Chapter 10
Going Up: Incorporating the Local Ecology of New York City Green Roof Infrastructure into Biology Laboratory Courses

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10.1 Introduction

> We will be sampling soil from green roofs from around NYC. Yes, we will be going up on roofs in January. Come to class on the 19th prepared to spend a considerable amount [of time] outside in cold, windy conditions. Dress warm!!!! This is mandatory except if you have a medical or other excused absence. (Correspondence between Dr. Matthew Rhodes and the Barnard Lab in Molecular Biology Class, January 5th, 2017)

With that email, I was committed. For the Spring 2017 semester, the Barnard molecular biology lab course would conduct a project lab investigating the microbial communities underlying New York City green roofs. The work was a continuation of another Barnard project lab conducted by Dr. Krista McGuire a few years earlier surveying the microbial communities inhabiting different types of green infrastructure around New York City. By necessity, soil samples had to be acquired the first week of class, in late January, in New York City, atop a roof, along the Hudson River. *What if it snowed? What if it was 10 °F? What if there were 60 MPH winds?* I said a quick prayer, began checking the weather incessantly, and barring actual physical danger to the students, committed the class to a field day.

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As it turned out, January 19, 2017, was an unseasonably warm, 50 °F and sunny day. Thank luck. Thank global warming, climate change, and the urban heat island effect. Fifteen Barnard and Columbia students sampled soils from the roofs of the US Postal Service Morgan Processing and Distribution Center and the Jacob Javits Convention Center. Despite the relatively mild conditions, by 4 PM, students were huddling for warmth. Had it been ten degrees colder, there would have been a mutiny; twenty and I would have been teaching a course to approximately two students. Dr. McGuire, in her wisdom, had scheduled her project lab for the fall semester, thereby necessitating field excursions in early September as opposed to mid-January.

Why then was I standing atop a roof in January with fifteen students, carrying three down jackets in my backpack? Why did I gamble on a winter field excursion? What goal did I hope this would achieve? For both of our project labs, we intended to expose the students to real-world ecological challenges threatening the sustainability of modern cities, efforts at both mitigation and sustainable design practices, and novel and cutting-edge ecological research. We hoped that this exposure to sustainable, responsible, and equitable urban development would motivate the students to lifetimes of climate justice awareness or even advocacy and inspire them to explore sustainability-related research endeavors. Inherent within our chosen projects were first-hand exposure for the students to climate exacerbated inequities, such as combined sewage overflow, and active attempts at remediation via green infrastructure. In turn, we intended for our students to gain a deeper understanding of these ecological challenges in the city in which they lived and achieve a more personal connection to their laboratory research projects.

This gamble and these hopes seemed to pay dividends as Tejashree (Teja) S. Gopal, a student in the Spring 2017 Molecular Biology Laboratory, later reflected:

> I must admit, when Dr. Rhodes first announced that we were taking a field trip to gather soil samples for our class, I was a little apprehensive. As a neuroscience major, my knowledge of plants and soil biodiversity was limited to what I had learned freshman year in Introduction to Biology. However, I was intrigued by the research nature of the course and was eager to see how we were going to develop the project. We met the first day of class in our classroom but soon were whisked away from campus to collect soil samples from two green roofs in New York City.

The successful field excursion provided a memorable introduction to the course, even for students with vastly divergent backgrounds. The uncertainty and novelty of the research project nature of the course promoted student buy-in that persisted throughout the semester.

10.2 Background

10.2.1 The Problem with Cities

For better or worse, our planet's urbanization seems destined to continue unabated in the coming decades (United Nations DESA/Population Division, 2017). Cities certainly provide many advantages to a global population numbering over seven billion, such as the energy efficiency of mass transit systems and their concentration of human population densities, leaving more land for other species and purposes. However, current urban practices are also at the root of many of the most egregious socioeconomic and environmental catastrophes facing the planet. Many Barnard students, residing and studying near Harlem, New York, are all too aware of these issues that they regularly encounter, despite living in one of the preeminent cities in a highly developed country.

Every time a Barnard student encounters people who are homeless mere blocks from campus, they face the abject poverty and income inequality faced by many New York City residents. Every time it rains heavily and streets and subway stations flood with storm water contaminated by raw sewage, they face the inadequacy of the New York City sewer system. Every time an uncomfortable 95 °F day amplifies to a sweltering 105 °F by seas of dark asphalt, they encounter the worsening realities of global climate change and the urban heat island effect. These are but a few problems facing New York City and virtually all other major metropolitan areas (Wu, 2014). The poorer the city, or even the poorer the neighborhood, the more pronounced these issues become.

