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Designing and implementing a novel graduate program to develop transdisciplinary leaders in urban sustainability

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ABSTRACT

Urban settings are increasingly faced with challenges across natural and engineered environmental systems, threatening the sustainability of urban centers where >50% of the world's population resides. The pressures of aging infrastructure, water and air pollution, and environmental justice exemplify the growing need for urban professionals to employ complex scientific reasoning across disciplines where they can effectively address the multi-faceted issues of urban sustainability. Here we present an innovative model for preparing the next generation of public, private, and academic leaders to address complex problems in urban sustainability. Specifically, we outline the design and implementation of an integrated, adaptable graduate training program, with the goals of science leadership, curriculum relevancy, community impact, broader applicability, recruitment into science, technology, engineering and mathematics (STEM) programs and careers, and program sustainability. This program addresses human-ecosystem challenges using a transdisciplinary approach to produce scientific products in partnership with local communities, businesses, industries, scientists, and policy makers, while providing a mechanism to understand and overcome contemporary societal challenges. Students receive rigorous training in their home disciplines, coupled with training across disciplinary lines and developmental experiences, to prepare them to communicate, collaborate, and innovate in a variety of contexts. Training success is evaluated across measurable competency domains including problem definition, research methods, communication, collaboration, and problem-solving. After three years the program expanded relationships across fields and professions, successfully established 18 internship opportunities with community partners, created a new dual-title PhD program open to students in 5 academic departments, and facilitated the co-production of knowledge with external partners. This model bridges the gaps between research,

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education, and application, providing an integrated, rigorous graduate training program that fosters collaborative problem-solving between STEM graduate students and the broader community of professionals conducting sustainability work in a post-industrial urban setting.

KEY WORDS

Graduate programs; higher education; interdisciplinary research; STEM; transdisciplinary research; urban sustainability.

INTRODUCTION

Urbanization places immense demands on natural capital and ecosystem services (Gómez-Baggethun and Barton, 2013). Although these demands are acutely placed on urban areas, they cast a wider influence on the natural environment both because of the interconnectedness of the environment and global flows of capital and trade (Donaghy, 2012). Given the local and global downstream impacts, plus the increasing rate, of urbanization (United Nations, 2019), there is an urgency to address the sustainability of urban ecosystems and ensure their persistence for future generations.

Sustainability in post-industrial cities, often referred to as Rust Belt cities, is complicated by structural inequalities that exacerbate racial disparities, leaving people of color (POC) exposed to higher levels of pollution (Zwickl, Ash, and Boyce, 2014) or inadequate or compromised infrastructure (Bullard, 1999). Indeed, exposure to pollution in Rust Belt cities has followed a trend of placing new hazardous facilities in predominantly POC neighborhoods (Mohai and Saha, 2015; Pastor et al., 2001) and leaving pollution behind in these neighborhoods as manufacturing left for the suburbs (Taylor, 2014). The effects of such compromised urban infrastructure on POC were recently seen during the Flint, Michigan water crisis (Butler, Scammell, and Benson, 2016; Greenberg, 2016), and are evident in larger cities such as Detroit, Michigan, where POC experience a lack of the basic services required for health and welfare (Mohamed, 2018).

The complexity of challenges in the field of urban sustainability necessitates a transdisciplinary approach that enables a variety of disciplines and stakeholders to collaborate on addressing the many interconnected issues (Lang et al., 2012; Norström et al., 2020), with sometimes conflicting objectives. The complex links among natural, engineered, production, and socioeconomic systems are poorly understood at the urban scale (Bettencourt and West, 2010), and the science of communicating these links to policy makers and the public requires constant refinement because of their intricate, technical, and quickly evolving nature.

However, in traditional science and educational models situated within disciplinary silos, there are limitations to the successful transfer of scientific findings into action (van Kerkhoff and Lebel, 2006), a situation known as the "knowing–doing gap" (Pfeffer and Sutton, 1999), which has been identified in a variety of environment-science related fields such as landscape ecology (Montgomery et. al, 2018), restoration ecology (Reyers et. al, 2010), and ecosystem management (Matzek, et. al, 2014). Alternative models of knowledge transfer involve integration and active engagement among key stakeholders (van Kerkhoff and Lebel, 2006), where sharing of knowledge between researchers and nonscientists is an ongoing process using adaptive

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management approaches. Collaboration among academics and other professionals, in addition to an integrated understanding of urban systems, is essential for sustainable management of urban environments (Lang et al., 2012; Norström et al., 2020).

The emerging field of team science, which involves collaboration among multiple disciplines, provides a framework to navigate complex interactions and facilitate integration (Bennet and Gadlin, 2012; Read et al., 2016). The distinction between interdisciplinarity, which "analyzes, synthesizes, and harmonizes" links among disciplines, and transdisciplinarity, which integrates the knowledge and "transcends traditional boundaries" (Choi and Pak, 2006) is important for translational research. Transdisciplinary collaborations thereby involve varied stakeholders, focus on solving complex societal problems, and develop new knowledge, theories, and frameworks that transcend the contributions of unique or integrated disciplinary knowledge (Klein, 2018). Nurturing the transition along the inter- to trans-disciplinary continuum begins during formative education and extends through advanced academic training and into ongoing professional development.

