COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE
NSF 20-595 **03/25/2022**

☐ Special Exception to Deadline Date Policy

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NSF PROPOSAL NUMBER

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)
DGE - NSF Research Traineeship (NRT)

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316-02-5986

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IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE
OHIO STATE UNIVERSITY, THE

AWARDEE ORGANIZATION CODE (IF KNOWN)
0030908000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
1960 KENNY RD
COLUMBUS,OH 43210-1016 US

NAME OF PRIMARY PLACE OF PERF
Ohio State University

ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE
174 W18th Avenue
COLUMBUS,OH 43210-1369 US

IS AWARDEE ORGANIZATION (Check All That Apply) ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS

☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT
IGE: Training Wicked Scientists to Catalyze Convergence in Transdisciplinary Teams

SHOW LETTER OF INTENT ID IF APPLICABLE

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ **499,552**	**36** months	**09/01/2022**	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
☐ BEGINNING INVESTIGATOR
☐ DISCLOSURE OF LOBBYING ACTIVITIES
☐ PROPRIETARY & PRIVILEGED INFORMATION
☐ HISTORIC PLACES
☐ VERTEBRATE ANIMALS IACUC App. Date
PHS Animal Welfare Assurance Number
☒ TYPE OF PROPOSAL **Research**
☒ HUMAN SUBJECTS Human Subjects Assurance Number
Exemption Subsection **pending** or IRB App. Date
☐ FUNDING OF INT'L BRANCH CAMPUS OF U.S IHE
☐ FUNDING OF FOREIGN ORGANIZATION OR FOREIGN INDIVIDUAL
☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED
☒ COLLABORATIVE STATUS **Non-Collaborative**

PI/PD DEPARTMENT

PI/PD POSTAL ADDRESS
174 W. 18th Avenue
Columbus,OH 43210
US

PI/PD FAX NUMBER
614-292-4155

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME **Mark Moritz**	**PhD**	**2003**	**614-247-7426**	**moritz.42@osu.edu**
CO-PI/PD **Elizabeth Newton**	**PhD**	**1996**	**256-653-1310**	**newton.387@osu.edu**
CO-PI/PD **Nicholas C Kawa**	**PhD**	**2011**	**614-292-2391**	**nckawa@gmail.com**
CO-PI/PD **Yolanda Zepeda**	**MS**	**1990**	**614-292-5848**	**zepeda.3@osu.edu**
CO-PI/PD **Alison E Bennett**	**PhD**	**2005**	**614-292-6403**	**bennett.1242@osu.edu**

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent)

By electronically signing and submitting this proposal, the Authorized Organizational Representative (AOR) is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding conflict of interest (when applicable), flood hazard insurance (when applicable), responsible conduct of research, and organizational support as set forth in the NSF Proposal & Award Policies & Procedures Guide (PAPPG). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, §1001).

Certification Regarding Conflict of Interest

The AOR is required to complete certifications stating that the organization has implemented and is enforcing a written policy on conflicts of interest (COI), consistent with the provisions of PAPPG Chapter IXA; and that, to the best of his/her knowledge, all financial disclosures required by the conflict of interest policy were made; and that conflicts of interest, if any, were, or prior to the organizations expenditure of any funds under the award, will be, satisfactorily managed, reduced or eliminated in accordance with the organizations conflict of interest policy. Conflicts that cannot be satisfactorily managed, reduced or eliminated and research that proceeds without the imposition of conditions or restrictions when a conflict of interest exists, must be disclosed to NSF via use of the Notifications and Requests Module in FastLane.

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Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

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(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

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(This certification is not applicable to conference proposals.)
By electronically signing the Certification Pages, the Authorized Organizational Representative is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Chapter IX.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.
The AOR shall require that the language of this certification be included in any award documents for all subawards at all tiers.

Certification Regarding Organizational Support

By electronically signing the Certification Pages, the Authorized Organizational Representative (or equivalent) is certifying that there is organizational support for the proposal as required by Section 526 of the America COMPETES Reauthorization Act of 2010. This support extends to the portion of the proposal developed to satisfy the Broader Impacts Review Criterion as well as the Intellectual Merit Review Criterion, and any additional review criteria specified in the solicitation. Organizational support will be made available, as described in the proposal, in order to address the broader impacts and intellectual merit activities to be undertaken.

Certification Regarding Dual Use Research of Concern

By electronically signing the certification pages, the Authorized Organizational Representative is certifying that the organization will be or is in compliance with all aspects of the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern.

Certification Regarding the Meeting Organizer's Written Policy or Code-of-Conduct that Addresses Sexual Harassment, Other Forms of Harassment, and Sexual Assault

(This certification is only applicable to travel proposals)
By electronically signing the Cover Sheet, the AOR is certifying that prior to the proposer's participation in the meeting, the proposer will assure that the meeting organizer has a written policy or code-of-conduct that addresses sexual harassment, other forms of harassment, and sexual assault, and that includes clear and accessible means of reporting violations of the policy or code-of-conduct. The policy or code-of-conduct must address the method for making a complaint as well as how any complaints received during the meeting will be resolved. The proposer is not required to submit the meeting organizer's policy or code-of-conduct for review by NSF.

Certification Regarding Family Leave Status (or equivalent)

(This certification is only applicable to career-life balance supplemental funding requests)
By electronically signing the certification pages, the Authorized Organizational Representative hereby certifies that the request for a technician (or equivalent) is because the (PI/co-PI/senior personnel/ NSF Graduate Research Fellow/postdoctoral researcher/graduate student) is, or will be, on family leave status (or equivalent) from the organization in accordance with the organization's policies. The Authorized Organizational Representative also affirms that the organization is able to fill the position for which funding is being requested, in an appropriate timeframe.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME		

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER

IGE: Training Wicked Scientists to Catalyze Convergence in Transdisciplinary Teams

Overview

The goal of this project is to pilot, test, and validate an innovative program that trains graduate students to become wicked scientists – researchers who are able to tackle the grand challenges of today and tomorrow. Much has been written about the challenges of wicked problems, such as adaptation to climate change, food insecurity, growing inequality, reducing traffic fatalities, cyber security, systemic racism, and emerging infectious diseases. These wicked problems are difficult to solve because of their complexity, uncertainties, and interdependencies, and because of stakeholders' conflicting interests and ideas about the problem and its solution. However, scholarship about wicked problems has not translated into the development of programs that train scientists to tackle these grand challenges in transdisciplinary teams. In order to effectively address such grand challenges, graduate students need to be experts in their respective fields, but they also need to develop the transdisciplinary skills to collaborate successfully with fellow researchers and other stakeholders. The proposed project uses a mixed-methods approach to assess a program that consists of an interdisciplinary minor that trains students in skills that make transdisciplinary teams inclusive and successful, including hands-on training in a hacking wicked problems practicum; and development of a community of practice consisting of students, alumni, faculty, and other stakeholders that fosters long-term professional learning of wicked scientists. These activities are integrated in a comprehensive program that not only trains graduate students from disciplines across the university but also aims to turn participating faculty into wicked scientists with inclusive, transdisciplinary skills.

