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Strengthening graduate education and addressing environmental challenges through solutions-oriented partnerships and interdisciplinary training

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Abstract

Graduate students across disciplines are eager for experiential training that enables them to address real-world environmental challenges. Simultaneously, communities across the world face numerous environmental challenges, including increased frequency of extreme heat in summer and poor air quality, and could benefit from the expertise and engagement of graduate students with the requisite skills and interests to address these challenges. In this paper we bring together lessons learned from three interdisciplinary graduate training programs focused on preparing graduate students to contribute to urban environmental solutions by working in partnerships with non-academic organizations. We discuss the multiple elements required for partnerships to be mutually beneficial, including using a T-shaped approach to training that incorporates both *depth* and *breadth* while making strong efforts to broaden participation. We share lessons with the goal of enhancing graduate programs to improve training of students to address urban environmental challenges globally. This training aligns with the United Nations Sustainable Development Goal 17, "Partnership for the Goals," which aims to achieve sustainable development goals through partnerships among entities.

Background

Classically, graduate programs in environmental sciences or related STEM fields focus on cutting-edge, highly specialized basic research without an explicit

connection to or training in real-world policy and practice. However, there is a growing need to train graduate students in interdisciplinary research that also contributes to managing and/or solving (as opposed to solely identifying and assessing) environmental challenges. Simultaneously, the private sector, governments, and non-governmental organizations (NGOs) around the world are making concerted efforts to address environmental challenges. This includes developing climate mitigation and adaptation strategies with an environmental justice focus, with the overarching goal to make cities and other population centers healthier and more sustainable [1]. These non-academic organizations could benefit from contributions from graduate

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students whose training and expertise are appropriate and relevant to the challenges that cities face today and in the future. As 56% of the world's population currently lives in cities (with an expected rise to 68% by the year 2050), interdisciplinary training that enables students to tackle urban challenges has never been more urgent [2].

Addressing these challenges requires change and innovation in graduate education. One element involves developing sufficient *depth* of expertise in a particular discipline while incorporating *breadth* in training, which includes academic training outside the student's own discipline, as well as cross-cutting skills like science communication. This so-called "T-shaped approach" [3, 4] to training addresses the workforce's need for researchers who can navigate across a range of disciplines, while still achieving the academic goals of developing expertise in a particular discipline. We believe that combining a T-shaped training approach with formalized external partnerships is an effective way to tackle environmental challenges while giving graduate students the interdisciplinary solutions-oriented training they seek. This approach is also aligned with the United Nations Sustainable Development Goals (SDGs) and their framework for achieving measurable solutions to environmental challenges. SDG 17, "Partnership for the Goals," provides a blueprint for graduate student training that incorporates an interdisciplinary, collaborative approach to problem-solving.

In this paper we provide examples of three graduate programs that include aspects of both T-shaped training and focus on graduate student partnerships within and outside universities. The Boston University Graduate Program in Biogeoscience and Environmental Health (BU URBAN), University of Connecticut Team-based, Transdisciplinary, Estimating Risks, and Real-world Analysis (Team-TERRA) Program, and the Wayne State University Transformative Research in Urban Sustainability Training (T-RUST) Program are all interdisciplinary graduate programs aimed at addressing real-world urban environmental challenges.

We provide lessons learned from these programs to develop generalizable insights for other graduate programs that also aim to provide deep disciplinary knowledge while improving the training of students to address urban environmental challenges globally. We discuss how strategies for collaborative and solutions-oriented research align with efforts to broaden participation in graduate training. We also discuss how these programs prepare graduate students for multiple career paths. Finally, we conclude the paper with reflections

on the challenges associated with carrying out and sustaining these programs.

