystems.  
• Microbial Systems: 21 – Most bacteria in nature live in biofilm communities  
• Impact of Microorganisms: 27 – Because the true diversity of microbial life is largely unknown, its effects and potential benefits have not been fully explored. | • Oral/Written communications  
• Teamwork/Collaboration |
PARKS et al.: REACHING URBAN STUDENTS WITH ECOLOGY CURE

Interpret how microbiota play key functional roles in diverse ecosystems and the relevance to society.  
- Quantitative reasoning  
- Partner presentations of primary literature and guided class discussion  
- STEM Conference participation  
- Final report as a scientific publication  
- Final research presentations  
- Metabolic Pathways: II – Bacteria and Archaea exhibit extensive, and often unique, metabolic diversity.  
- Metabolic Pathways: I3 – The survival and growth of any microorganism in a given environment depends on its metabolic characteristics.  
- Impact of Microorganisms: 25 – Microorganisms provide essential models that give us fundamental knowledge about life processes.  
- Scientific Thinking: 31 – Ability to understand the relationship between science and society

Analyze how microbial interactions and environmental pressures drive selection within ecological populations.  
- Qualitative reasoning  
- Final report as a scientific publication  
- Final research presentations  
- Evolution: 2 – Mutations and horizontal gene transfer, with the immense variety of microenvironments, have selected for a huge diversity of microorganisms.  
- Evolution: 3 – Human impact on the environment influences the evolution of microorganisms.  
- Microbial Systems: 22 – Microorganisms and their environment interact with and modify each other.

The course information is then aligned with American Society for Microbiology (ASM) Curriculum Guidelines and National Association of Colleges and Employers (NACE) competencies.

financial or political interest that can be present for typical monitoring programs. Research questions will be around the theme of urban water quality, and they will be inclusive of students’ local knowledge and interests when determining their specific question regarding the ecological influences on sites and potential contamination. Water contamination is detected with indicator bacteria of sewage pollution, following the standards set by the Environmental Protection Agency (e.g., Method 1600 [30]) and protocols of local monitoring groups. Students will apply various methods to detect indicator bacteria, including IDEXX Enterolert (31), Petrifilm cultures (32), PCR (33), qPCR (34), and microbiome sequencing (35, 36). As part of their independent research, students will evaluate which monitoring or detection method best addresses their question, including the appropriate sampling schema (37, 38). Campus and community partnerships will facilitate collecting and analyzing nutrient levels and additional environmental data. Student results will contribute to the local knowledge regarding water quality, including generating data reports for local agencies and monitoring groups. The greatest contribution that the students have the opportunity to make is in researching how the local environment and public health are related in geographic areas in which they have a vested interest.

**Fermentation ecology**

Fermentation Ecology offers students an amenable tool, kombucha, to develop and test authentic research questions on a complex microbial community. The organizing research question in this lab focuses on how treatment with botanical flavorings and antimicrobial compounds affects the community dynamic and physiology of the complex microbial community responsible for kombucha fermentation. Students identify testable treatments for the kombucha based on their own interests, including cultural and ethnic histories, and commercially available flavorings of kombucha. We also seek to isolate and identify the key members of the consortium in the lab’s continuously evolving kombucha culture. Fermentation and brewing are inherently interesting to many students, even before they discover the rich microbiological background and potential applications of these fields of study. The interest
in fermentation and fermented foods cuts across cultural and experiential lines, with lively discussions in the lab about beer, wine, cheese, yogurt and culturally traditional fermented foods, promoting multicultural dialogue and inclusivity in the classroom. Lab courses that incorporate fermentation biology in the form of beer and wine analysis provide an opportunity to capture students’ interests and offer training in lab techniques, experimental design, and scientific literacy (39, 40). Kombucha fermentation has also been used to teach analytical chemistry in a traditional lab setting, though not as an inquiry-based, CURE-style course (41). This engagement leads students to consider the applications of their research and think about how laboratory skills can apply to a variety of career opportunities they may not have previously known exist. In Fermentation Ecology students identify their own research questions and work collaboratively to design appropriate experiments to test their hypotheses. Student success in the course requires a familiarization with a new field of literature, rigorous application of the scientific method, creative problem-solving skills, and team work, as well as data analysis, writing, and oral presentation skills.