10.2.2 Green Infrastructure to the Rescue

Green infrastructure installations, or areas designed to contain vegetation, have been implemented across urban environments to alleviate some of the ecological challenges caused by human development. Cities are now investing in large-scale green infrastructure projects such as urban parks, roadside plantings known as bioswales, and green roofs.

In the quintessential concrete jungle, impermeable urban substrates like conventional roofs, roads and sidewalks, and parking facilities absorb little precipitation. Instead, nearly the entirety of rainfall rapidly funnels to urban sewer systems where it mixes with raw sewage. Thus, during periods of heavy rain, especially in low and poorly drained areas, the sewer system can rapidly become overwhelmed (Fig. 10.1). In these "combined sewer overflow events," a combination of storm water and raw sewage is dispelled into surrounding streets and waterways.

The soils and growing media comprising green infrastructure have far greater water holding capacity than traditional, impermeable urban surfaces such as asphalt and concrete (Carter & Jackson, 2007). During heavy rainfall, more water is retained in the green infrastructure soils and subsequently returned to the atmosphere via plant transpiration, reducing runoff and the likelihood of costly and dangerous combined sewer overflow episodes (Carter & Jackson, 2007). For this reason, green infrastructure figured prominently in New York City Mayor Michael Bloomberg's forward-thinking sustainability plan for the future of New York, PlaNYC (*Mayor's Office of Recovery & Resiliency*, 2017). More specifically, PlaNYC presented an effort to prepare New York City for future population increases and climate change, focusing on improved housing, energy efficiency, water infrastructure, and air

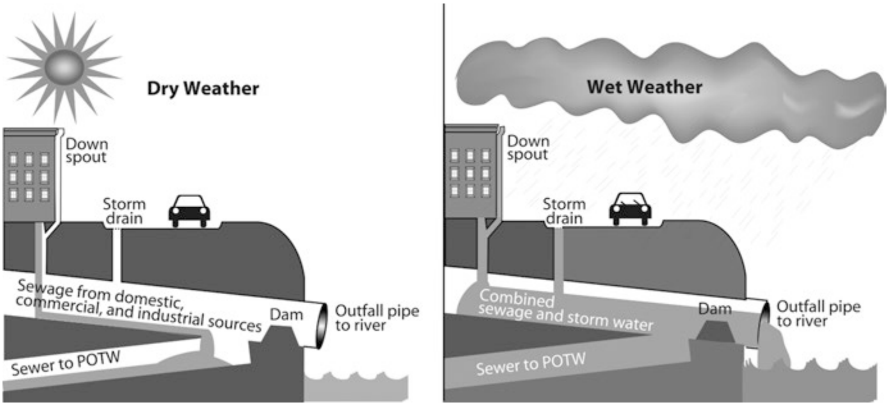

Fig. 10.1 Combined sewage system functioning under dry conditions (left panel) and wet conditions (right panel). The addition of storm drainage combines with raw sewage and overwhelms existing infrastructure causing raw sewage to bypass the Publicly Owned Treatment Works (POTW) and discharge directly into waterways. (Reproduced from the United States Environmental Protection Agency, Report to Congress: Impacts and Control of CSOs and SSOs 2004 (US EPA, 2004))

quality, amongst other aims. In addition to combatting sewage overflow, green roofs can help contribute to virtually all of these PlaNYC objectives.

Another key benefit of green infrastructure is reducing the urban heat island effect. Much of a city's surface, such as asphalt roads and shingles, are dark radiation-absorbing surfaces. These surfaces capture far more solar radiation than rural and suburban areas. On a typical summer evening, cities like New York City can be upwards of ten degrees warmer than surrounding suburbs (Solecki et al., 2005; US EPA, 2017). Green roofs absorb significantly less heat than traditional building materials. This feature combines with the natural evapotranspiration of plants, whereby plants utilize solar energy to raise and evaporate water, greatly reducing the heat transmitted to the underlying building. Estimates suggest that green roofs placed upon buildings, such as the one atop the Jacob Javits Convention Center have the potential to save New York City upwards of a net 16 million dollars annually (Akbari & Konopacki, 2005) in reduced cooling costs as well as reducing carbon emissions required to generate the electricity used for cooling.