Partnerships within universities: T-shaped training

Emerging research demonstrates that prioritizing interdisciplinary education at the beginning of a graduate program (rather than establishing fundamental knowledge alone) offers early career researchers and practitioners the skills necessary to tackle sustainability challenges, which tend to be complex and interdisciplinary [5]. There is a natural tension between gaining a broad understanding of scholarship, policy, and practice, while still developing a specialized set of skills to fulfill departmental thesis or dissertation requirements, which is addressed by the T-shaped training model [3]. In addition, for graduate programs to generate the next leaders in sustainability, they must engage students with partners outside of academia and prioritize interdisciplinary science within the academy, while giving students the opportunity to become experts in their field of interest, which aligns with SDG 17 [6].

Each of the three example graduate programs described in this paper utilizes T-shaped training. For example, in the BU URBAN program, in addition to discipline-based courses to capture *depth* in either Biogeoscience or Environmental Health, students are required to take one course outside their primary discipline and a course in statistics to capture *breadth*. In addition, an introductory colloquium course engages faculty members across participating departments to present on their research and professional trajectories, exposing students to a variety of qualitative and quantitative approaches and strengthening the opportunity for collaboration across disciplines. Team-TERRA trains their students to develop *depth* in disciplines within their field and *breadth* through an interdisciplinary two-semester course taught by multiple instructors that covers Environmental Risk Assessment, Science Communication, and Risk Communication from many different disciplinary angles. T-RUST trains their students to develop *depth* in disciplines like Urban Anthropology, Urban Ecology, and Civil and Environmental Engineering and *breadth* through six interdisciplinary courses. To develop training in interdisciplinary and team-based work, T-RUST has graduate students from different departments join interdisciplinary groups to address a real-life practitioner-informed urban sustainability research problem and suggest viable solutions. Likewise, Team-TERRA trainees form interdisciplinary teams to assess a local environmental risk in cities that emerges through interviews and meetings with local community partners.

Training for working with non-academic partners

Although the above steps provide the foundation for the interdisciplinary scholarship necessary to address urban environmental challenges, additional programming is necessary to prepare students for outward-facing partnerships and longer-term work to address environmental challenges. Workshops provide hands-on skill-building and exposure to career paths not typically emphasized in traditional academic settings. For example, BU URBAN, Team-TERRA, and T-RUST all include formal programming in science communication. Science communication workshops and classes emphasize tailoring scientific writing and other forms of communication to various audiences, including pitching research to journalists, translating research into a white paper, facilitating stakeholder meetings, and developing a web presence. Urban governance workshops in BU URBAN educate trainees about the inner workings of city government through attendance at city council meetings, meetings with governmental agencies, and training sessions in policymaker engagement, drafting legislation, and testifying at public hearings. Team-TERRA hosts workshops in data analysis and survey design and has trainees work in diverse, transdisciplinary teams to help address environmental challenges. For example, one team worked collaboratively to determine sustainable solar siting in Connecticut, another worked together to predict river contamination effects on food, water, and ecosystem services provided by two rivers in Connecticut, and a third completed a study to examine emergency department data for heat-related illness cases in the state to determine relationships between temperature, humidity, and human health.

More generally, these program activities are aligned with doctoral students' growing interest in careers outside of academia [7], which are not often well supported by doctoral programs that emphasize careers as research faculty members [8]. As such, students are often left to search independently for resources on non-traditional career paths and skill building [9]. Workshops that focus on communication, public speaking, networking, and digital literacy are often ranked as most useful to PhD alumni for preparing them for their current jobs, both as research faculty and outside of academia [10]. Creating access to information on non-academic careers especially benefits students from underrepresented minority (URM) groups who are more likely to follow non-academic career paths than their peers from well-represented groups [11]. As examples, both BU URBAN and Team-TERRA routinely offer workshops on non-academic opportunities hosted by practitioners from government, business, and non-profit organizations.

They also provide formal training in applying to non-academic jobs, including the differences between curriculum vitae and resumes and how to promote both academic and non-academic skills and experiences during the job search. Together, these are the types of activities that support the building of skills required to establish effective partnerships across sectors [6].