Intellectual Merit

The program aims to make three transformative contributions to growing convergence in transdisciplinary teams and programs. First, it uses a comprehensive and integrated conceptual framework of wicked science to develop the training program. The framework integrates a systems-thinking approach as well as a critical approach that considers the roles, interests, and perspectives of stakeholders. Second, because becoming a wicked scientist is a long-term proposition and takes more than the completion of a minor, it will pilot a model of continuing education that takes the form of a community of practice that engages current students, alumni, faculty, and other stakeholders working on wicked problems. The community of practice will be a critical component in both the training of students and the ongoing professional learning of our alumni. Third, the project uses a mixed-methods approach that integrates validated psychometric assessments and ethnographic methods to examine whether and how the program succeeds in the training of wicked scientists and creating an institutional culture of convergence that supports the program.

Broader Impacts

The proposed project has several broader impacts. First and foremost, it pilots, tests, and validates a program that trains graduate students to become wicked scientists who have both deep disciplinary expertise and inclusive, transdisciplinary skills, knowledge, and competencies to catalyze convergence in teams that tackle the grand challenges in a wide range of STEM careers. Second, it leverages existing resources to create an inclusive program that supports students from diverse backgrounds who have been marginalized in the sciences. Third, it creates resilient structures at the Ohio State University that will foster a culture of convergence in the study of wicked problems by training participating faculty in wicked science and linking stakeholders from multiple transdisciplinary teams across and beyond campus. Fourth, the lessons from our training program will be organized and disseminated so that they can be readily adopted by other institutions of higher education in the United States and beyond.

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INNOVATIONS IN GRADUATE EDUCATION

The goal of this project is to pilot, test, and validate an innovative program that trains graduate students to become wicked scientists who are able to tackle the grand challenges of today and tomorrow—what are otherwise known as wicked problems. The concept of wicked problems describes a wide range of local, national, and global grand challenges including climate change, food security, growing inequality, cyber security, systemic racism, and emerging infectious diseases. Wicked problems have two fundamental properties: first, they are dynamic complex systems with many interdependencies; and second, stakeholders have different values, interests and conceptions of the problem and its solution. Rittel and Webber, who developed the concept of wicked problems, note that because wicked problems are complex and political, it is impossible to "solve" them [1]. However, we argue that when researchers are trained to work effectively in inclusive, transdisciplinary teams that consider both the complexities *and* politics of these wicked problems, it will lead to more resilient, sustainable, and equitable outcomes (even if problems are never permanently solved).

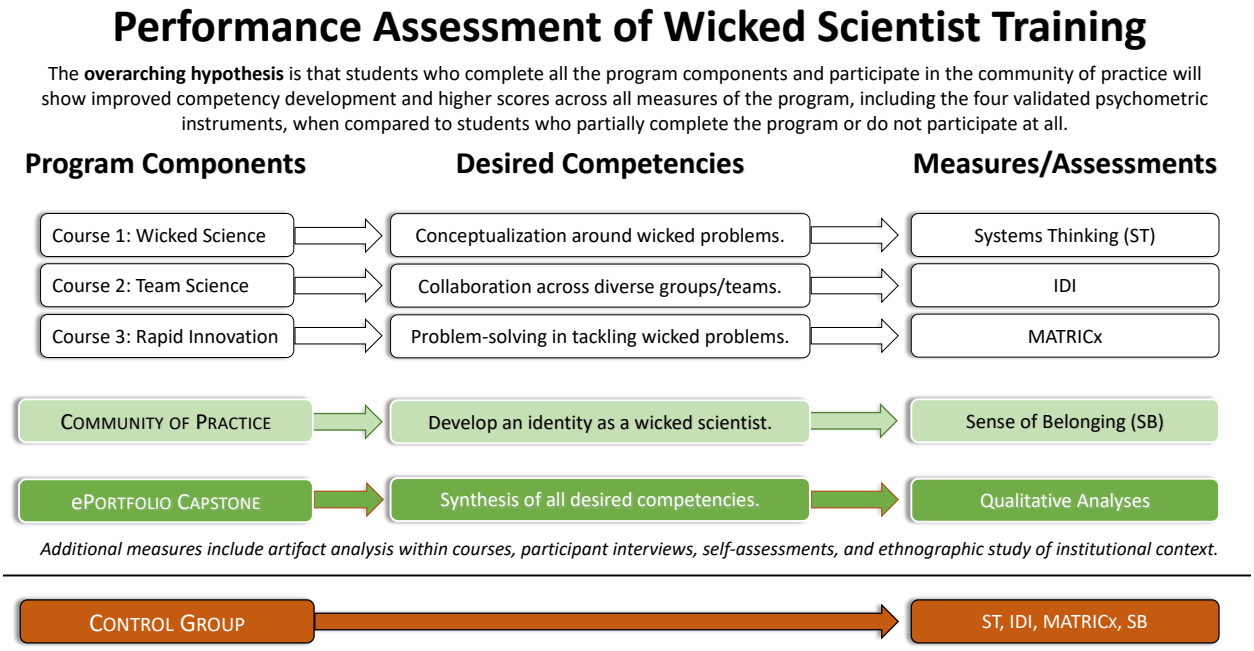
The standard scientific approach is to conceptualize problems as having straightforward technical solutions but ignoring the complexity and political dimensions of such problems can have serious consequences. The Space Shuttle Columbia disaster, for example, was not simply the result of technical malfunction but the result of underlying organizational and cultural issues within NASA, including its hierarchical organization, challenges of public-private partnerships, and a culture that normalized deviance [2]. In other words, rocket science is not just a scientific or engineering problem but a wicked problem that is highly complex and involves numerous stakeholders. And though much has been written about the challenges of wicked problems [3, 4] and the need to address them [5, 6], this call to action has not prompted the development of programs that train students to tackle wicked problems in transdisciplinary research teams [7].

Because today's grand challenges are wicked problems, it is no longer sufficient for graduate students to be only experts in their respective fields. They also need to have the skills to collaborate effectively in diverse teams of researchers and other stakeholders. The need for graduate students with both deep disciplinary training and the transdisciplinary skills to tackle wicked problems has been identified in numerous reports from the National Science Foundation [8], National Academies of Sciences [7, 9, 10], Council of Graduate Schools [11], National Science & Technology Council [12], and organizations like Google [13]. The cultivation of personal and professional skills is especially critical for realizing the "diversity bonus"—the benefit teams gain from generating new ideas through the diversity of their members [14-16].

Resubmission Statement

In response to the critical and supportive feedback from the reviewers on our past submission, we have made five main changes: (1) we completed the development of the Graduate Interdisciplinary Specialization in Wicked Science and two of the courses have already been offered at least once, so that we can start the knowledge generation activities right away in the first year; (2) we developed a mixed-methods approach to study whether and how our program and its components are successful in training students in the competencies of wicked scientists; (3) we formulated a hypothesis about the development of wicked competencies in our program and developed a strategy for evaluating the hypothesis using four validated psychometric assessments; (4); we have developed a figure that summarizes the performance assessment of the training program; and (5) we expanded our team with experts in engineering education and interdisciplinary team science.