While disciplinary silos still prevail in graduate education, the inherent pedagogical advantages of interdisciplinary efforts in graduate training are widely recognized (Fam et al., 2018; Frodeman et al., 2010). Examples include the National Science Foundation (NSF) 2011-2016 Strategic Plan (National Science Foundation, 2011) and the National Institutes of Health (NIH) Clinical and Translational Science Programs (National Center for Advancing Translational Science, 2018). Support for this kind of integrated, problem-based training is even stronger in Europe (Taylor, 2011). Even so, interdisciplinary efforts can be stymied by obstacles at administrative levels and institutional and professional barriers to implementation (Fam et al., 2020; Klein, 2010). Major barriers include recognized and accepted criteria to assess professional achievement and advancement (Klein and Falk-Krzesinski, 2017), institutional funding for teaching and graduate student support, and academic employment opportunities. Somewhat less intractable barriers include credit for joint- or co-teaching, support and staffing for synthesizing courses, the allocation of recognition and 'credit' for external funding, and joint dissertation chapters and publications (Klein and Falk-Krzesinski, 2017).

Considering the institutional barriers listed above, emergent workforce needs in transdisciplinary competence, and the urgency for solutions to urban sustainability problems, we sought to develop a program that addresses those gaps in academic graduate training. Wayne State University (WSU) is located in downtown Detroit, an aging Rust Belt city undergoing a profound revitalization. As an urban research institution, many of our students are actively engaged with the community. This makes us uniquely poised to develop an innovative program to advance transdisciplinary graduate training and address some of our city's pressing issues, with broad applicability to other urban centers.

Named *Transformative Research in Urban Sustainability Training* (T-RUST), our overarching objective was to develop the structures needed to support transitions along the disciplinary – transdisciplinary continuum for students, faculty, and community partners. Our six goals were to 1) educate graduate students to make important contributions to urban environmental system research, policy making, and interdisciplinary problem solving (***Science Leadership***); 2) develop a curriculum for our science leaders to meet the needs of the labor market in urban sustainability (***Curriculum Relevancy***); 3) effectively address local urban sustainability problems through an interdisciplinary lens (***Community Impact***); 4) generate knowledge that has applicability in other urban settings (***Broader Applicability***); 5) recruit students that fulfill the need to educate students of underrepresented groups (***STEM Recruitment***

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Pipeline); and 6) develop a self-sustaining program that thrives beyond the life of the grant funding period (***Program Sustainability***). Here we describe the steps we took to design and implement the program, the challenges we encountered, and lessons learned after three years of successful implementation, with the hope that this model can be used and adapted by other institutions looking to advance graduate training and produce the next generation of transdisciplinary leaders.

PROGRAM DESIGN

Program structure

T-RUST is an NSF Research Traineeship (NRT) program, which is a 5-year program "designed to encourage the development and implementation of bold, new, and potentially transformative models for STEM graduate education training" (NSF, 2019). The proposal request encourages innovative, evidence-based programs designed to meet the challenges of a changing workforce and research needs. T-RUST was designed along these lines and specifically to prepare its graduates to lead public and private partnerships addressing complex environmental issues of urban centers.

The initial development of this program began through the construction of a research proposal cultivated by faculty at WSU. The core program leadership team consisted of one PI, 4 co-PIs, 4 senior personnel, and an external evaluator representing 8 disciplines split evenly between STEM, social sciences, and the humanities. The majority of the faculty leadership team had previously established collaborative relationships and a history of collaborative publishing and teaching, developing campus wide initiatives, and interdisciplinary seminar series, which helped build a strong foundation for the program.

The leadership team identified the six goals of the T-RUST program (listed above) and designed a novel logic model with various training components to achieve these goals (Figure 1). Each training component mapped to a specific goal, and was guided by a well-developed assessment component led by an expert in performance improvement and an external program evaluator.