Internships and partnerships with non-academic organizations

For early career scientists, cross-disciplinary science-policy internships can be extremely beneficial [12]. An internship with a partner organization outside of academia (e.g., government office, NGO, private sector) potentiates unique and transformative experiences for graduate students to develop new relationships, skills, and perspectives beyond their academic discipline while also pursuing their degree. Science-policy internships for early STEM graduate students are also an opportunity to learn how their scientific research could influence policy and practice, expand their professional networks, and explore career paths outside of academia [13]. Partner organizations, in return, gain personnel with advanced skills who are trained in interdisciplinary problem-solving, can advance their mission, and potentially turn into long-term employees. However, to be successful, students need to both obtain training relevant to non-academic partnerships and have support throughout the internship process with an eye on skill development and ensuring that the internships are mutually beneficial.

We have found that providing internships for graduate students with non-academic institutions enables the students to gain *breadth* in their training, while building upon the *depth* of expertise they are expected to have in their discipline. Internships provide students with *breadth* by enabling them to learn how to apply the disciplinary knowledge they learn through coursework and their own research (*depth*) to real-world challenges. Internship timelines, structures, and deliverables in the example graduate programs are scoped and planned together between the student, program manager, internship host, and sometimes the program's advisory board. In one case, in 2020 a BU URBAN trainee completed an internship with Speak for the Trees, an NGO that aims to improve tree canopy cover in Boston to make it more equitable across neighborhoods. The student created a map of tree equity in Boston by combining data on tree canopy coverage with heat and pollution measurements and block-level population demographics (<https://treeboston.org/tree-equity/>). The effort was enhanced by the student's expertise in data analytics and GIS which enabled them to provide new maps and visualizations that the small NGO did not have the capacity to do, and the

student was able to leverage interdisciplinary skills such as communicating across sectors. The strength of this collaboration led to a mutually beneficial and sustained partnership between BU URBAN and Speak for the Trees. In 2022, Speak for the Trees included URBAN trainees as scientific consultants on a funded Environmental Protection Agency Environmental Justice seed grant to broaden the participation of local community members in tree planting and stewardship and advocacy for tree equity in Boston. By co-producing knowledge on trees and neighborhoods with community members, Speak for the Trees enabled trainees to share their academic training with the community, and also learn about community attitudes and culture related to trees.

Likewise, internships through T-RUST provided students with opportunities to work with NGOs like Re-Root Pontiac and the Chandler Park Conservancy. Internships were identified through a variety of mechanisms including by the program's advisory board of practitioners from diverse sustainability fields, faculty advisors, and the students themselves. Prior to students starting the internship, T-RUST mentors met with the internship host and identified areas in the internship to broaden a student's experiences by providing breath outside of their field or discipline. For example, the Chandler Park Conservancy internship was focused on designing and constructing bioswales to help mitigate urban flooding related to aging infrastructure and changing climate. The internship incorporated opportunities to include experiences in engineering (physical design), biology (plant selection) and communication (development of signage and public education), providing a breath of experiences beyond the student's background. Additionally, this internship required students to work in interdisciplinary teams of civil and environmental engineers, hydrologist, biologist, and urban planners.

Internships in Team-TERRA were developed by trainees and their advisors in consultation with program leaders. Although multiple opportunities with local businesses, non-profits, and government agencies were developed for the program, we found that trainees prefer opportunities that are more specifically suited to their future career paths. For example, one student completed an internship working for a federal agency that put her on a path toward employment in her field, while another student expanded her communication skills by working with a local K-12 school district. Giving trainees the freedom to choose internships that are most appropriate to their careers may be more challenging than selecting from a menu of options, but it provides a better fit for them. These internships clearly provided greater depth to trainees' experiences, but they also provided greater breadth by exposing them to new ideas that span beyond

their academic fields, particularly in applying their knowledge to organization-specific questions that inevitably span across disciplines.