To address the call for the development and implementation of bold, new, and transformative approaches in STEM graduate education training, we developed an innovate program and performance assessment summarized in the figure below and further explained in this proposal.



Intellectual Merit

Our proposed program contributes to NSF's Big Idea of **Growing Convergent Research** by piloting, testing, and validating a program that trains graduate students who will catalyze, i.e., cause or facilitate, convergence in transdisciplinary teams around wicked problems. There is considerable overlap between the concepts of *convergent research*, *transdisciplinarity*, and *wicked science*. According to NSF, *convergence research* "is a means of solving vexing research problems, in particular, complex problems focusing on societal needs. It entails integrating knowledge, methods, and expertise from different disciplines and forming novel frameworks to catalyze scientific discovery and innovation." Whereas interdisciplinary research involves researchers from different disciplines collaborating on a joint research problem working towards synthesis, *transdisciplinary research* also integrates the conceptual contributions of stakeholders in the study of the problem while working towards an engaged, socially responsible science [17-19]. Stakeholders refers here to anyone with a stake in the problem, including but not limited to individuals from communities, businesses, non-governmental organizations, local, regional, and national governments, and researchers themselves. Finally, *wicked science* is transdisciplinary because it involves collaborations among researchers from different disciplines as well as other stakeholders, and it is convergent research because it tackles vexing societal problems, i.e., wicked problems [20].

The program aims to make three transformative contributions to growing convergence in transdisciplinary teams and programs. First, we have developed a comprehensive conceptual model of wicked science that informs our training of wicked scientists [20]. Second, because becoming a wicked scientist is a long-term engagement that takes more than the completion of a minor or a single graduate degree program, we will develop a model of continuing education that takes the form of a *community of practice* [21, 22] that includes students, alumni, faculty, and other stakeholders, with a shared interest, passion,

concern, or practice of tackling different wicked problems. Third, we will use a mixed-methods approach that integrates validated psychometric assessments and ethnographic methods to examine whether and how the program succeeds in training wicked scientists and creating a culture of convergence that supports the program.

In this proposal, we describe how we will pilot, test, and validate an innovative program that trains students to become wicked scientists. By this, we mean researchers with: (1) the interpersonal skills to catalyze convergence in inclusive, transdisciplinary teams; (2) the skills to navigate the politics and complexity of wicked problems; and (3) the competencies that prepare them for professional careers and long-term engagement with wicked problems. To be clear, wicked science is not just a catchy term – we use this neologism because it accurately and effectively describes the conceptual framework that informs our program [20].

Conceptual Framework of Wicked Science

Our proposed program is innovative because it is grounded in our conceptual framework of wicked science [20], which provides a clear vision for program goals, learning outcomes, and assessment. Starting with the original concept of wicked problems [1], we used the logic of backward course design to determine what skills and competencies graduate students need to become effective wicked scientists, then we identified how to assess such learning outcomes and proficiencies [23-25], working closely with experts from the Drake Institute for Teaching and Learning Research at The Ohio State University (OSU).

Rittel and Webber originally identified ten basic properties of wicked problems, including that each wicked problem is different, researchers bring their own biases to the problem, there are no permanent solutions, and a solution's effectiveness is hard to assess because it alters the nature of the problem [1, 26]. To simplify, we argue that wicked problems have two fundamental properties: first, they are complex with many interdependencies and uncertainties; and second, they are political, as stakeholders have different values, interests and conceptions of the problem and its solution. Considering the challenges posed by wicked problems, it might seem that developing a training program for graduate students is nearly impossible. However, we insist that developing such a program is possible by systematically translating Rittel and Webber's concept into a novel conceptual framework known as wicked science [20].

In the scientific literature on wicked problems [27], the focus is often on the complexity of wicked problems [28], while stakeholder politics are often ignored [3] or downplayed [5]. This is also true for the literature on transdisciplinary training of graduate students [29, 30]. We argue that wicked scientists need training in systems approaches that emphasize the political dimensions of such problems—how they are shaped by differentials of power and stakeholder positioning in relation to them. This calls for a transdisciplinary framework that requires expertise from different disciplines as well as engagement of all affected stakeholders [31]. This also means that wicked scientists must cultivate inclusive, transdisciplinary skills to work with all relevant stakeholders [14] while learning to communicate effectively in different modalities that are appropriate to different groups of stakeholders.

While there are no easy solutions for wicked problems, this does not mean that improvement is impossible. The intractable nature of wicked problems is precisely what makes training students to tackle them so important. Although these problems by definition cannot be permanently solved [32], they are problems that we cannot afford to ignore [33]. Though it may be difficult to draw general lessons about wicked problems because each one is distinct, our program shows that general lessons can be drawn from *how* to tackle wicked problems in transdisciplinary teams and *how* to prepare students to do the same.

Graduate Interdisciplinary Specialization in Wicked Science

We used the concept of wicked science described above to develop the training program. The program consists of two components: (1) training in skills that make transdisciplinary teams inclusive and successful, including hands-on training in a hacking wicked problems practicum, which will be implemented as a **Graduate Interdisciplinary Specialization**, a minor approved by the Ohio State Graduate School; and (2) a **Community of Practicing Wicked Scientists** consisting of students, alumni, faculty, and other stakeholders that fosters long-term professional learning through events, seminars, and workshops. The activities are integrated in a comprehensive program that not only trains graduate students but also aims to turn participating faculty into wicked scientists who will model the inclusive, transdisciplinary competencies [34]. The program does not replace disciplinary training but rather builds on it. Students will be trained in their home departments in theories and methods of their respective fields as this remains a corner stone of graduate education and professional preparation according to reports from the National Science Foundation [8], National Academies of Sciences [7, 9], and Council of Graduate Schools [11].

The goal of the Graduate Interdisciplinary Specialization in Wicked Science is to train students to become wicked scientists – researchers with the skills and attitudes to tackle wicked problems. After completion of the program students will be able to:

1. Tackle wicked problems using a systems-thinking approach that seriously considers politics, i.e., the roles, interests, and perspectives of stakeholders.
2. Collaborate effectively with stakeholders and team members from diverse personal and disciplinary backgrounds and experiences.
3. Communicate scientific research and ideas to diverse audiences and through different modalities.
4. Meet ethical, collegial, and professional expectations and standards in collaborative research and other professional endeavors.
5. Articulate a sense of purpose and develop competencies, skills, and habits that prepare them for life-long learning about and engaging with wicked problems.

We derived these five learning goals from our conceptual framework of wicked science and developed 16 learning outcomes and 58 proficiencies using backward course design [35-39]. The last proficiency is to “have fun”, which is critical for the long-term project of cultivating the grit, attitude, and courage for tackling wicked problems [40]. Students will achieve these proficiencies and develop the necessary competencies to foster inclusive, transdisciplinary teams that tackle wicked problems in a three-course series.