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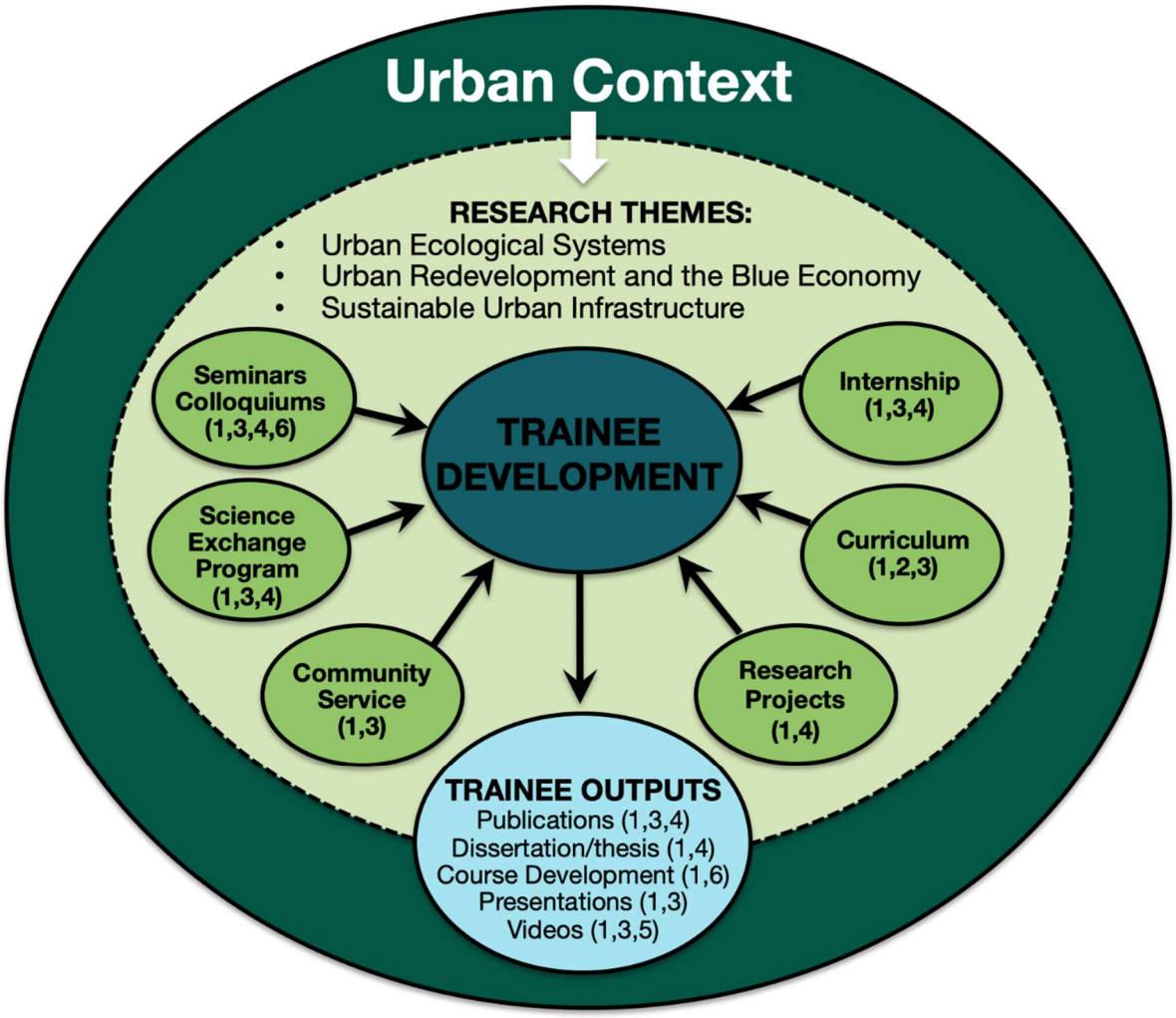

Figure 1: Transformative Research in Urban Sustainability Training (T-RUST) program logic model. Numbers refer to the six core program goals: 1) Science Leadership; 2) Curriculum Relevancy; 3) Community Impact; 4) Broader Applicability; 5) STEM Recruitment Pipeline; and 6) Program Sustainability. Each training component maps to two or more core program goals.

A common assumption is that if a group of researchers from different disciplines is formed, it will automatically result in research that crosses disciplinary boundaries. However, literature suggests that for such efforts to be successful it requires mastery of specific competencies (Committee on Facilitating Interdisciplinary Research and Committee on Science, Engineering, and Public Policy 2005; Brown 2014). Therefore, the design of this innovative program centered on a competency model for multiple-discipline urban sustainability graduate training (Table 1), composed of five domains further subdivided into 19 competencies, and was based on a review of the literature and input from the program leadership team. The competency model was further refined and validated during the initial implementation stage to reflect workforce demand with input from an External Advisory Board (EAB) of diverse community stakeholders to inform the final program design.

Students participating in the T-RUST program (hereafter, “trainees”) in the past three years have engaged in team-based research projects focused on local urban sustainability issues. The trainees have undergone an interdisciplinary competency-based curriculum and developed

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transdisciplinary competence by participating in diverse learning activities anchored in authentic learning environments through community engagement and internship opportunities. Critically, the program and trainee activities have been guided by the EAB consisting of members representing governmental agencies, industry, research and development, technology, the non-profit sector, academia, and community organizations. EAB members have provided guidance on the identified research focus areas for each trainee team as well as program activities.

Table 1: Interdisciplinary Urban Sustainability Competency Model.