Partnerships through broadening participation

Recruitment

A crucial element in developing graduate training programs to address urban environmental challenges is to acknowledge the importance of a diverse workforce that includes representation from affected communities. Those who identify as African-American/Black, American Indian or Alaska Native, or Hispanic/Latino—collectively referred to as Underrepresented Minorities (URMs)—are underrepresented in STEM graduate programs. In 2022, people who identify as URM made up 34% of the U.S. population [14], but only 9.1% of individuals who earned Science and Engineering doctorates [15]. A lack of available mentors and a lack of an inclusive institutional environment make it less likely for talented URM students and faculty to remain in STEM fields and prevent them from contributing to the STEM workforce [16].

BU URBAN has a multifaceted strategy to broaden participation. Recruitment efforts include sending student representatives annually to meetings such as the Society for the Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) National Diversity in STEM Conference, building relationships with faculty at Minority Serving Institutions (MSIs), and using social media and professional listservs such as the Black Doctoral Network to promote the program. BU URBAN engages in “high-touch” recruitment strategies to build relationships and trust with prospective students and provide support as necessary to demystify the graduate application process, including through publications and videos explaining the graduate application process [17, 18].

Similar to BU URBAN, Team-TERRA focuses recruitment activities on attending URM-focused meetings like those listed previously and individually contacting faculty from MSIs and groups (such as the Louis Stokes Alliances for Minority Participation) to encourage applications from prospective graduate students. Trainee opportunities are also marketed at professional meetings, conferences, and associations, with an emphasis on student trainees talking with prospective students. Team-TERRA prioritizes a personalized approach to recruitment especially via current trainees, including URMs, who are highly successful at recruiting interested students.

T-RUST recruits new students both internally at Wayne State University and with established external research partnerships. T-RUST is housed within Wayne State University in the heart of Detroit, Michigan, a city

with a majority minority population. T-RUST has made strong recruitment efforts internally as an urban university with a diverse population to serve as an entry point into higher education for URM students [19]. Additionally, T-RUST leveraged partnerships with largely Hispanic (e.g., University of Puerto Rico) and predominately black colleges (e.g., Marygrove College) to identify top students in STEM fields to apply to the program. These recruitment efforts were supported with targeting social media groups to demographically focused groups such as BlackInEngineering in X (formerly Twitter).

Retention

Retention is a concern across all graduate programs, but the issue is heightened among programs with a strong emphasis on diversifying the workforce. In addition, engagement in interdisciplinary training and outside partnerships can broaden connections and strengthen ties within the training programs themselves, but there is some risk of weaker ties with home departments and slower progression through graduate training.

All three graduate programs therefore incorporate numerous retention-focused elements that go beyond typical departmental activities. They all incorporate real-world skills and information related to non-academic career paths, which are known to improve retention of students from URM groups [20, 21]. This includes regular in-person and virtual communication channels, collaborations with departmental and other university programs, and group and individual check-ins moderated by faculty and staff. In addition, BU URBAN provides multiple mechanisms for trainees to provide feedback on individual events and the program, including anonymous channels when needed. Responsiveness to concerns by individual students or the group increases a sense of belonging and engagement. The availability of stipends without additional teaching requirements is another valuable element, as is a “Broadening Participation” award that funds participation in public engagement activities that reach under-represented groups and provide capacity building for scientific communication and research centered on inclusion, equity, and intersectionality. These awards also create opportunities for trainees to engage K-12 audiences, especially in lower-income communities and communities of color, in authentic science and science communication [22].

Beyond a robust set of check-ins for students related to their individual progress and the program as a whole, Team-TERRA also hosts social gatherings to create a sense of community and belonging for the students, as well as “research share” events: an evening out at a pub with food provided to network and socialize. Additional student support is provided via a core peer group, which

has been overwhelmingly the highest rated aspect of their program.