To train students in the skills that make transdisciplinary teams inclusive and successful, we used the existing educational infrastructure of a Graduate Interdisciplinary Specialization, which is available to graduate students from across the university. The Graduate Interdisciplinary Specialization in Wicked Science consists of three required courses: **5505: Wicked Science** (3 credits), **5510: Interdisciplinary Team Science** (3 credits), **5620: Rapid Innovation for Public Impact** (4 credits), and the completion of an **ePortfolio** capstone course (1 credit). To briefly highlight the most salient competencies developed in each of the courses: the *Wicked Science* course is about conceptualization of wicked problems as complex and political, the *Interdisciplinary Team Science* is about collaboration in diverse teams, the *Rapid Innovation for Public Impact* is about hands-on problem solving, in the community of practice students develop their identities as wicked scientists, and in the *ePortfolio* students reflect on and demonstrate that they synthesized these competencies. Our curriculum map – not included in the proposal – links all the proficiencies to specific assessments in the courses and ePortfolio.

The program starts in the 2022-2023 academic year and incorporates two previously taught courses: *Interdisciplinary Team Science* (offered for the first time in Autumn 2021) and *Rapid Innovation for Public Impact* (offered for four years). *Wicked Science* is a new course that

will be offered in Autumn 2022. The proposal for the specialization is under review by the graduate school; we expect final approval by May 2022. Moving forward, all courses will be offered at least once a year. Students will be able to complete the program in one or two years, depending on the requirements of their home department. The courses are open to all graduate and professional students, who can take any number of courses in any order. The program is flexible to facilitate the participation of students from different graduate programs. We expect that many students may take one of the courses, and then decide to enroll in the other courses and complete the specialization.

In the **Wicked Science** course, students learn the concepts and strategies for analyzing the dynamics, complexities, and interdependencies of wicked problems as well as how to critically assess the roles, interests, and perspectives of different stakeholders in wicked problems [41]. Students learn those skills by applying the concepts and strategies to a wicked problem of their choice, which involves identifying and prioritizing research questions that will help them understand the wicked problem and its feedbacks; identifying relevant stakeholders, their roles, interests, and perspectives; identifying methodological approaches that can be used to study the problem; reflecting on possible unintended consequences of intervention into the wicked problem; considering ethical challenges; and developing and communicating options for interventions for the different stakeholders. We draw from existing resources and evidence-based best practices in developing the learning activities in the course [42-44]. We also use different approaches to teaching systems thinking [45, 46], design thinking [47, 48], transdisciplinary teamwork [40, 49] and orientations [50], to create inclusive and collaborative environments, and use of reflections to develop metacognition in transdisciplinary teams [51].

In the **Interdisciplinary Team Science** course, students learn to work effectively in interdisciplinary teams. In addition to learning about the field of science of team science (SciTS) [52], students learn best practices for building and leading interdisciplinary teams that are intentionally collaborative, diverse, equitable, and inclusive [53-55]. The course is co-taught by staff and faculty from across campus and involves multiple active learning activities in which students either reflect on their own team experiences or engage in simulations in which they take the role of different stakeholders. The weekly homework assignments include psychometric assessments that help students reflect on their strengths in collaborative competencies as well as identify skills that need further development [56, 57]. The capstone assignment is a collaboration plan in which students apply what they learned about best practices for building and leading interdisciplinary teams [58, 59].

The hacking practicum or **Rapid Innovation for Public Impact** is modeled after *Hacking for Defense* (H4D) courses taught at Stanford and other universities. While student teams in the original Hacking for Defense course worked on problems provided by the Department of Defense, in other iterations of the course, like UC Berkeley's *Hacking for Impact*, teams worked on problems provided by municipal and non-government organizations. The practicum uses the methodology of Stanford's Lean LaunchPad, which has proven to be successful in NSF's Innovation Corps classes taught at universities across the country [60]. In the practicum, students apply and hone their inclusive, transdisciplinary skills on sets of wicked problems that are provided by university, community, and other partners. Student teams work closely with stakeholders from partnering organizations as they tackle these wicked problems. This semester, for example, student teams are working on a wide range of wicked problems, including access to childcare for parenting students, identifying misinformation about sustainable energy, and reducing fatalities on Columbus' streets.

The **ePortfolio** serves as a one-credit capstone for the specialization. In the portfolio, students will synthesize, integrate, and demonstrate that they have learned the knowledge and competencies of wicked scientists. This is important because wicked science is more than the sum of the three courses. Key components of the portfolio are a self-assessment of competencies, reflections on the learning process, i.e., meta-cognition, and discussion of career

plans, including how to leverage wicked competencies in their professional field [61-63]. Students starting the specialization will develop the portfolio over time, using the work that they complete in each of the three courses, and with feedback from instructors, peers, and other members of the community of practice. Students will develop the portfolio for the career and professional field that they plan to pursue. Following the program's faculty advisor judgement that the portfolio meets the minimal requirements, an interdisciplinary panel consisting of faculty, members of the community of practice, and professionals from the student's career fields will conduct a formative evaluation of the portfolio and provide critical and supportive feedback for the next career steps. In addition to "celebrate the wins" and "acknowledge the struggles," the panel also provides an external assessment of student competencies [64, 65]. We use the ePortfolio app that the university adopted for the General Education program.

Throughout the program, students will continue to reflect on the **ethical and moral dimensions of tackling wicked problems** but particularly through collaboration with different stakeholders and direct hands-on engagement with wicked problems themselves. The nature of wicked problems means that students will encounter ethical, moral, social, and political quandaries that lack simple resolutions. Therefore, students will have to train their "ethical muscles" throughout the program and learn how to analyze and reflect on ethical issues both individually and collectively with fellow students and other stakeholders [66]. We have integrated ethics training throughout the program, including all courses and the community of practice. In addition, we leverage existing resources at Ohio State as recommended training, including the *Training Program in the Responsible Conduct of Research* of the *Center for Ethics and Human Values*, which offers interactive, expert-led, multidisciplinary training in the responsible conduct of research for graduate and professional students as well as faculty.

Continuing Education in a Community of Practicing Wicked Scientists

Because becoming a wicked scientist is a long-term proposition that takes more than the completion of the Graduate Interdisciplinary Specialization, we will use a model of continuing education that takes the form of a community of practice that engages current students, alumni, faculty, and other stakeholders working on wicked problems. The **community of practice** is a critical component in both the training of students and the ongoing professional learning of our alumni [67]. Communities of practice are formed by people with a shared interest, concern, or passion for something they do or practice, and they learn how to do it better through regular social interaction [21, 22, 68, 69]. In our community of practice, a primary goal is encourage students and other novices movement from peripheral to full participation in activities as they develop their competencies and professional identities as wicked scientists [70].