10.2.3 Green Infrastructure Around New York City

Various green infrastructure installations are spread throughout the New York City area, each with a particular ecology and environmental challenges (McGuire et al., 2013). Roadside bioswales offer narrow, fragmented, and often disturbed sanctuaries of various trees and flowering plants. In contrast, urban parks such as Central Park or Riverside Park offer some of the few contiguous vegetated areas in New York City. Green roofs such as the one atop the Javits Center must contend with relatively high winds as well as significant direct sunlight, exposing the plants and soils to temperature spikes and high levels of solar radiation (Takebayashi & Moriyama, 2007).

Like most green roofs in the US, the Morgan Center and Javits Center green roofs incorporate plants from the genus *Sedum*. Though not native to the New York City environment, succulent *Sedum* spp. have proven highly resilient to the seasonal temperature fluctuations, daily temperature fluctuations, irregular rainfall, and high winds present atop northeastern United States rooftops (Monterusso et al., 2005). A select few New York City green roofs utilize native species, and they offer similar levels of water retention and temperature reduction compared to *Sedum* spp. green roofs (Lundholm et al., 2010). However, an additional benefit of native species green roofs is that they can offer valuable repositories of plant and microbial biodiversity and provide forage and habitats for wildlife, including insects and birds.

10.2.4 Don't Forget the Microbes

Naturally, as both of the professors teaching these courses were trained as environmental microbiologists, both the Microbiology Laboratory course and the Molecular Biology Laboratory course placed a significant emphasis on microorganisms, an often undervalued component of every ecosystem. Microorganisms comprise more biomass on this planet than all animal life combined (Whitman et al., 1998) and figure prominently in virtually every planetary chemical cycle (Falkowski et al., 2008). The sustainability and continuing effectiveness of the performance of green infrastructure ties intimately to the quality of the underlying soils and growing media (McGuire et al., 2013), which affects and is affected by the health of the plant and microbial ecosystems.

Soil and growing media quality are a complex interaction of biotic and abiotic processes. One pivotal component of soil and growing media is the soil microbiome. Microbes, including fungi and bacteria, play various roles in belowground ecology, including decomposition, nutrient cycling, and water cycling. In the case of green roofs, for example, low-quality growing media will detrimentally affect plant health, thereby reducing the water carrying and temperature reducing capacity of the green roof, two of the critical purposes of green roofs. Therefore, a better understanding of the factors that shape green infrastructure soil microbial communities is imperative for optimizing the long-term effectiveness of green infrastructure.

10.3 Course Descriptions

10.3.1 Microbiology Project Laboratory (Fall 2013)

In 2013 a project laboratory was designed by Dr. McGuire for students enrolled in Microbiology Laboratory (BC3321) to evaluate microbial communities in green infrastructure across New York City. A total of 15 students enrolled in the course.

The purpose of the project lab was to provide students with training in traditional and cutting-edge microbiological techniques in conjunction with direct field experience sampling soils and growing media from parks, green roofs, and tree pits. The course syllabus included 3 weeks of field sampling and additional sampling by the teaching assistant (TA; Seren Gedallovich, Barnard class of 2013) and student volunteers. The students and the TA sampled 15 green roofs, six parks, and 16 tree pits. The park samples were taken from forest sites, suburban parks, and urban parks to traverse an urban to rural gradient. Using these samples, students were trained in sterile sieving techniques, culturing, microbial biomass assays, mycorrhizal fungal quantifications, DNA extractions, amplifications of microbial DNA (PCR), and data analysis.

The ultimate goal of the class project was to produce a manuscript-style publication assessing the biogeography of microbial communities in green infrastructure across NYC and across the urban to rural gradient. Each student chose a subset of the work within this larger project framework to address their own research questions for their final project. For example, one student was interested in whether or not microbial biomass shifted across the urban to rural gradient, and another student was interested in quantifying human pathogens across different green infrastructure types. A collaborative effort of Columbia and Barnard students chose to explore the impact of nitrogen deposition from dog urine on the soil microbiome of roadside green infrastructure. This in-class project evolved into a senior thesis and then a co-first author publication for these students (Lee et al., 2019). The course's final session was a conference-style day of presentations in which each student made a poster highlighting their research projects, data analyses, and results.