In T-RUST, social activities play a large and successful role in creating an inclusive environment and increasing retention. Students are asked to identify activities they would enjoy, and a variety of activities have been successful in bringing together multidisciplinary groups of students, faculty, and advisory board members. These interactions resulted in novel collaborations with students from different disciplines, including student-led grants to work with community partners.

Lessons learned

As we look across these three training programs spanning public and private universities, we have learned key lessons regarding how to build and maintain interdisciplinary graduate training programs that address urban environmental challenges. The most prominent of these relate to interdisciplinary coursework and connections with dissertation research, the internship experience, and broader questions related to institutional buy-in and program sustainability.

Interdisciplinary coursework and connections with dissertation research

While all programs successfully developed curricula reflecting T-shaped training approaches through including a combination of coursework in core disciplines that provide students with expertise (i.e. *depth*) and courses in other disciplines that provide *breadth*, there are multiple challenges that need to be acknowledged. One core issue is that these types of interdisciplinary programs engage students across multiple departments, each of which has their own requirements and structure, which create barriers for participation. Adding too many requirements places an undue burden on students, resulting in extended graduation timelines and a potential disincentive for enrollment. On the other hand, having more limited requirements minimizes interdisciplinarity and program cohesion. Programs addressed this tension through incorporation of flexible programs (including using workshops or seminars to provide focused content in lieu of courses), but this issue requires continual attention.

Another challenge related to coursework is that participating students will come with varied experiences, making the same content challenging for some and redundant for others. In addition, as these programs moved from ideals at the time of creation, all programs found they needed to be flexible in terms of changing requirements over time while maintaining the goals of the programs. For example, Team-TERRA initially required a specific geographic information systems course, but soon found

that alternative quantitative courses were more useful to individuals and transitioned to a system in which each trainee proposes a quantitative course that is most relevant to their goals. BU URBAN similarly expanded the set of courses allowed across disciplines to enhance flexibility.

Also, robust T-shaped graduate training often requires elements beyond coursework to be successful. For example, BU URBAN requires students to have one dissertation committee member from a department affiliated with BU URBAN but outside their discipline, to foster long-term cross-departmental relationships and generate incentives and support for interdisciplinary scholarship. While this supports the student and fosters faculty collaboration, this requires extra time of faculty to participate in more graduate student committees than they would otherwise do. This model evolved from an initial requirement of an interdisciplinary dissertation chapter to codify collaborations, which was quickly revised to an interdisciplinary dissertation committee due to time and funding challenges, reinforcing the need for flexibility while maintaining core principles to encourage interdisciplinary engagement.

Relatedly, for doctoral students, it is challenging to sustain the interdisciplinary structure throughout the dissertation process, given both funding structures and the contents of research grants in home departments. Many students found it difficult to integrate their non-academic experiences and internships into their dissertations, and at times had faculty advisors who voiced concerns about engagement in the program increasing the time to degree and distracting from their core dissertation research. Programs used strategies, including small research grants for interdisciplinary projects and interdepartmental dissertation committee requirements, and often loosened requirements over time to maintain student participation. While these programs had multiple success stories and fostered increased interdisciplinarity, ultimately research grants with an interdisciplinary and solutions-oriented focus are needed to ensure that students can have sustained engagement and training throughout their graduate careers.

Internships

A common challenge across programs is balancing trainees' needs to have short and flexible internships with the organizations' needs to have sustained project support. While internships create a one-time transformative training opportunity for students, partnerships require a longer-term relationship among groups that is not reliant on individuals for continuity [23]. Developing and maintaining trust between partners is critical to a successful partnership. While the graduate students are at the

center of the experiences, their progression through the training programs requires that the relationship be sustained by the leading faculty and program managers. This makes institutionalizing these partnerships and building trust critical to long-term success [24]. Creating sustaining partnerships with local NGOs, government agencies, or the private sector can allow trainees from multiple cohorts to engage in longer-term efforts to address urban environmental challenges. However, diversity of student interests and a common desire to develop new projects rather than building from previous internships can create a lack of continuity and proliferation of partnerships that require support after the individual student internship is completed.