We plan to model our community of practice on the structure and activities of the *Student Community of Practice and Engagement (SCOPE)* organized by the Battelle Center for Science, Engineering, and Public Policy. For the last three years, the network has connected hundreds of students and professionals online and in-person, including through a community conversation, in which students get a broader sense of a wide range of wicked problems by connecting with professionals from industry, government, community organizations, and academia who are invited as guest speakers. The conversations allow students to learn and network within the professional fields that most interest them. And students will also learn how professionals stay motivated, develop their attitudes, and derive satisfaction from their work tackling wicked problems. The **professional members of our community of practice** will also play a critical role in the program's three courses. As these professionals work directly on wicked problems, they have developed the competencies of wicked scientists in their careers. For this reason, they will offer invaluable insights to students in our program but also more generally to the question of what makes professionals effective in tackling wicked problems in transdisciplinary teams and how to create a culture of convergence.

To facilitate the participation of stakeholders from outside the university, we will host regular community meetings at the centrally-located **STEAM Factory,** or STEAM, which is a diverse and inclusive grass-roots network in the Ohio State community that focuses its activities on creative and interdisciplinary collaboration, innovation, and dissemination. STEAM helps us to bridge the gap between Ohio State and the larger Columbus community through research dissemination and outreach that is accessible, approachable, and combines formal and informal learning. To support collaboration, STEAM provides a network and accessible off-campus space near downtown Columbus where researchers from all disciplines can broaden their perspectives, share resources, spark creative research ideas, and form collaborations across areas of common interest. Currently there are almost 200 faculty affiliates from more than 60 departments, 13 colleges, and 40 institutes. Most of our team members are STEAM affiliates.

In all the courses, students will learn to **communicate research on wicked problems to diverse audiences**, which entails recognizing the needs of different audiences, knowing the norms and structures of different modes of communication, and selecting appropriate venues for communication and dissemination. Our program will focus on scientific writing for interdisciplinary audiences and communicating science to non-academic audiences using different modalities, including social media, storytelling, podcasts, zines, and other outreach and engagement activities, such as citizen science projects [71-75]. The use of social media is not only important for sharing research findings, but also for attracting community interest, keeping stakeholders engaged, and securing their critical feedback on research. Students will have the opportunity to share their work with broader audiences at community events at the STEAM Factory, like *Franklinton Fridays* and *Columbus Science Pub*. Finally, an important focus of our program involves translating research findings into options for tackling wicked problems to policy makers and business leaders and presenting these findings and options clearly, compellingly, and in appropriate formats for these stakeholders. Translating science into policy options is particularly prominent in the course *Rapid Innovation for Public Impact*, where we will draw from existing resources and evidence-based best practices, such as the RAPID Outcome Mapping Approach [76] and the Change Management Toolbook [77].

Target Graduate Student Populations

The training program is designed to target graduate students in departments affiliated with the Interdisciplinary Institutes at Ohio State such as the *Sustainability Institute*, *Translational Data Analytics Institute*, and *Infectious Diseases Institute*. But the program is open to all graduate and professional students from across the university and the program is designed so that it is relevant for a very wide range of wicked problems. Graduate students in programs from Anthropology to Veterinary Medicine are researching grand challenges that can be studied as wicked problems, but none of these programs train students in the skills that are necessary to work effectively in inclusive, transdisciplinary teams, which is necessary to tackle wicked problems. The success of the program depends on the participation of students from a wide range of disciplines and backgrounds. The diversity that participating students, faculty, and other stakeholders bring to the program is what allows students to develop and practice inclusive, transdisciplinary skills that foster a culture of convergence.

In August 2020, we conducted an online survey of all graduate students from colleges across the university – Agriculture, Arts and Sciences, Engineering, Medicine, Nursing, Public Policy, Social Work, and Veterinary Medicine – to assess whether they would be interested in enrolling in the program, taking the courses, and/or participating in the community of practice. A majority of the 50 students who responded indicated that they were interested in taking the courses *Interdisciplinary Team Science, Wicked Science, Rapid Innovation of Public Impact*, or participate in the *Community of Practice* (56%, 70%, 52%, and 56%) and if we include the students who responded that they *may* be interested the percentages are even higher (96%,

98%, 93%, and 91%). Asked if they would be interested in enrolling in the Graduate Interdisciplinary Specialization in Wicked Science, 34% answered “yes” and 62% “maybe”.

PERFORMANCE ASSESSMENT

We will use a mixed-methods approach to **assess whether and how the program is successful in training wicked scientists, and in particular, what components of the program are most effective for the development of core competencies in wicked science**. Because our program is large in terms of scope – training students to become wicked scientists through participation in a graduate interdisciplinary specialization – a mixed methods approach is appropriate [78-80]. Our study is informed by several premises. First, the intervention is a program that consists of three courses and an ePortfolio, which allows us to examine the development of students’ skills, knowledge, and competencies at both the course and program level. Second, the concept of wicked scientists is broad and multi-dimensional, and thus requires a holistic approach for building and assessing core competencies. Third, since students are not trained in a vacuum, an examination of the larger institutional context of the program is critical for understanding student participation. Moreover, program implementation is a dynamic process that involves multiple stakeholders, including faculty, administrators, and students who play an active role in shaping the program. In short, one could argue that piloting, testing, and validating this training program is a wicked problem in itself – it is a complex program with multiple components, things will likely not go as planned, changes will be made in the curriculum over time, and there will be disagreements about the program. Our mixed-methods approach matches the program’s complexity and dynamics and involves pre- and post-tests in courses, validated psychometric assessments, evaluation of student work in courses, analysis of the ePortfolio, observations of teaching and learning activities in the courses and community of practice, and interviews with students, faculty, administrators, and other stakeholders.

There are **four main ways in which we assess the performance of the program**: (1) assessment of courses and course components and their effectiveness in training different core competencies; (2) an overall assessment of students’ core competencies after completion of the graduate interdisciplinary specialization; (3) controlled comparison of core competencies of students enrolled in the program and those who are not; and (4) a study of the larger institutional context and how it affects student training and the program more broadly. **The overarching hypothesis is that students who complete all the program components and participate in the community of practice will show improved competency development and higher scores across all measures of the program, including the four validated psychometric instruments,** when compared to students who partially complete the program or do not participate at all**.**

To assess which components of the program are successful in training core wicked competencies we use pre- and post-tests that are specific for each of the three courses; observations of teaching and learning activities; and evaluation of the work that students produce in the classes. In the curriculum map we developed for the graduate interdisciplinary specialization, we show that some competencies are developed and assessed across multiple courses, while others are developed and assessed in one of the courses. First, we use pre- and post-tests to assess course-specific competencies. For example, the tests for the *Wicked Science* course may ask students to explain the primary characteristics of wicked problems (proficiency A1a in our curriculum map.) These tests will be administered as surveys in our course management system Canvas and student have to complete, or at least open the survey, to get access to the course (pre-test) or submit the final assignment (post-test). Second, we will observe teaching and learning activities in all three classes, focusing especially on active learning exercises in which students demonstrate the concepts and skills they learned, for example, role-play activities in the *Interdisciplinary Team Science* course or team presentations

in the *Rapid Innovation for Public Impact* course. We will also conduct semi-structured interviews with students and instructors to examine whether and how students are developing course competencies. Third, we will evaluate the work that students produce in these classes to further assess whether and how students are developing the wicked science competencies. For example, our learning outcome: "know how to develop rapport, trust, and a sense of community in teams with stakeholders of diverse backgrounds", will be assessed in the *Interdisciplinary Team Science* course in a reflective essay in which students demonstrate what they learned about team building. We will conduct three rounds of data collection and analysis in each of the three courses. The estimated number of students enrolled in at least one of the courses in three years is 160, with about 30 completing the specialization.