Since students did not complete the processing of all the samples necessary for the final publication, a postdoc from the McGuire lab, an undergraduate researcher from the Microbiology project lab who enrolled in research for credit (Adam Abin), and an additional undergraduate thesis student, finished the remaining analyses (Gill et al., 2020). In the process, they added additional samples to the overarching project, which included road medians and bioswales.

10.3.2 Molecular Biology Project Laboratory (Spring 2017)

Building on Dr. McGuire's 2013 Microbiology Laboratory course results, together we decided that for the Spring 2017 Molecular Biology Laboratory course, the class would focus exclusively on New York City green roofs. In particular, the class would seek to compare the microbial communities underlying *Sedum* spp. Versus native green roofs and test their response to typical levels of heat stress found atop a New York City roof in the summer. Thus, on January 19th, the class sampled soils from the Morgan Center and Javits Center *Sedum* spp. roofs.

The course TA, Katherine (Kaye) Shek (Barnard class of 2015), sampled the Jackie Robinson, Hansborough, and Chelsea recreation center roofs the same week. The recreation center roofs were all comprised of native rather than *Sedum* species. Together, the class and Kaye collected almost 200 soil samples. The soil samples were then processed according to the protocols of the Earth Microbiome Project that standardize the characterization of environmental microbial communities (Caporaso et al., 2011, 2012).

We began the semester with a fully developed syllabus and plan that rapidly needed adjustment due to equipment malfunctions or experimental failures. Built-in flexibility was a must. Looking back upon the course organization, Teja described her experiences:

> As the class progressed, Dr. Rhodes introduced us to the molecular biology techniques that we would be using to look at the diversity of the soil samples we had collected. The syllabus Dr. Rhodes distributed the first day of class had a clear plan of the semester, detailing which experiments we would be conducting each week. However, as with any research project, things did not go according to plan. When one experiment failed, Dr. Rhodes was required to come up with a new plan for the following week's class, and thus began the semester's journey, shaped by our work. I found the flexibility of the project refreshing, given that many other classes in college are meticulously planned out. Something about the exploratory nature of this project fostered such a wonderful class dynamic, where we all, including Dr. Rhodes and our TA, Kaye, worked together to collectively reach our goal.

Thus, overcoming obstacles that often occur during scientific investigations added elements of stress and authenticity to the semester.

For a final project, the students utilized the QIIME (Quantitative Insights into Microbial Ecology) bioinformatics platform to analyze the DNA sequences (Caporaso et al., 2010). Each group of four students worked with only 1/200th of the data set to facilitate data analysis and reduce the time and computer resources required. With modern DNA sequencing technology, this reduced data set still comprised hundreds of thousands of DNA sequences. During the last day of class, as the QIIME analysis revealed results that confirmed and contradicted our original hypotheses, numerous students expressed feelings of accomplishment and satisfaction. On a side note, it is one of our favorite teaching endeavors to introduce students to the powers of computing beyond Microsoft Word and the graphical user interface. To the uninitiated, even limited computing expertise comes across as "magic." Eliminating the mental roadblocks that many students place between themselves and their computer is inevitably a rewarding experience.

Another distinct advantage of the project lab format, as noted below by student and TA, Kaye Shek, is that the entire semester was dedicated to furthering a single objective. This single objective enabled students to place their efforts in a broader context and to observe firsthand how the techniques that they were mastering could be utilized to answer questions and obtain both informative and potentially actionable results.

10.4 Course Results

10.4.1 Microbiology Course Results

Results from the 2013 project lab can be briefly summarized by three main conclusions: (1) both fungal and bacterial communities vary predictably across different types of green infrastructure (green roofs, parks, bioswales, etc.) and across geographic location, (2) microbial communities are more abundant and diverse in non-urban soils, and (3) increased N deposition from sources such as canine urine are detrimental to microbial biomass and diversity (Lee et al., 2019). Think about the important functions of green infrastructure the next time you see someone's dog urinating on them.