Domain 1: Problem Definition
1.1 Demonstrate critical thinking about an environmental problem
1.2 Demonstrate understanding of urban sustainability in various climates
1.3 Conceptualize urban environmental problems using an environmental system framework
Domain 2: Research Methods
2.1 Pose important interdisciplinary research questions
2.2 Select appropriate research designs that are responsive to interdisciplinary research problems and questions
2.3 Develop data collection instrumentation that aligns to interdisciplinary research design and demands
2.4 Implement interdisciplinary research protocols
2.5 Use analytical methods responsive to interdisciplinary research demands
2.6 Ensure ethical conduct of interdisciplinary research
Domain 3: Communication
3.1 Effectively communicate research findings and implications
3.2 Use appropriate communication approaches, methods, and means for communicating across areas of expertise to a variety of different audiences
3.3 Effectively communicate the evolving need for interdisciplinary research to sustainably respond to societal demands
Domain 4: Problem-Solving
4.1 Apply appropriate analytical problem-solving techniques responsive to interdisciplinary demands
4.2 Apply relevant research findings from a variety of disciplines to solve urban sustainability problems
4.3 Identify viable solutions to interdisciplinary problems based on clearly defined requirements.
Domain 5: Collaboration
5.1 Actively collaborate with interdisciplinary teams
5.2 Demonstrate understanding of relevant current issues and concepts in other fields
5.3 Apply methods for engaging affected communities
5.4 Empower governmental and community leaders with information to shape public policy, organize, advocate, educate, and redevelop with a focus on issues

Science leadership

Under the first goal, T-RUST has provided training for graduate trainees to make important contributions to urban environmental system research, policy making, and transdisciplinary problem solving. Trainees led interdisciplinary team-based research, with mentorship from diverse faculty role models and the EAB. The research projects were centered on several key themes related to urban sustainability (Table 2) and were required to result in at least one publication per team that reflects the interdisciplinary collaboration aspects of the research project (see Appendix S1: Table S1).

Additional program components related to the leadership goal include leading project and grant proposals, and both academic and community presentations. Leadership training was also developed through community-building seminars, workshops, colloquia, and video documentaries to provide students with opportunities in skilled communication. Specifically, filmmaking opens the door to multimedia verbal and nonverbal communication, increasingly

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important in the digital age, and engages our trainees in disseminating their research to both technical and nontechnical audiences.

Another novel component of the T-RUST program was a requirement for PhD trainees to develop a 1- or 2-credit graduate-level capstone seminar course in their senior year. Trainees could collaborate and co-teach the capstone under the guidance of program faculty. A capstone course ties together and demonstrates the interconnected nature of the different research tracks among the various teams within the context of urban sustainability. The courses are made available to fellow trainees and the wider body of graduate and undergraduate students, and facilitate transfer of knowledge to the next generation of STEM scholars.

Table 2: Urban Sustainability Research Tracks.

Research Theme	Description
Urban Ecological Systems	The evaluation and maintenance of ecosystem services requires the integration of natural science, social science, and engineering-based environmental studies with community and education outreach research projects to sustain the urban ecological systems upon which human quality of life depends.
Urban Redevelopment and the Blue Economy	From land use and urban re-design, to global supply-chain and behavioral economics, and sociological and natural systems that make cities healthy and vital places, this research track unites social and physical sciences with engineering and design for spatially and socially integrated solutions. Studies of the "Blue Economy" are particularly relevant for cities with waterfronts that are reinventing themselves.
Sustainable Urban Water Infrastructure	Analysis of the natural, engineered, and societal systems that have formed the current water infrastructure of Detroit provides the foundation for understanding the complex inter-relationships and progressive solutions for sustainable urban infrastructure. Specialties within this track include drinking water treatment and distribution, wastewater management, and the use of big data and sensor technologies in decision-making for improved infrastructure sustainability.

Curriculum relevancy

The goal of T-RUST curriculum was to be relevant to students from varied disciplines with diverse academic interests while at the same time meeting the needs of the labor market in urban sustainability. The curriculum was aligned to the interdisciplinary competency model (Table 1) and designed to provide training to students to meet the evolving demands of a well-prepared workforce in urban sustainability by situating many learning activities in community engagement and internship opportunities (Appendix S1: Table S1, S2). The curriculum was designed using a societal demand framework (Guerra-Lopez & Hutchinson, 2017), which reduced bias in the selection of courses and topics and anchored the curriculum in core competency areas necessary for addressing urban sustainability needs and priorities, which was expected to maximize the readiness of program graduates for employment.

A key component of curriculum development was the creation of a dual-title PhD in urban sustainability (e.g., PhD in Biological Sciences-Urban Sustainability) framework, which

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provided an innovative mechanism for existing doctoral programs across the university to integrate a second content area into all program milestones, such as coursework, the candidacy examination, and dissertation project. The dual-title degree program also served as a mechanism to engage students fully in the program beyond their one or two years of NSF funding, as well as a recruitment tool to attract students to WSU.

Community impact

As an urban institution, WSU's mission communicates the importance of T-RUST delivering positive impact to the local community. Thus, from the start we integrated community service requirements with class roles and program expectations so that students would be connected with local community organizations, cultural values, and the role of local activism. Also crucial was training in adequate communication of scientific knowledge, and the integration of values associated with scientific training into neighborhoods, local schools, and local government. Trainees were expected to participate in 20 hours of community service or outreach events per year, such as lecturing at a local K-12 school, participating in citizen science, or leading hands-on stewardship or learning activities. Such community service activities contribute to student development and training, have positive impacts on the community, and reach multiple audiences, including prospective students from traditionally underrepresented groups. The goal was to help trainees develop communication skills as they engage with community groups and citizens, while broadening their ability to understand multiple vantage points.