Research questions	Methods (and sample size)	Analysis	Outcome
1. What course components are successful in training what competencies?	Pre- and post-tests, coursework, class observations, interviews (~160 students).	Comparison of pre- and post-test, coursework analysis, qualitative analysis of interview and observational data.	Identification of course components that are more (or less) successful in training wicked competencies.
2. Do students who complete the specialization increase their competencies?	ePortfolio and panel of professionals, validated psychometric assessments (~30 students).	Comparison of scores at start and end of the program; evaluation of portfolio, analysis of panel feedback.	Assessment of the success of the program in training wicked scientists.
3. Do students who complete the program have more competencies than those who do not?	Validated psychometric assessments of three groups: completed a course, completed program, and a control group (~320 students).	Comparison of scores of three groups at the end of the project.	Controlled assessment of student development of competencies.
4. How does the institutional context affect the success of the program?	Ethnographic methods, incl. observations and semi-structured interviews (~45 students, faculty, admin, other stakeholders).	Qualitative analysis of interview data and fieldnotes, including grounded theory.	Strategies for navigating the institutional context to promote program sustainability.

For an **overall assessment of the program and whether it succeeds in training wicked scientists** we use two approaches. First, we compare students' scores on three validated psychometric assessments at the start and end of the program. All students in the three courses will complete the following four assessments at the start of the semester: MATRICx [81, 82], Systems Thinking [83, 84], Intercultural Development Inventory (IDI) [34, 85-87], and Sense of Belonging (SB) assessments [88]. Dr. Lotrecchiano, lead developer of the MATRICx instrument, will consult on analysis of the assessment data. Our team member, Dr. Zepeda, will be trained and licensed as an IDI Qualified Administrator. When students complete the specialization or graduate without completing the specialization, we will ask them to complete the assessments again. By comparing the scores for these assessments at the start and end of the program, we will be able to assess the medium-term impacts of the courses and the program. Second, a panel consisting of faculty and program partners will evaluate the ePortfolio that students produce as capstone assignment for the specialization. In particular, we will focus our analysis on students' self-assessment of their wicked science competencies,

reflections on the learning process, and discussion of their career plans, including how they plan leverage their competencies in their professional field [62, 89].

We will conduct a **comparative study of students in the program with students who are not participating in the program** to examine whether the program and the courses succeed in the development of wicked science competencies. We will compare three groups: students who complete the program, students who partially complete the program, e.g., take one or two courses, and students who do not participate at all in the program. We will use the same validated psychometric assessments with a sample of students similar to participating students demographically, disciplinarily, and in their research focus. The comparative study allows us to check to what extent the students participating in the program are a self-selected group that already has many of these competencies before starting the program, what courses are associated with what competencies, and/or whether the changes are due to maturation. Assessments will be conducted when students graduate from Ohio State.

We will conduct an **ethnographic study of the institutional context of the program** to examine whether and how the program is successful in creating an institutional culture of convergence that supports the training of wicked scientists. This ethnographic study will capture how the program is adapting to institutional and outside demands, and whether those adaptations are working to meet the goals of producing transdisciplinary researchers. The ethnographic research will specifically examine what program participants and partners understand as the structural constraints and affordances (1) internal to the program itself, (2) in relation to the institution, and (3) in the program's relationship to partners outside the institution. Participant observation and interviews with participants, administrators, and other stakeholders will offer insight into how the program adapts to needs and pressures at different levels [90].

One of our methodological contributions to the study of innovations in graduate education is the use of a mixed methods approach, including ethnographic methods, to study the processes and institutional context of graduate education. This allows our team to identify processes and outcomes that are not as easily quantified as number of degrees, grants, publications, but are nonetheless vital to successful programs, including a culture of creativity, inclusion, and equity. We realize that our approach is not as controlled as other educational studies, but our mixed methods approach is both rigorous and reasonable for studying the effectiveness of this program. Moreover, by considering the complexities and the context of the program, it facilitates translation of our program from Ohio State to other graduate institutions.

Dissemination and Plans to Promote Broader Adoption

The program and its educational components are designed so that they can be readily adopted by faculty and programs at other universities. To promote such broader adoption, we will share successful approaches, practices, and models through multiple platforms.

We will report the results of our knowledge generation activities in peer-reviewed journals (e.g., *Journal of Sustainability in Higher Education*, *Advances in Engineering Education*). After publishing our scientific articles, we will disseminate our findings through *Integration and Implementation Insights*, which is a blog curated by Professor Gabriele Bammer at the Australian National University and promoted through social media to reach a wide international audience of researchers, teachers, and practitioners interested in transdisciplinary approaches towards understanding and acting on complex problems. Other venues aimed at broader audiences are *The Conversation* for which we have written several posts [91-94].

We will disseminate our program through networks and consortiums in higher education, including the *Innovations in Graduate Education (IGE) Acceleration Hub of the Council of Graduate Schools* and the *Center for the Integration of Research, Teaching, and Learning* (CIRTL). Ohio State University is a CIRTL member, which was founded in 2003 as an NSF Center for Learning and Teaching in higher education and seeks to enhance excellence in

STEM education through development of a national faculty committed to implementing and advancing evidence-based teaching practices for diverse learners. We intend to contribute to CIRTL programming by offering workshops and leading an online learning community on wicked science. In addition, the three courses have been developed in Canvas, which is the learning management system used by Ohio State and many other universities. The courses will be published in the *Canvas Commons*, where anyone with a Canvas account can download, import, and use our courses and individual modules. Canvas accounts can be created for free.

Information about the program will also be published on a program website, including the meetings and workshops of our *Community of Practicing Wicked Scientists*. We will record talks and presentations and make them available on our website so that others can use them in their courses and programs. To promote synergies across campus, we will also cross-post program information on websites of our partner organizations, in particular the STEAM Factory and the aforementioned interdisciplinary institutes at Ohio State. To reach audiences and promote creative collaboration among stakeholders beyond campus, we will also produce a series of zines on the wicked problems that are tackled in the program. Zines are self-published booklets that include expository essays, photography, and art [73]. They serve as a unique format for scientific communication to diverse audiences and can be produced in physical and digital formats [95]. Zines will be disseminated digitally and in print format at local libraries.

Project Team and Management

A core team of PIs and senior personnel will manage the program and performance assessment activities, but it will be assisted by a larger, transdisciplinary community. The core team consists of: **Mark Moritz** (PI), Professor, Anthropology; **Nicholas Kawa**, Assistant Professor, Anthropology; **Rachel Kajfez**, Assistant Professor, Engineering Education; **Elizabeth Newton**, Executive Director of the Battelle Center for Science, Engineering, and Public Policy; **Yolanda Zepeda**, Assistant Vice Provost, Office of Diversity and Inclusion; **Alison Bennett**, Assistant Professor, Evolution, Ecology, and Organismal Biology; **David Sovic**, Assistant Director, Drake Institute for Teaching and Learning; **Teresa Johnson**, Program Manager, High-Impact Curriculum Expert, Office of Student Academic Success; **Charlene Brenner**, Director of the STEAM Factory; and **Ethan Rivera**, Student Programming Lead, Battelle Center.