Despite the harshness of the urban environment, the comparatively small size of green roofs, and the inherent spatial isolation of urban green infrastructure, considerable microbial diversity was uncovered in all types of infrastructure. Green roofs, in particular, had high levels of bacterial diversity and, in some cases, had greater numbers of taxa than ground-level infrastructure. Interestingly, microbial communities from engineered bioswales had a greater diversity of both fungal and bacterial communities compared to other types of ground-level infrastructure, possibly due to increased resource inputs in the form of storm water. In bioswales, storm water is intentionally directed into the engineered installation, which brings a plethora of resources to feed microbes. By contrast, parks, tree pits, and green roofs primarily receive rainwater and less street-side runoff (and no runoff in the case of green roofs).

10.4.2 Molecular Biology Course Results

The results of the QIIME analyses proved to be both informative and unexpected. The class first looked at the overall species diversity (how many species of microbes were present) in the different green roofs. Our initial hypothesis was that the two *Sedum* spp. green roofs would display lower levels of diversity when compared to the native species green roofs due to the homogeneous nature of the overlying plant life. We also hypothesized that heat stress, experimentally imparted by heating soil samples prior to microbial analysis, would reduce the microbial diversity of the respective roofs.

Our analysis did show the native species green roofs to have more species diversity than the Javits Center *Sedum* spp. green roof shown in Fig. 10.2. However, the Morgan Center *Sedum* spp. green roof shown in Fig. 10.3 appeared to be more akin to the native green roofs than to the Javits Center green roof. The cause for this is unclear. However, students noted an increased level of plant species that were growing spontaneously on the roof in addition to deliberately planted vegetation atop the Morgan Center green roof. They also noted a shallower soil depth in the Javits

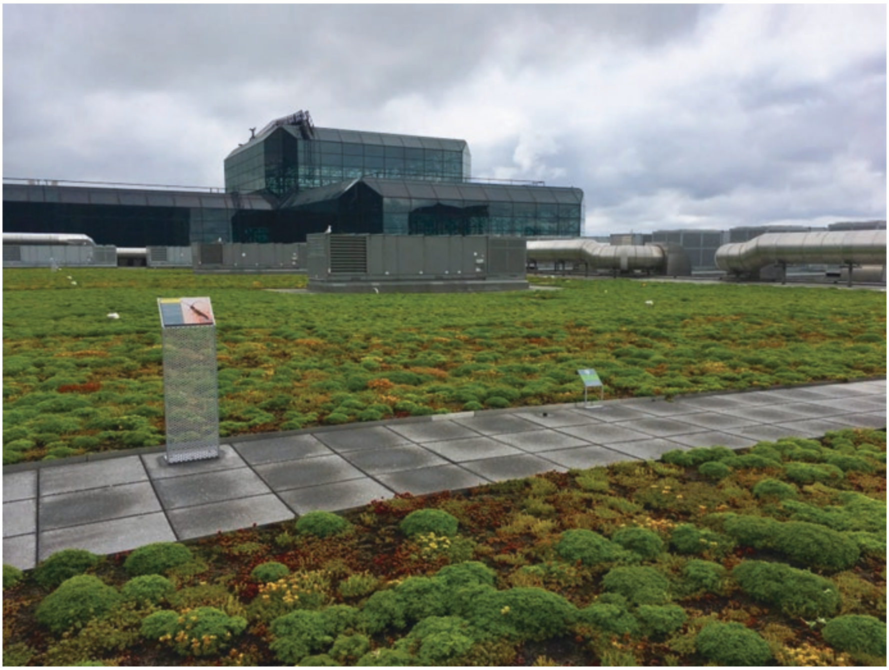

Fig. 10.2 The Jacob Javits Convention Center *Sedum* sp. green roof

Fig. 10.3 United States Postal Service Morgan Center Processing Plant *Sedum* sp. green roof showing considerable contamination of non-Sedum grasses

Center green roof compared to the other four roofs. Both observations suggest a reduction in available microbial habitats in the Javits Center roof in comparison to the other four roofs.

The overall level of microbial diversity does not necessarily indicate how alike two different communities are. Two communities may have similar levels of microbial diversity but be comprised of entirely different assemblages with highly distinct ecological functions. We hypothesized that the Javits Center and Morgan Center roofs would appear similar and that the three native roofs would map together. Once again, unexpectedly, the Javits Center green roof appeared distinct from the other four roofs, with the Morgan Center roof demonstrating similar species composition to the native green roofs. A fuller investigation of 32 New York City green roofs did show distinct differences between those with *Sedum* spp. versus native consortia (Hoch et al., 2019).