**Lab space development**

A graduate research lab was retrofitted to function as the ME collaborative instructional research lab. Developing the space accommodated for multiple workflows and sharing equipment, ensuring effectiveness for the different goals and approaches of each CURE. The lab space has a central room, where students work and collaborate, and separate, adjoining rooms for specific research applications. The central room was organized such that there are desk-height areas for student work with laptops and lab notebooks, and flexible student space with bench-height tables. The central lab also includes refrigerators, freezers, incubators and other shared equipment. Adjoining spaces include a clean room for molecular work, a thermocycler and gel electrophoresis room, a media preparation and growing room, a staining and microscopy room and a storage/collaboration space for student personal items. An additional adjoining room includes solution preparation areas and a fume hood with chemical storage and incubators. The combination of open and compartmentalized lab space encourages collaboration and fosters a research community amongst the CURE students. Students are encouraged to make the space their own and use it for group planning meetings as well as lab work.

**CONCLUSION**

Students self-select into CUREs according to their interest and schedule. Several ME CUREs have no prerequisites, thus providing opportunities for first- and second-year undergraduates. Inherent in the CURE program is an opportunity for students to gain valuable research experience without searching for exclusive mentored experiences in faculty research labs. CUREs provide many of these same training opportunities (8) through a process that students are familiar with, course registration, while also providing graduation requirement credit and resume building.

The diversified structure of the ME CUREs topics and skills provides experiences for all students. Students who may not elect to continue their education following graduation gain experience that can help them on a path towards technical careers in clinical laboratories or government agencies. These courses are designed to serve the students regardless of career trajectory, preparing students with the career competencies necessary to be successful in any professional environment.

The CUREs have broader impacts through community involvement and outreach. The Winogradsky column and kombucha courses are involved with an annual Fermentation Fest: students host a science corner about microbial ecology, fermentation, and antimicrobials that students investigated. This outreach bridged communication with a local kombucha brewing company, leading to conversations about career readiness and job opportunities. The water quality lab will generate actionable data following regulatory protocols for monitoring and detection at sites with local relevance to students. Interdisciplinary collaboration opportunities include chemistry (kombucha and antimicrobial additives), computer science (metagenomic data analysis processes and tools), and geosciences (built environmental design impacts on water quality).

The ME CUREs are invested in impactful research experiences for our students. Currently, all three faculty members are conducting IRB-approved (H19106) research to investigate the impact of CUREs upon STEM identity, confidence, and persistence. In order to achieve success in developing a variety of ME CUREs, a series of complex challenges had to be overcome, both logistical and organizational in nature. To convince departmental leadership, we had to develop a strong rationale for the value of the courses, in spite of their relatively high per-student cost, demand for dedicated, specially designed laboratory space, and commitment to offer these courses instead of other, more traditional, lab/lecture courses. One compromise for meeting teaching needs of other courses was to adjust to the University’s suggestion of increasing course enrollment in lecture courses. Allowing larger enrollments in required lecture courses, without compromising our teaching philosophies, increased the available time for both students and instructors to schedule a ME CURE. By offering a variety of ME CURE topics from a group of experienced instructors who collaborate closely together, we provide a wealth of experience to our students and an area of strength for our department. Such experiences are further magnified through incorporation of discussions about the multicultural impacts and relevance that the labs yield via the experimental design, as well as through the community engagement and activities that are incorporated into the
ACKNOWLEDGMENTS

The authors declare that they have no conflicts of interest.

REFERENCES

1. U.S. News. 2019. Most Innovative Schools – National Universities, U.S. News & World Report. https://www.usnews.com/best-colleges/rankings/national-universities/innovative. Accessed fall 2019.

2. Jones A. 2019. Georgia state sets a record for overall enrollment, most qualified freshman class in university history. Georgia State University News Hub, August 22.