The graduate interdisciplinary specialization will be administered by Moritz, including tracking students enrolled in the courses and specialization to identify assessment needs. The instructors for the courses are Kawa (Wicked Science), Bennett (Interdisciplinary Team Science), Newton (Rapid Innovation for Public Impact), and Moritz (ePortfolio). The community of practice will be co-organized by Moritz, Brenner, and Rivera. Zepeda will lead the recruitment activities to broaden participation of students from underrepresented groups. The knowledge generation activities will be led by Moritz. The other members of the research team are Kajfez, Kawa, Johnson, Zepeda, Sovic, and a Graduate Research Assistant (GRA) from Kajfez's *Research on Identity and Motivation in Engineering* (RIME) lab. Pre- and post-tests and the psychometric assessments will be administered by the instructors of the courses. Class observations and interviews will be conducted by the GRA, Moritz, and Kawa. Data analysis, data management, and dissemination of findings will be joint efforts of the research team led by Moritz. Weekly team meetings, meetings every two months with **Marcia Nation** (external evaluator), semi-annual meetings with the advisory board, annual reports and visits to NSF will be organized by Moritz and the GRA.

Institutional Support for the Program

We will leverage existing resources at Ohio State to make our program successful and sustainable. For many reasons, **The Ohio State University** is the ideal institution to pilot, test,

and validate our proposed program to train wicked scientists. Ohio State is a land grant university that is committed to addressing the grand challenges of our time, including the opioid crisis, systemic racism, food insecurity, harmful algae blooms in Lake Erie, climate change, and now the COVID-19 pandemic. The university has heavily invested in interdisciplinary research and teaching through the creation of institutes that have hired more than one hundred new faculty engaged in interdisciplinary research and resulted in the establishment of new institutes, including the *Sustainability Institute*, *Translational Data Analytics Institute*, and the *Infectious Diseases Institute*. Administrators and faculty throughout the university have been enthusiastic supporters of our proposed program because it aligns well with the goals of the university and is advancing institutional synergies in research and teaching.

The proposed program will be supported by an **Institutional Advisory Board** that is comprised of Dr. Alicia L. Bertone, Dean of the Graduate School; Dr. James L. Moore III, the Vice-Provost of the Office of Diversity and Inclusion; and the leaders of Ohio State's Discovery Themes that address the grand challenges: Dr. Elena Irwin, Sustainability Institute; Dr. Tanya Berger-Wolf, Translational Data Analytics Institute; and Dr. Michael Oglesbee, Infectious Diseases Institute. The Institutional Advisory Board will advise the team on matters related to the organization of the program, training of students, relations with community and university partners, and efforts to scale up the program both within and beyond the university. The team will provide a written report and meet with the institutional advisory board twice a year.

Finally, leveraging institutional support is necessary but not sufficient for the success of our proposed program. We also need to foster a **culture of convergence** among participating faculty, students, staff, and other stakeholders that nurtures and supports innovation in wicked science. Fostering this culture is critical for the long-term sustainability of the program. We will develop a culture of convergence by training faculty to become wicked scientists through collaborative activities, co-teaching courses, and participating in events and training workshops through the *Community of Practicing Wicked Scientists*. The idea is that culture is an important part of the scientific and educational infrastructure, including for increasing diversity, equity, and inclusion in the sciences [96]. Culture may be an "invisible infrastructure", but it is nonetheless integral to science, education, and the workplace.

BROADER IMPACTS

The program has two main broader impacts. First, we will pilot, test, and validate a program that trains graduate students to become wicked scientists with deep disciplinary expertise and inclusive, transdisciplinary skills to catalyze convergence in the teams that tackle the grand challenges of today and tomorrow. Second, we will leverage existing programs to broaden participation of students from underrepresented groups and develop an inclusive program.

The most important broader impact of our program is the **training of the future workforce**: wicked scientists who are ready to tackle grand challenges. One of the long-term outcomes of our program is a more skilled and diverse workforce that will be able to contribute effectively and meaningfully to improving urban mobility, public health, climate resiliency, cyber security, racial justice, and equitable economic development, amongst others. While the funding period of three years is too short to measure our graduates' direct impacts on wicked problems under study, we will lay the foundation for a long-term assessment of the program's effectiveness. In particular, we will develop a system to track alumni after completion of the program and their graduation from Ohio State. This system will allow us to survey our alumni and, in the future, examine whether they work in transdisciplinary teams, whether and how they use their wicked science skills, what kind of work they seek, and how this reflects a commitment to studying wicked problems. Alumni will continue to be part of our community of practice and be kept informed of events, trainings, and workshops via a listserv and social media, including LinkedIn. Every three years, we will send out a survey to our alumni to update our contact list

and collect data on their professional activities, including any specific wicked problems they are working on, the approaches that they use, and the competencies that they have retained and apply. We will use questions from existing workforce surveys to collect data that is comparable with other surveys, such as the *Survey of Earned Doctorates* [97, 98].

Second, we aim to **broaden participation and develop an inclusive program** at Ohio State where students from underrepresented groups feel safe to be themselves and empowered to speak out. We recognize that the university is an institution where not everyone feels safe or supported. Students who identify as women, genderqueer, Black, Indigenous, or People of Color are less likely than their peers to enroll in and complete advanced degrees in STEM fields. Isolation and tokenization, lack of respect from others in the academic community, and lack of identifiable mentors or collegial support are critical factors that discourage STEM diversity and success [99, 100]. To overcome institutional barriers to diversity, our program will use evidence-based practices that build and sustain a critical mass of students from underrepresented groups [101, 102] and leverage existing programs to promote our program, and in particular, the **Office of Diversity and Inclusion's** *Graduate & Professional Student (GPS) Visitation Program*.

Mentorship is a critical component of the professional learning of graduate students and that is particularly true for students from groups that are underrepresented in STEM fields and for students in interdisciplinary programs without an organizational home [103, 104]. In other words, to support the success of all graduate students, our training program uses a comprehensive mentoring program [105]. To facilitate mentoring relationships that promote the academic integration and professional learning of students, we will cultivate an inclusive institutional culture that provides validating experiences for all members of the academic community [106]. In addition, we will train students in the competencies that are critical for success in graduate school and beyond but are not taught in regular courses, the so-called hidden curriculum [107, 108]. Hidden curriculum activities are integrated in all four courses.