Broader applicability

To facilitate applicability to other regions and partners, T-RUST incorporated numerous opportunities for knowledge-sharing among and between trainees, community members, researchers, policy makers, and the public. Our goal to expand our impact to other urban centers was established through new and existing collaborations with the University of Windsor and the University of Puerto Rico-Mayagüez (UPRM). Windsor is a Canadian urban center located across the Detroit River from Detroit and WSU and shares similar sustainability challenges. We also facilitated trainee presentations at local, national, and global conferences, publications, video documentaries, student exchanges with other institutions, and community presentations.

STEM recruitment pipeline

Underrepresentation of various marginalized groups in STEM fields remains an ongoing problem, and greater inclusivity in recruitment is one way to increase representation (Shadding et al., 2016). However, commitment to studying STEM fields is not developed entirely during undergraduate education, but rather over the course of an educational lifetime. Students from underrepresented populations often come from underfunded and under-resourced institutions in which they often do not envision a future within STEM fields, demotivating them from pursuing such studies. We aimed to build out the 'pipeline' by working with students from every stage in their educational careers (K-12 and beyond) by leveraging WSU resources, working with existing advocacy groups on campus and in Detroit, and engaging students from Puerto Rico through pre-existing relationships with UPRM. Active trainees played an important role in pipeline-building through their volunteering and community engagement efforts, which were facilitated in part by providing opportunities through our connections.

In addition to active efforts in bridging the STEM gap, a focus on inclusive language in recruitment materials and online program promotion strategies (e.g. social media campaigns,

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posts on disciplinary listservs) served to garner program interest from underrepresented students in STEM outside of the direct relationships fostered by program participants.

Program sustainability

To develop a self-sustaining program that thrives beyond the life of the NSF funding period, trainees and faculty actively sought external funding to support interdisciplinary collaborations. Trainees were required to prepare at least one external proposal to a funding agency, which provided experience in grant writing and potential financial support for their studies beyond the training period. Additionally, the suite of dual-title PhD degrees (referenced above) served to formalize the program requirements and integrate the training with existing institutional structure.

MONITORING AND EVALUATION

Monitoring and evaluation were essential components of program planning and implementation, generating ongoing formative feedback that helped the team improve the program on a continual basis. A robust monitoring and evaluation system was developed to ensure strong program alignment and began during program design by establishing a shared understanding of the program's goals and defining core activities as means to achieve those goals (Guerra-Lopez, 2012; Guerra-Lopez and Elo Hicks, 2015). The leadership team followed a process of integration during the design (i.e. proposal) stage to ensure that each of the envisioned core activities had a clear and direct relationship to at least one programmatic goal (Figure 1). For example, Seminars and Colloquiums were designed to support goals 1, 3, 4, and 5 while Community Service activities were meant to support 1 and 3. Additionally, key trainee outputs were also identified and mapped to core program goals. For example, the number of publications was intended to serve as an indicator of goals 1, 3, and 4, while the videos were aligned to goals 1, 3, and 5.

The core program activities and trainee outputs provided an integrated framework for identifying measurable indicators that would allow the program leadership team to monitor how well each of the core program components and activities were supporting the program goals. The program leadership team worked with the evaluator during the program design stage to develop a set of measurable indicators for each program goal to track progress and support implementation and program management (Appendix S1: Table S1). A sample of measured outputs from the first three years of implementation is highlighted in Table 3. The monitoring and evaluation of program activities and results have been vital components of effective, evidenced-based program implementation and management. As such, the independent evaluator was engaged in multiple aspects of the design and annual evaluations have been used to provide guidance for ensuring that the program stays on target to achieve the objectives that we, and NSF, agreed were worth pursuing.

During the first few months of the program launch, the team reviewed the monitoring and evaluation plan, including measurable indicators, to ensure its relevance and make necessary modifications to support implementation. At that time, the team also agreed on most data collection methods, tools, and procedures. Development of data collection tools, such as an online student activity tracker, included input from the program faculty, who collaborated to ensure alignment to key program indicators (e.g., number of interdisciplinary publications, type

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of professional development activities). Procedures for deploying the tools, and using the data, were also collaboratively developed. For example, annual completion of the trainee activity tracker was coordinated with annual reviews so that they could efficiently provide data to faculty advisors, and support feedback and advisory sessions with students.

Additionally, the competency model was used as the foundation for curriculum planning during the program design stage and courses were selected and mapped to each of the nineteen competencies (Appendix S1: Table S2). The relevancy of the courses and skills was evaluated every year through several mechanisms, including an internal Curriculum Development Committee and an EAB review (later described under Implementation).

Evaluation and other feedback collection tools also reflected the program competencies to ensure that mastery of these competencies was being reinforced across foundational and applied learning activities. For example, post-internship tools included a section to allow both the internship supervisors and the trainee intern to elaborate on which specific set of competencies was developed during the internship experience and in what ways. This exemplifies how monitoring and evaluation have been used to support program planning, implementation, and adaptation (ongoing improvements).

Table 3: Monitoring and Evaluation Initial Results.