10.5 Reflections on an Ecological Project Lab

10.5.1 From the Professors

There is always the element of the unknown and the unknowable with any novel laboratory experiment. Will the experiment work? Will the results be meaningful? If not, was it due to a faulty hypothesis, a faulty setup, or human error? It is a common source of anxiety for any researcher from undergraduate through the tenured professor. When career and course outcomes are thrown into the mix, they only compound the anxiety. Contingency plans can be made, but they are just that, contingency.

Teaching a project lab for the first time was a humbling and a learning experience. From the outset, there were difficult questions to be addressed. Where was the budget going to come from? The Javits Center graciously donated the funds to support the class project and additional green roof research. What was the overarching goal? A class authored Nature paper would be nice but would anything that enhanced the learning environment be enough to justify the increased cost and stress?

These, in turn, raised additional questions. Principally, how ambitious could we make the project design? For the molecular biology course, we opted for five rooftops, three native and two *Sedum* spp., which seemed like a reasonable amount of work for the students (and the professor along with the course TA) to accomplish. Those also were the roofs that we were able to gain access to. Although five roofs would not be sufficient to publish a peer-reviewed research publication, we wanted the results to be informative for larger forthcoming green roof projects. As stated above, the course design would also enhance the students' learning experience. Ultimately, both hopes became a reality.

With that perspective, we would consider the Barnard Molecular Biology Green Roof Project Lab an unmitigated success. We obtained both unexpected and informative results. Many students openly expressed appreciation for venturing beyond the traditional laboratory experience of predetermined experiments and outcomes. Despite the chill, the students overwhelmingly appreciated the field excursion. It was a fantastic tone-setting experience for the semester and provided the class with a close-up view of the latest attempts to combat urban ecological problems. Students also expressed satisfaction with the knowledge that they were conducting research that had never been done.

Nevertheless, perhaps we were still overly ambitious. In retrospect, a project lab would be a more guaranteed success if it was not an independent research project in and of itself but rather an offshoot of ongoing work already well underway in the lab. Other students, researchers, and technicians dedicated to the project could help eliminate many of the risks and stressors associated with running a project lab. Preliminary data, well-established in-house protocols, and having additional hands on deck could facilitate the project and aid with contingency plans. As assistant and visiting professors respectively at the time, we had significant hurdles to overcome in attempting to conduct a successful project lab. For an adjunct, the barriers would be nearly insurmountable. It is yet another example of the disservice done to students by the academic world's increasing reliance on a revolving door of adjunct faculty.

Not surprisingly, a few of the class experiments failed outright, such as our attempt at a gel extraction. Given the time constraints of the course, these experiments could not be repeated. Others worked sufficiently to demonstrate the concept but insufficiently to obtain meaningful results, such as our attempt at constructing a library of DNA clone sequences to correspond to a representative population of arbuscular mycorrhizal fungi sampled across all roofs. A silver lining is that some students, Teja included, actually expressed appreciation for being exposed to the frustrations associated with novel scientific research. But enough of the experiments worked sufficiently well to provide meaningful results to analyze later. Any successful outcome for the course would have been impossible without the tireless efforts of the course TA, Kaye Shek, whose perspective both as an undergraduate student involved in green roof research and as a TA for the course is provided below. Kaye worked tirelessly with the students and behind the scenes to ensure that samples were processed and ready for class.

Since conducting their respective project labs in the Fall 2013 and Spring 2017 semesters Dr. McGuire and Dr. Rhodes have moved on to different institutions. Dr. McGuire is now an Associate Professor at the University of Oregon. Having the resources of a high throughput lab at a Research 1 university has facilitated Dr. McGuire in incorporating elements of a project lab in guiding undergraduate research projects in her lab, often mentored by graduate students. She continues to engage undergraduates in fieldwork, including green infrastructure research in Portland and Eugene, OR, and has also taken several students to Malaysia, Puerto Rico, and Panama. Dr. Rhodes is now an Assistant Professor at the College of Charleston. Dr. Rhodes teaches multiple microbiology laboratory sections per semester with more of a medical emphasis at a very large (10,000 undergraduates) liberal arts college. These responsibilities have precluded the incorporation of project lab elements into the microbiology laboratory curriculum. However, faculty at the College of Charleston who teach the molecular biology laboratories often structure the lab as a project lab by attempting to isolate and characterize novel virus strains. The anticipated reintroduction of an upper-level environmental microbiology course to the College of Charleston's curriculum could once again offer the opportunity to design a project lab course emphasizing the potential impacts of environmental microbiology research to global sustainability and equity.