Another component of the program is **training participating faculty to become wicked scientists** with inclusive and transdisciplinary skills as they will train and mentor the students, and in particular, students from underrepresented groups [109]. To that end, we will leverage existing diversity, equity, and inclusion efforts within Ohio State. First, participating faculty will be trained in *Inclusive Mentoring* and *Service-Learning* through workshops offered by the **Ohio State Mentoring Initiative**, which has been the lead office at Ohio State in training faculty, postdoctoral fellows, and graduate students to become inclusive and effective mentors and mentees. The workshops have been developed by the Center for the Improvement of Mentored Experiences in Research (CIMER) and distributed by the National Research Mentoring Network (NRMN), which is a nationwide consortium that provides trainees across STEM fields with evidence-based mentorship and professional learning programming [110, 111]. Workshops emphasize the benefits and challenges of diversity, inclusivity, and culture within mentoring relationships, and more broadly the research workforce. Staff have been trained by *Knowinnovation* to facilitate innovation and team science workshops.

To support the proposed program and participating students, we have grown a network of **Departmental Ambassadors,** who have expressed enthusiastic support for the program as we have developed it over the last few years. The ambassadors are faculty and staff who will promote our program with students and faculty in their department and share information about relevant courses, co-curricular activities, community of practice, and other events in their departments. Ambassadors will foster an inclusive, transdisciplinary culture within their respective departments and advocate for students interested in pursuing the wicked science specialization. The network of ambassadors is one of our strategies for broadening the participation of students from groups that are underrepresented in the sciences. We are recruiting additional ambassadors from across the university, and in particular from the eighty faculty and staff that are participating in the STEAM Factory's **Racial Justice Pathways**

program. Faculty and staff participating in the program are supported to create a comprehensive, coherent plan for learning about and taking action to address structural and institutional racism in the context of their work at Ohio State; reflect on knowledge gained and how to incorporate it into practice via facilitated peer-to-peer mentoring; and develop, implement, and evaluate a practice or intervention focused on enhancing racial justice in their chosen area.

Finally, we will use the alumni survey to continue to engage with our alumni and support alumni from underrepresented groups as they face bias or discrimination as professionals [112-114]. Broadening participation is critical for the success of our program because it leads to better (wicked) science [14, 115], even it is not always recognized [116, 117].

EXTERNAL EVALUATION

Dr. Marcia Nation, Principal and Owner, Nation Evaluation Associates, LLC, will serve as the external evaluator for this project, employing a utilization-focused approach that includes formative and summative elements [118]. Her evaluation roles will be to: (1) serve in an independent capacity to gather formative feedback from students, faculty, and other community of practice (CoP) participants; (2) provide the PI team with feedback and information in a timely manner for continuous improvement; and (3) determine the program's value, worth, and significance in year three. The evaluation plan below outlines the data collection strategies that will be used in this evaluation. Dr. Nation will meet with the PI team six times a year remotely to review curriculum implementation, outcome progress, and knowledge generation activities. Dr. Nation will use an Appreciative Inquiry framework [119] to engage the project team in reflecting about project implementation semi-annually and Wenger et al.'s framework for evaluating value creation in the CoP [120]. Student formative feedback surveys will be informed by the Departmental Sense of Belonging and Involvement Scale [121]. These and the CoP surveys will be conducted using Survey Monkey. Student focus groups and advisory board interviews will take place via Zoom. Dr. Nation will use short, timely evaluation reports and online presentations to engage students, faculty, and other participants in reflecting about the direction of the program and in discussing the value of monitoring and evaluation in wicked science projects, thus building evaluation capacity among faculty and students. Annual reports will summarize evaluation results, recommendations for program improvement, and how prior recommendations were addressed.

Formative evaluation questions	Measurements and indicators	Data collection strategies	Years
To what degree has the program been implemented as planned? What challenges have emerged, and what was the response?	Actual implementation vs. plans, challenges & responses, ability of team to integrate feedback into plan	Bi-monthly meetings with PI team; semi-annual Appreciative Inquiry process with team to surface "what is / might be / should be "	1-3
What progress has been made on creating a diverse, inclusive, and supportive program for students?	Student recruitment, student demographics, students' feelings of support and belonging	Recruitment and participant data, fall student survey, spring student focus groups, semi-annual surveys of CoP	1-3
What has been students' experience in the specialization? Is it meeting needs and expectations?	What has worked and not worked for students, degree of meeting expectations/needs	Fall student survey, spring student focus groups	1-3

Who is participating in the CoP? How have participants responded to CoP activities?	Participation in CoP meetings, potential and realized value of CoP	Participation data, CoP surveys with Likert-scaled & open-ended questions	1-3
To what extent have students and other CoP participants sustained their engagement in the program? What factors have influenced this?	Engagement in project activities over time, factors that promote and inhibit participation	Student and CoP participation data, semi-annual CoP surveys, student focus groups and surveys, surveys of students leaving the program	1-3
Summative evaluation questions	**Measurements and indicators**	**Data collection strategies**	**Years**
To what extent has this project contributed to knowledge and methods for training graduate students to catalyze convergence in transdisciplinary teams?	Evidence of student outcome attainment, evidence of connection between program activities and outcomes, publications & outreach	Document program model with evidence from research, evaluation results, and interviews with Institutional Advisory Board	3
Who has benefitted from this program, and how have they benefitted?	Students, faculty, and other CoP members report valuing and benefitting from the program	Student surveys and focus groups, CoP surveys, interviews with Institutional Advisory Board, research data on competency gains	3

RESULTS FROM PRIOR NSF SUPPORT

CNH: Exploring social, ecological, and hydrological regime shifts in the Logone Floodplain, Cameroon (BCS-1211986, 2012-2018) **Mark Moritz** (PI), Michael Durand, Ian Hamilton, Bryan Mark, and Ningchuan Xiao. Intellectual Merit: This interdisciplinary research project focused on the impact of human activities and climate change on African floodplains. We developed an integrated computer model that simulates the dynamic couplings among social, ecological, and hydrological systems of the Logone floodplain and examine the role of fishing canals on the coupled system of the floodplain. Our findings indicated that the canals are a highly efficient fishing technique that are well adapted to the boom-and-bust dynamics of floodplain fish. Broader Impacts: We synthesized the findings of our research in a policy brief aimed at stakeholders at the regional, national, and international levels [122] and we contributed to capacity building at two NGOs: the Cameroonian Association for Environmental Education and the Center for Research and Development of Pastoralism. We trained twenty-five MA and PhD students from the University of Maroua and Ngaoundéré in research of Coupled Human and Natural Systems (CHANS) during a four-day workshop in Cameroon. We presented papers at conferences and published eleven papers and others in the pipeline [18, 123-134], one undergraduate thesis [135], one dissertation [136], and two agent-based models [137, 138]. In addition, we contributed to the "Rome Declaration" developed at the FAO *Freshwater, Fish and the Future* conference [139], published a film about canal fishers [140], and published data in the HydroShare data repository [141]. The project also involved an ethnographic study of the interdisciplinary collaboration in our team [18, 131].

BII-DESIGN: Defining the point of no return in microbe mediated symbioses (DBI-2021932, 2020-2021) **Alison Bennett** (PI). Intellectual Merit: This project focused on team development instead of research outputs and has supported five workshops with manuscripts forthcoming. Broader Impacts: contributed to development of the *Interdisciplinary Team Science* course.

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