Impact Area	Preliminary Accomplishments
Science Leadership	● 20 students presented at national academic conferences ● $57.5k in student-awarded grants ● 2 T-RUST faculty received a $1M grant for collaborative research
Curriculum Relevance	● Courses in 12 disciplines available to trainees ● 15 faculty and 37 students participated in interdisciplinary seminar course (BIO 7310) over 3 semesters ● 21 External Advisory Board (EAB) members participated in curriculum review process
Community Impact	● 19 students (3 cohorts) conduct ongoing community-focused collaborative interdisciplinary research (5 projects) ● 18 students completed community-focused interdisciplinary internships
Broader Applicability	● 6 faculty and 16 students participated in national/international exchanges
STEM Recruitment Pipeline	● 21% of T-RUST student body from underrepresented groups in STEM ● Over 50 local middle and high school students visited WSU campus each year to learn about STEM fields and urban sustainability
Program Sustainability	● 5 dual-title PhD degrees are available to students (another 2 awaiting approval) ● 32 active EAB members

IMPLEMENTATION

Program administration

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During the first year, faculty participation grew as additional supportive faculty joined the program. By the end of the third year, T-RUST faculty represented 11 disciplines, distributed among 5 schools (College of Liberal Arts and Sciences, College of Engineering, College of Fine, Performing, and Communication Arts, College of Education, and the School of Medicine), 11 departments (Anthropology, Biology, Civil Engineering, Communication, Economics, Geology, Learning Design and Technology, Pharmaceutical Sciences, Pharmacology, Physiology, and Urban Studies and Planning), and the University of Puerto Rico.

At the onset of the program, the core leadership team formed committees to lead various aspects of the program. Each committee consisted of 4 faculty members with one serving as the committee chair. Committees included the 1) *Graduate Admissions Committee* that reviewed and made decisions on student admission and assessed student progression though data collection; 2) *Research Innovation Committee* that helped identify research opportunities that reflect interdisciplinary studies following recommendations put forth by the EAB; 3) *Curriculum Development Committee* that worked with the EAB to assess the curriculum, and helped develop the dual-title degree program; 4) *Student Professional Development Committee* that worked to identify internships, organize the research exchange program, and find opportunities for exposure to non-academic careers and grant writing; and 5) *Recruitment Committee* that was responsible (in part) for recruiting students from within and outside of WSU with a focus on underrepresented groups.

The core leadership team also formed and engaged the EAB early in implementation. The EAB was initially formed based on local connections and pre-existing relationships with experts in varied aspects of urban sustainability, as described above. In addition, EAB members who could help provide access to sites, data, resources, and internship opportunities for trainees were identified. EAB members served as important mentors to the trainees, with the vision that these interactions will extend beyond the duration of the trainees' graduate studies. We initially invited 34 professionals to the EAB, and over time new members have been invited based on the relevance of their work and expertise to enhance student training through diverse perspectives. Biannual meetings served to update the EAB on program success and student research, and provide a forum for idea exchange, bridging the gap between academic research goals and specific needs of the community.

A full-time program manager position was created to run the day-to-day implementation of T-RUST and to develop and identify new activities to accomplish program goals. These tasks included administering all student training logistics (e.g. individual development plans, coursework and degree requirements, research project development), identifying internship, community service, funding, and professional development opportunities, tracking program progress and outputs (Appendix S1: Table S1), maintaining online presence (website and social media), facilitating community partnerships, coordinating faculty responsibilities, and communicating program activities to the EAB and broader community. A highly competent program manager was essential to the continued success of T-RUST.

Student training

Both doctoral and master's students were recruited into the program on an annual basis and remained in the program throughout their graduate studies. Fellowships were awarded on a merit basis for typically the first year in the program. Upon acceptance, all first-year trainees were required to enroll in the flagship course (BIO 7310; Appendix S1: Table S2) during their first semester, which introduced them to the field of urban sustainability and the range of

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disciplines relevant to its study. This course was co-taught by the faculty team from their individual disciplinary perspectives of urban sustainability, with guest lectures from the EAB. The core curriculum (Appendix S1: Table S2) comprised courses from all participating academic disciplines, including existing courses that were taught as is or modified as needed. Modifications to existing courses included adjusting topics, readings, and assignments to a) have a local Detroit focus; b) be relevant to urban sustainability issues; and c) appeal to and accommodate trainees from multiple disciplines. To make the modifications, course instructors consulted with T-RUST faculty and within their departments, and when applicable, their department's curriculum committee.

Each year, first-year trainees were encouraged to form relationships both within and outside of their courses, and collaborate on course projects. This set the foundation for developing interdisciplinary teams by the end of the first semester, when trainees met with their T-RUST faculty advisors to propose their research ideas. Trainees were divided into teams (3-6 trainees) and were formed to be as multidisciplinary as possible, including combinations of the applied sciences, social sciences, humanities, and engineering. Trainee research projects were conducted throughout the tenure of their graduate studies and were partially supported by student-led collaborative grants totaling approximately $58k in the first three years of the program. By the end of the third year, 27 trainees participated in T-RUST, including two graduates.

New professional development opportunities were created by the T-RUST faculty, program manager, and other WSU partners including workshops, seminar series, and a new conference on campus (see Institutional Impact). Workshops included topics such as Lessons in Interdisciplinary Writing, Effective Oral Presentations, and Creating Video Documentaries. Existing campus seminars (e.g. Water@Wayne) were leveraged to provide leadership opportunities for trainees who invited speakers of their choice, served as their campus host, and planned their schedule.