3. Georgia State University. 2019. Georgia State University is an enterprising urban public research institution in Atlanta, the leading cultural and economic center of the Southeast. Georgia State University. https://www.gsu.edu/about/. Accessed fall 2019.

4. GSU DSS. 2019. IPORT. Georgia State University Office of Decision Support Services.

5. GSU Biology Dept. 2019. BioFacts, Georgia State University Biology Department. https://biology.gsu.edu/. Accessed fall 2019.

6. SACS COC. 2017. Principles of accreditation: foundations for quality enhancement, 6th ed. Southern Association of Colleges and Schools Commission on Colleges.

7. Georgia State University. 2019. College to Career, Georgia State University. https://collegetocareer.gsu.edu/. Accessed fall 2019.

8. Merkel S. 2012. The development of curricular guidelines for introductory microbiology that focus on understanding. J Microbiol Biol Educ 13:32–38.

9. Killpack TL, Melón LC, Marszeller P. 2016. Toward inclusive STEM classrooms: what personal role do faculty play? CBE Life Sci Educ 15(3):es3.

10. Lopatto D. 2010. Undergraduate research as a high-impact student experience. Peer Rev 12:27–30.

11. Bangera G, Brownell SE. 2014. Course-based undergraduate research experiences can make scientific research more inclusive. CBE Life Sci Educ 13:602–606.

12. Corwin LA, Graham MJ, Dolan EL. 2015. Modeling course-based undergraduate research experiences: an agenda for future research and evaluation. CBE Life Sci Educ 14:es1.

13. Schinske JN, Balke VL, Bangera MG, Bonney KM, Brownell SE, Carter RS, Curran-Evenett D, Dolan EL, Elliott SL, Fletcher L, Gonzalez B, Gorga JJ, Hewlett JA, Kiser SL, McFarland JL, Misra A, Nenortas A, Ngeve SM, Pape-Lindstrom PA, Seidel SB, Tuthill MC, Yin Y, Corwin LA. 2017. Broadening participation in biology education research: engaging community college students and faculty. CBE Life Sci Educ 16(2):mr1.

14. Cooper KM, Gin LE, Akeeh B, Clark CE, Hunter JS, Roderick TB, Elliott DB, Gutierrez LA, Mello RM, Pfeiffer LD, Scott RA, Arellano D, Ramirez D, Valdez EM, Vargas C, Velarde K, Zheng Y, Brownell SE. 2019. Factors that predict life sciences student persistence in undergraduate research experiences. PLOS One 14:e0220186.

15. Shaffer CD, Alvarez C, Bednarcki AE, Dunbar D, Goodman AL, Reinke C, Rosenwald AG, Volyniak MJ, Bailey C, Barnard D, Bazinet C, Beach DL, Bedard JE, Bhalla S, Braverman J, Burg M, Chandrasekaran V, Chung HM, Clase K, Dejong R, Diangelo JR, Du C, Eckdahl TT, Eisler H, Emerson JA, Frary A, Frohlich D, Gossler Y, Govind S, Haberman A, Hark AT, Hauser C, Hoogewerf A, Hoopes LL, Howell CE, Johnson D, Jones C, Kadlec L, Kaehler M, Silver Key SC, Kleinschmit A, Kokan NP, Kopp O, Kuleck G, Leatherman J, Lopilato J, Mackinnon C, Martinez-Cruzado JC, McNeil G, Mel S, Mistry H, Nagengast A, Overvoorde P, Paetkau DW, Parrish S, Peterson CN, Preuss M, Reed LK, Revie D, Robic S, Roecklein-Cranfield J, Rubin MR, Saville K, Schroeder S, Sharif K, Shaw M, Skuse G, Smith CD, Smith MA, Smith ST, Spana E, Spratt M, Sreenivasan A, Stamm J, Szauter P, Thompson JS, Wawersik M, Youngblom J, Zhou L, Mardis ER, Buhler J, Leung W, Lopatto D, Elgin SC. 2014. A course-based research experience: how benefits change with increased investment in instructional time. CBE Life Sci Educ 13:111–130.