Future programs incorporating internship experiences also need to recognize that many external organizations, particularly community groups or environmental justice leaders, have finite bandwidth and high demand on their small staffs. While this implies that these organizations can benefit greatly from the support that graduate students can provide, especially with thematic alignments and programmatically paid internships, it also contributes to challenges with communication and sustained engagement as well as with reaching clear internship agreements that optimize student experiences. More generally, sustained partnerships are challenged by the financial dimensions of the internship, as well as by administrative barriers. On the former, centralized university funding to cover internship experiences is extremely valuable, as it reduces tensions with faculty advisors and ensures equity across partner organizations with varying levels of resources. On the latter, universities have requirements for student experiences while partner organizations have requirements for interns and other staff, and reconciling these requirements can be challenging.

Institutional buy-in and program sustainability

Finally, institutionalization and program sustainability are major challenges. All three programs discussed were initially supported through grants from the National Science Foundation Research Traineeship (NRT) program that seeks to advance the interdisciplinary and comprehensive training of STEM graduate students. These grants are non-renewable, creating challenges for long-term sustainability especially given the "high-touch" nature of these training programs given the internship elements and the need for cross-departmental and cross-campus coordination. Graduate programs of this sort are unlikely to have large enrollments, making it difficult to support and sustain programmatic elements and dedicated program managers without creating real and/or perceived inequities in student academic support and

access to resources. Also, professors often are required to teach discipline-specific courses in their department and cannot add new interdisciplinary courses easily or without adding substantially to their workload. There are alternative training grant mechanisms (e.g., NIH T32 grants) that can be renewed, and these can allow for investments in innovation to grow and evolve.

Another aspect of long-term sustainability of these types of graduate programs relates to having a critical mass of students, faculty, and administrators supporting the program. While all programs had success with recruitment, enrollment decisions are ultimately made by home departments that need to make a sustained financial commitment to students beyond the 1–2 year stipends made available by these training programs. All programs had a critical mass of enthusiastic faculty, but in some cases, there was a decline in faculty engagement over time, given a lack of incentives for innovative education efforts that may come at the expense of research productivity. Administrative support for programs ultimately hinges on connections with broader institutional initiatives, which can vary over time and be influenced by leadership turnover. Another challenge relates to recruitment of students from URM groups, which can be time- and resource-intensive, and where innovative practices within small programs could not always be sustained in home departments or across the universities.

Conclusions

In conclusion, while many challenges exist related to forming and sustaining graduate programs that incorporate a T-shaped training approach to address urban environmental challenges, we learned through reviewing these three graduate programs that many can be overcome to provide graduate students with the interdisciplinary, hands-on, solutions-oriented training they are seeking. By providing them with coursework, workshops, and internship opportunities, they develop the skills necessary to work with partners while still in graduate school and to pursue multiple career paths upon graduation. Together, these three graduate programs provide examples of how to make graduate programs effective in contributing to SDG 17 and forming the multi-stakeholder partnerships necessary to manage and address the world's environmental challenges. Sustaining these programs will require renewed and prolonged dedication to interdisciplinary training from the university, funding agencies, and beyond.

Abbreviations

BU	Boston University
DGE	Division of Graduate Education
MSI	Minority Serving Institutions

NGO	Non-governmental organization
URM	Underrepresented minority
NSF	National Science Foundation
NRT	National Science Foundation Research Traineeship
SDG	Sustainable development goal
SACNAS	Society for the Advancement of Chicanos/Hispanics and Native Americans in Science
Team-TERRA	Team-based, Transdisciplinary, Estimating Risks, and Real-world Analysis
T-RUST	Transformative Research in Urban Sustainability Training

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