Community & practitioner engagement

Both formal and informal partnerships with colleagues in varied disciplines and institutions were important for student training and integration within the community and professional fields. T-RUST has been able to leverage these relationships to exchange ideas, share lessons learned from applying urban sustainability, and further the development of skills for the faculty and students beyond WSU. Partnerships with the University of Windsor and UPRM were planned elements, and both WSU and our partner universities have benefited from a number of exchanges (Table 3).

Community members and urban sustainability practitioners were consulted for both programmatic and substantive input. From a programmatic perspective, the EAB evaluated the curriculum, specifically on strengthening the links between the coursework and the interdisciplinary demands of effectively addressing urban sustainability problems. A survey was conducted annually to receive input on course syllabi, including new courses that were added to the curriculum. Critically, EAB members hosted student internships, which were often customized to target urban sustainability competencies (Table 1). Many EAB members also gave seminars and guest lectures on campus, through seminar series and a conference that T-RUST cohosted with various campus partners, from which several new collaborations developed.

From a research perspective, EAB members provided feedback to trainees who were given the opportunity to present their work at the biannual EAB meetings, which infused

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professional and local knowledge to their projects. We have taken steps toward the transdisciplinary goal of knowledge co-production in involving the EAB and other community members at early stages in the research.

Additionally, trainees demonstrated strong enthusiasm and initiative in seeking out opportunities for local outreach and community service. Activities have included hosting girls in STEM from a local public school, citizen science surveys with Friends of the Rouge River, involvement in local conferences, and trainee-led presentations to community groups. One organization in particular, ReRoot Pontiac (founded by a trainee) works to transform blighted land into environmental learning opportunities for kids. Many trainees have been involved in this project, and one group collaborated to expand the mission (ReRoot Detroit) and bring the work to our own backyard. This is just one example of trainee-driven community impact involving interdisciplinary collaboration.

Institutional impact

T-RUST has facilitated new structures and connections within WSU. The dual-title PhD in urban sustainability was approved and adopted by 5 academic departments across 4 schools (Anthropology, Biology, Civil Engineering, Communication, and Pharmaceutical Sciences) and has been provisionally approved by 2 academic departments across 2 schools (Economics, Pharmacology). Minor adjustments were made to the T-RUST requirements to accommodate departmental requirements and ensure no time was added to degree completion. As mentioned elsewhere, new courses and curriculum have been adopted by WSU, which has far-reaching impacts beyond the T-RUST program as these courses are available to the wider student body. T-RUST also co-hosted a new annual conference on campus with two campus centers and the Office of the Vice President for Research (OVPR), and other collaborations stemming from T-RUST may result in a new NIH Superfund Center.

Through T-RUST, WSU has set aside a designated space for interdisciplinary collaboration equipped with computers and furniture. The space is now used by several campus interdisciplinary groups, including Healthy Urban Waters and the Detroit Biodiversity Network, whose mission is to engage students in hands on projects that support and improve the sustainability of urban ecosystems on campus and in surrounding Detroit communities.

Starting in the second year, meetings were held with WSU's Corporate and Foundation Relations office and directors of Philanthropy and Alumni Relations to identify sources of external financial support and strategize program communications in an effort to maximize readership, recruitment, and engagement with T-RUST. Annual meetings were held with the WSU Provost; discussions were underway regarding faculty cluster hires that would support the thematic vision of T-RUST, which also aligns with the WSU Mission. However, the COVID-19 pandemic stalled these discussions for now as university resources are redirected to address more pressing research and needs.

We launched our STEM recruitment process by creating communication channels to existing advocacy groups on campus that work directly with underrepresented groups to promote academic success and community building. Building a relationship with our campus Federal TRIO (U.S. Department of Education, n.d.) and reBUILD (Building Infrastructure Leading to Diversity) offices allowed us to direct resources towards pipeline building at different educational levels. Under the TRIO umbrella, our relationship with the McNair Scholars program gave us the opportunity to offer extracurricular STEM opportunities to underrepresented undergraduate students with an interest in graduate studies. Similarly, we

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maintained relationships with other on-campus organizations such as the Tribal Learning Community and the Center for Latinx American Studies, and the communication channels built with these programs yielded opportunities to target the local K-12 segment (Table 3). Additionally, we secured funding for 1 trainee through our relationship with the Initiative for Maximizing Student Diversity (IMSD) office.

We developed the website and recruitment materials to emphasize our commitment to diversity and reflect the diversity of our trainees (Table 3) and of the broader WSU community. Social media was used extensively to have a broader reach to showcase T-RUST and advertise enrollment periods. We leveraged our relationship with UPRM for recruiting and developed materials using feedback on culturally relevant language to describe professional development opportunities. This is an ongoing process as we continue to learn how to support the Black, Indigenous and People of Color community in graduate education.

LESSONS LEARNED

The advantage of an adaptive design is that it allowed the leadership team to regularly assess program outcomes, tune into what was working, and proactively adjust activities, explore opportunities, or seek out new partnerships.