16. Auchincloss LC, Laursen SL, Branchaw JL, Eagan K, Graham M, Hanauer DI, Lawrie G, McLinn CM, Pelaez N, Rowland S, Towns M, Trautmann NM, Varma-Nelson P, Weston TJ, Dolan EL. 2014. Assessment of course-based undergraduate research experiences: a meeting report. CBE Life Sci Educ 13:29–40.

17. Cromley JG, Fiske ST, Perez T, Kaplan A. 2015. Undergraduate STEM achievement and retention: cognitive, motivational, and institutional factors and solutions. Policy Insights Behav Brain Sci 3:4–11.

18. Ward JR, Clarke HD, Horton JL. 2014. Effects of a research-infused botanical curriculum on undergraduates’ content knowledge, STEM competencies, and attitudes toward plant sciences. CBE Life Sci Educ 13:387–396.

19. Parks ST. 2015. Microbial life in a Winogradsky column: from lab course to diverse research experience. J Microbiol Biol Educ 16:82–84.

20. Tan TW, Lim SJ, Khan AM, Ranganathan S. 2009. A proposed minimum skill set for university graduates to meet the informatics needs and challenges of the “-omics” era. BMC Genomics 10(Suppl 3):S26.

21. Nelson K, Courier M, Joseph GW. 2011. Teaching tip—an investigation of digital literacy needs of students. J Inform Sys Educ 22:95–109.
22. Buonaccorsi VP, Boyle MD, Grove D, Praul C, Sakk E, Stuart A, Tobin T, Hosler J, Carney SL, Engle MJ, Overton BE, Newman JD, Pizzorno M, Powell JR, Trun N. 2011. GCAT-SEEKQuence: genome consortium for active teaching of undergraduates through increased faculty access to next-generation sequencing data. CBE Life Sci Educ 10:342–345.

23. Cline SG, Prokop JW. 2018. Framework, barriers, and proposed solutions for engaging students in bioinformatics research. Abstr Int'l Conf Bioinformatics Comput Biol, CSREA Press.

24. Mulder N, Schwartz R, Brazas MD, Brooksbank C, Gaeta B, Morgan SL, Pauley MA, Rosenwald A, Rustici G, Sierk M, Warnow T, Welch L. 2018. The development and application of bioinformatics core competencies to improve bioinformatics training and education. PLOS Comput Biol 14:e1005772.

25. Bolyen E, Rideout JR, Dillon MR, Bokulich NA, Abnet CC, Al-Ghalith GA, Alexander H, Alm Ej, Arumugam M, Asnicar F, Bai Y, Bisanz JE, Bittinger K, Brejnrod A, Brislawn Cj, Brown CT, Callahan Bj, Caraballo-Rodriguez AM, Chase J, Cope Ek, Da Silva R, Diener C, Dorrestein PC, Douglas Gm, Durall DM, Duvallet C, Edwards CF, Ernst M, Estaki M, Fouquier J, Gauglitz Jm, Gibbons Sm, Gibson Dl, Gonzalez A, Gorlick K, Guo J, Hillmann B, Holmes S, Holste H, Huntthenower C, Huttley Ga, Janssen S, Jarmusch Ak, Jiang L, Kaehler Bd, Kang KB, Keefe Cr, Keim P, Kelley St, Knights D, Koester I, Kosciolk T, Kreps J, Langille Mgi, Lee J, Ley R, Liu YX, Loftfield E, Lozupone C, Maher M, Marotz C, Martin Bd, McDonald D, McVer Lj, Melnik Av, Metcalf Jl, Morgan Sc, Morton Jt, Naimey At, Navas-Molina Ja, Nothias Lf, Orchanian Pb, Pearson T, Peoples Sl, Petras D, Preuss Ml, Pruesse E, Rasmussen Lb, Rivers A, Robeson M3 2nd, Rosenthal P, Segata N, Shaffer M, Shiffer A, Sinha R, Song Sj, Spear Jr, Swafford Ad, Thompson Lr, Torres Pj, Trinh P, Tripathi A, Turnbaugh Pj, Ul-Hasan S, van der Hoof Ak, Vargas F, Vazquez-Baeza Y, Vogtmann E, von Hippel M, Walters W, Wan Y, Wang M, Warren J, Weber Kc, Williamson Chd, Willis Ad, Xu Zz, Zaneveld Jr, Zhang Y, Zhu Q, Knight R, Caporaso Jg. 2019. Reproducible, interactive, scalable and extensible microbiome data science using QIIME 2. Nat Biotechnol 37:852–857.