10.5.2 From a Student

Tejashree Gopal, Barnard class of 2018, was enrolled in the Molecular Biology Laboratory in Spring 2017.

Looking back on the class, I think I most appreciate how I grew as a scientific writer. Being assigned to write about something that I had so little prior knowledge of was a truly eye-opening experience, not only to the topic of biodiversity itself but also to the fundamental process of writing a research paper. In many of my other classes, I have been asked to write research papers but have often been able to rely on my knowledge of the subject. When writing this research paper, I was, for the first time, challenged to learn everything that I could about the urban heat island effect, climate change, heat shock proteins, soil biodiversity, and many other related topics that I would never have had the opportunity to learn about were it not for this class.

I must admit that I struggled a lot along the way. The first writing assignment we had – to write an introduction for the first set of experiments we conducted – was one of the most challenging tasks I have confronted in my time at Barnard. I floundered, unsure of where I should even start. But as the class went on, I learned more effective techniques to find sources, extract information from dense publications, and write in a concise manner. Soon, I was writing papers of which I was tremendously proud.

As I started to write my thesis for my senior year at Barnard, I was incredibly grateful for the skills that I learned in this class. I felt extremely privileged to have had the experience of carrying out a research project from the initial stage of collecting samples to the final product of a published research paper, illustrating the research project from start to finish.

10.5.3 From Both Sides of the Table

Katherine (Kaye) Shek, Barnard class of 2015, was an undergraduate research student in the McGuire lab, and Teaching Assistant (TA) for the Molecular Biology Laboratory in Spring 2017.

As an undergrad, I took as many laboratory courses as I could. I wanted to understand my interests and strengths better, and what that meant for my career trajectory (or even to help me understand what to do after graduating). As most young scientists do, I thought about my future goals in the context of global issues: find a cure for cancer, stop global warming, feed the hungry – make a difference. It's this drive to make a difference that I believe boosts many young students into STEM fields and is important to consider when planning and designing undergraduate courses. This reason, among many, is why I consider the project-based laboratory courses in Molecular Biology and Microbiology at Barnard invaluable experiences to not only my personal growth as a scientist but also to my undergraduate peers and the students I worked with as a teaching assistant.

The immersive nature of a project lab course gives students an opportunity to make a real contribution to original research. This value was tangible in the Molecular Lab classroom: students were more confident to ask questions throughout every lab technique we covered to better place each activity and its purpose into the big picture. There was excitement and pride amongst classmates as we obtained results, and genuine curiosity and interest when certain procedures failed. As a TA, it was rewarding to have a classroom full of engaged students and it felt realistic to teach the methods and techniques through troubleshooting failures and celebrating successes. As a student in the course, I felt like I was making a useful contribution not only to the actual research project, but also to my own personal skills and experiences to build upon outside of class. (Frankly, as a student, the project lab felt both like a learning experience and a "resume builder," as I suddenly had many additional molecular biology methods that I could include on my CV. This was especially comforting as a soon-to-be college graduate with no plan. However, it was the learning experience that has paid off with more meaning in my life and nascent career.) Simply put, when compared to the more classical upper-level Biology lab course design, the project-based courses challenge students in a more fulfilling and realistic way.

In general, the 'classical' lab course syllabi include individual mini-experiments each week to focus on a particular organism or technique, not to be revisited until the final exam or an independent project at the end of the term. As a student in these courses, I enjoyed the opportunity to flex my creative muscles and design my own hypotheses to test in an independent project; however, as a TA in one of these lab courses, an issue with this particular design became apparent. By the time the final 2 weeks of the term rolled around and students were starting to design their independent experiments, nearly every student wanted to ask research questions that would take a full dissertation (and a hefty grant) to work towards an answer. Once their research questions narrowed down to a feasible degree, applying the methods they learned throughout the term outside of the context of the mini-experiments was a challenge to most students. I found myself running around to each student, helping them envision the methodological basis behind various techniques we had covered in depth earlier in the term. In contrast, the project laboratory allows students to answer broader research questions similar in scope and creativity to those they originally asked, spread out over a whole term, and learn new techniques along the way.