After three years of implementation and training four student cohorts, we found that significant interdisciplinary guidance was needed to support trainees as they developed a coherent group project and to prevent them from falling into the multidisciplinary trap (i.e. each student "staying in their lane"). The faculty-led workshops helped students break down this barrier and learn how the perspectives of outside disciplines can inform a broader understanding of their own respective disciplines. Trainees also sought out mentoring from faculty outside of their own discipline, which has proved extremely valuable.

Regular opportunities for informal social interaction among trainees and faculty helped foster a stronger sense of community in the program (e.g. brown bag lunch workshops, bowling, canoe trip, holiday party, city baseball game). These events also enabled better vertical integration of the program, creating opportunities for interaction among each cohort and faculty. A complaint among several trainee teams was ineffective or irregular communication among team members. This is a general challenge with teamwork, and compounded by the traditional PhD mindset of independent work. Social events helped with relationship building which gave students a better sense of accountability in their group projects, though this is an area of ongoing improvement.

It was valuable to recognize that some external partnerships may not pan out and that we needed to be ready to take advantage of emerging opportunities. For the T-RUST program, an emerging opportunity has happened in part due to the hiring of a new faculty member at a regional university. The alignment of their interests with the goals for the program have created new opportunities to broaden the impacts of T-RUST through faculty and trainee collaborations. An anticipated partnership from our proposal with an East Coast partner did not develop as hoped. From this experience, we learned that in addition to informal relationships with partners, it is important to formalize the roles, relationships, and action steps. Without these formalities it is easy for partnerships to fade as personnel shift and other issues become priorities.

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KEY CHALLENGES

An ongoing challenge with interdisciplinary work was that trainees were limited by their disciplinary perspectives in addressing urban sustainability problems; the training we provided aimed to fill this gap, in part by creating interdisciplinary research teams where trainees must collaborate and work through their research problems using the expertise and perspectives of their team members as well as their own. Collaborative projects typically started off as trial-and-error as trainees and faculty came to a common understanding of the research question. The faculty on this project have collaborated over the years on a number of interdisciplinary projects; but have yet to create a framework for urban sustainability that is greater than the sum of the individual disciplinary parts. Therefore, we are continually seeking better resources to guide the interdisciplinary process, and hope to develop guidelines or a facilitated process for student project development.

Team projects were complicated by the disparate graduate school timelines for Master's and PhD students. Since most of our trainees are PhDs, we have addressed this issue by guiding Master's trainees to complete a smaller sub-project within the context of the larger project during the 1-2 years they are in the program. Further, a joint publication or thesis/dissertation chapter is hampered by plagiarism policies and institutional restrictions on co-authorships and data sharing. We are exploring options to amend these policies to accommodate the evolution of research and team science.

Institutionally, widespread buy-in from a large number of faculty and administrators is critical to sustain an interdisciplinary initiative such as T-RUST. Some disciplinary requirements may need to be adjusted to accommodate an interdisciplinary training, which may be met with some resistance.

Along with religious institutions, universities are some of the oldest institutions we have created. They are set in their ways and resist significant change. The change advocated by transdisciplinary programs challenges enduring disciplinary structures that serve to organize university training and research. Faculty advance their own careers by meeting and exceeding disciplinary benchmarks, including implicit and explicit rules defining what makes a 'good' biologist, chemist, anthropologist, engineer, economist, etc., which exist for every discipline. While academics may challenge these boundaries, they are first expected to demonstrate their expertise in adhering to them. We found that some faculty still retreated to their respective departments, which reflects the institutional forces that incentivize disciplinary behavior. Departments remain the economically and politically dominant unit in faculty members' lives at universities, despite the intellectual promises that interdisciplinary work holds. This entrenched and enduring support for disciplines creates serious challenges for advancing interdisciplinary training and teaching (Fam et al., 2020). Slowly, however, models are being developed and adopted for interdisciplinary recognition and achievement (Falk-Krzesinski, 2017; Klein 2010).

CONCLUSION

In this paper we shared a description of the T-RUST program, an innovative graduate training model for preparing the next generation of public, private, and academic leaders to address complex problems in urban sustainability. Since its launch, the T-RUST program has successfully created an urban sustainability network that links together students, faculty,

community organizations, government partners, and the broader public. This network utilizes T-RUST as a hub for connecting people to projects, bringing together diverse interdisciplinary scientific communities to work in collaboration with regional partners to make substantial impacts – creating engaging and applied learning experiences for students. Though many lessons are continuing to be learned, the evaluations of the program illustrate that it is achieving its goals of science leadership, curriculum relevancy, community impact, broader applicability, STEM recruitment pipeline, and program sustainability.

As with many new ideas, the program encountered challenges along the way, principally cross-disciplinary communication among students in sharing and appreciating each other's research goals and methodological orientations, and institutional barriers to transdisciplinarity. Yet, given the preliminary success of the program, our transdisciplinary approach to preparing the next generation of urban sustainability leaders shows great promise as a framework for reconceptualizing how urban sustainability academic programs can become an integral part of community-driven efforts.

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