26. Caporaso Jg, Kuczynski J, Stombaugh J, Bittinger K, Bushman Fd, Costello Ek, Fierer N, Pena Ag, Goodrich Jk, Gordon Jl, Huttley Ga, Kelley St, Knights D, Koenig Ej, Ley Re, Lozupone Ca, McDonald D, Muegge Bd, Prrung M, Reeder J, Sevinsky Jr, Turnbaugh Pj, Walters Wa, Widmann J, Yatsunenko T, Zaneveld J, Knight R. 2010. QIIME allows analysis of high-throughput community sequencing data. Nat Methods 7:335–336.

27. R Core Team. 2019. A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

28. Mclellan Sl, Fisher Jc, Newton Rj. 2015. The microbiome of urban waters. Int Microbiol 18:141–149.

29. Cho S, Hiott Lm, Barrett Jb, Mcmillan Ea, House Sl, Humayoun SB, Adams Es, Jackson Cr, Frye Jg. 2018. Prevalence and characterization of Escherichia coli isolated from the Upper Oconee Watershed in Northeast Georgia. PLOS One 13:e0197005.

30. USEPA. 2006. Method 1600: Enterococci in water by membrane filtration using membrane-Enterococcus Indoxyl-beta-D-Glucoside Agar (mEI). United States Environmental Protection Agency.

31. Budnick Ge, Howard Rt, Mayo Dr. 1996. Evaluation of Enterolet for enumeration of Enterococci in recreational waters. Appl Environ Microbiol 62(10):3881–3884.

32. Vail Jh, Morgan R, Merino Cr, Gonzales F, Miller R, Ram Jl. 2003. Enumeration of waterborne Escherichia coli with petrifilm plates: comparison to standard methods. J Environ Qual 32:368–373.

33. Ahmed W, Goonetilleke A, Powell D, Gardner T. 2009. Evaluation of multiple sewage-associated bacteroides PCR markers for sewage pollution tracking. Water Res 43:4872–4877.

34. Kapoor V, Pitkanen T, Ryu H, Elk M, Wendell D, Santo Domingo Jw. 2015. Distribution of human-specific bacteroidales and fecal indicator bacteria in an urban watershed impacted by sewage pollution, determined using RNA- and DNA-based quantitative PCR assays. Appl Environ Microbiol 81:91–99.

35. Unno T, Staley C, Brown CM, Han D, Sadowsky MJ, Hur HG. 2018. Fecal pollution: new trends and challenges in microbial source tracking using next-generation sequencing. Environ Microbiol 20:3132–3140.

36. Newton Rj, Mclellan Sl, Dila Dk, Vineis Jh, Morrison Hg, Eren Am, Sogin Ml. 2016. Sewage reflects the microbiomes of human populations. MBio 6:e012574.

37. Ferguson Dm, Griffith Jf, Mccree Cd, Weisberg Sb, Hege- dorn C. 2013. Comparison of Enterococcus species diversity in marine water and wastewater using Enterolert and EPA Method 1600. J Environ Public Health 2013:848049.

38. Noble Rt, Blackwood Ad, Griffith Jf, Mccree Cd, Weisberg Sb. 2010. Comparison of rapid quantitative PCR-based and conventional culture-based methods for enumeration of Enterococcus spp. and Escherichia coli in recreational waters. Appl Environ Microbiol 76:7437–7443.

39. Gillespie B, Deutschman Wa. 2010. Brewing beer in the laboratory: grain amylases and yeast’s sweet tooth. J Chem Educ 87:1770–1775.