Obviously, choosing a general course design for effective teaching in Biology varies on a case-by-case basis: the ability to incorporate original research into a course depends entirely on the subject matter. In molecular biology, cell biology, or microbiology for instance, for the aforementioned reasons, I believe a project lab is an excellent means by which a young scientist can immerse themselves in learning new material that is otherwise challenging to grasp and retain, while simultaneously practicing the scientific method in a realistic context. Saying goodbye to the students walking out of the classroom on the last day with more than just a letter grade on their transcripts – specifically, with the ability to think and write like a scientist - was proof enough to me that the project lab environment leads to more meaningful and educational success.

10.6 Would We Do This Again? (Concluding Remarks)

Whether communicating basic scientific research to funding agencies, students, or the general public, one recurring challenge is placing the research into a broader and socially relevant context. The more esoteric and removed from a direct impact the research is, the more difficult this challenge can become. One advantage of designing both labs as project labs was that all laboratory exercises, from sample collection, to laboratory manipulations, through data analysis were all focused on a single theme. In this manner, students were given a more direct and comprehensive window into the broader scientific process and its potential impacts on society. In both the Microbiology Laboratory and Molecular Biology Laboratory courses, students observed how green infrastructure is attempting to solve global problems and societal inequities. As a whole, the final papers for both classes demonstrated a thorough understanding of the methodologies employed, the results obtained, and the background context motivating the project. For Teja in particular, "by the final writing assignment, [she] was impressed with [her] own ability to research completely new topics, gather information from a variety of sources, and reflect on how it related to the data we had collected in class." Furthermore, individuals from both courses could see the work to fruition and provide suggested steps toward improving the diversity, sustainability, and microbial health of green infrastructure.

There were successes, and there were failures. Progress was incremental. Let's face it; we were not going to solve the inequities, injustices, and dangers associated with global climate change in a semester. However, by sampling in the field, by processing those samples, by collecting data, by analyzing the data, and by writing up the results, students could experience first-hand the scientific process from start to finish. The site visits and field sampling provided a unique and memorable experience to illustrate the scientific questions and societal challenges we attempted to address. The data analysis and write-up provided an opportunity for students to measure progress and forced them to place their research in a broader context once again.

For us, the overwhelming sentiments of pride and accomplishment in completing an authentic research project, combined with a tinge of frustration at the end of the semester, signaled a successful project lab experience. The most significant impact for our students was that they have now participated in the non-linear march of scientific progress and its desired beneficial impact on society. To some who want to contribute to social justice causes, the uncertainty of basic scientific research may push them toward or solidify their desire for a career in medicine or other similar fields. Nevertheless, exposure to project-driven sustainability-related research during their college experience may contribute to a greater appreciation for basic research and help shape the finer details of their careers. But to others, experiences with authentic research may transform vague inspiration into the specific abilities and confidence required to support and motivate them to pursue a Ph.D. and a career in the basic sciences. We see both results in the students who have contributed to this chapter. The experiences as a TA for the 2017 molecular biology project lab solidified Kaye Shek's aspirations toward a Ph.D. and a career in environmental microbiology research. She is now completing her 5th year as a Ph.D. student with Dr. McGuire at the University of Oregon, investigating how variation in soil management practices alters vineyard microbiome structure and function. Meanwhile, for Tejashree Gopal, her experiences as a student in the 2017 molecular biology project lab contributing to basic research from project conception through publication have stuck with her into medical school.

The question then is not "would we do this again?" But instead, "when will we do this again?" Connecting molecular biology and microbiology laboratory techniques that are generally conducted in a laboratory with larger ecological and environmental principles, helps to focus the class on a broader purpose. Projects that give students direct exposure to sustainability concerns and allow them to directly observe the intended impacts of research enhance the authenticity of the experience.

Unfortunately, not every research project is an appropriate medium for a project lab. Not every course or institution is the appropriate venue. Nor will every topic have a strong undercurrent of sustainability or social justice. Often the questions addressed in the pursuit of scientific knowledge are on the esoteric side or have limited immediate applicability. Our chosen course topics on green infrastructure incorporated sufficient aspects of eco-justice, relevance, authenticity, and impact to be inclusive and spark the interest of the vast majority of our students. There are certainly numerous areas of scientific research that could serve this purpose to a similar extent, if not even more so. In that vein, when we have subsequently been called upon or will be called upon to teach biology laboratory courses in the future, we do so with the project lab structure in the back of our minds.

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