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Cohort Learning: Supporting Transdisciplinary Communication and Problem-solving Skills in Graduate STEM Researchers

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The 21st century STEM researcher is increasingly called upon to work collaboratively on large-scale societal challenges. In this setting, disciplinary methods and methodologies may function as starting points, but they lack a focus on the metacognition and inquiry-based thinking required to analyze, evaluate, and synthesize diverse global problems. Transdisciplinary theories of learning push researchers and students to make just such a move beyond the boundaries of disciplinarity and toward the co-creation and co-use of knowledge that is the result of interactions between the academic disciplines and society: government, industry, and civil society. For graduate programs with limited financial resources, faculty resources, and collaborative working spaces, cohort learning models may ameliorate the practical "costs" of transdisciplinary research and education while providing precisely the environment in which it may flourish. This article presents the rationale, structure, and assessment plan for one such STEM cohort learning community.

The 21st century STEM researcher is increasingly called upon to work collaboratively on large-scale societal challenges such as providing access to clean water and making renewable energy economical, both recognized as grand challenges by the National Academy of Engineering (National Academy of Engineering, 2017). In this setting, disciplinary methods and methodologies may function as starting points, but they lack a focus on the metacognition and inquiry-based thinking required to analyze, evaluate, and synthesize diverse, global problems. In particular, disciplinarity's emphasis on knowledge reproduction may trap researchers in a feedback loop that limits their abilities to redesign the research process, both practically and theoretically, and to ask and answer new types of questions.

What are the Limitations of Disciplinarity?

Traditional academic disciplines are deeply embedded in the American academy, both as an organizational tool for intellectual work and a structural tool for the institution itself (Frodeman, 2017; Gibbons et al., 1994; Graff, 2015; Klein, 2017). Operationally, the academy functions on the tacit assumption that disciplinary frameworks are already optimal. Additionally, accepted theories of situated knowledge (that knowledge is always the product of the context and culture in which it was created) lend support to the idea that disciplines function as an essential means of analyzing, evaluating, and disseminating research and scholarship (Apostel, Berger, & Briggs, 1972; Brown, Collins, & Duguid, 1989; Crow & Dabars, 2017). At the same time, these traditional means of knowledge production operate on researchers to shape the very types of questions they may ask, as well as the types of theories and methods they use to answer these questions. Fortunate students, as S.L.T. McGregor notes (2017), will be exposed to more than disciplinary thinking. They will most likely be encouraged to explore multidisciplinary learning (more than one discipline with no integration) and interdisciplinary learning (between disciplines and with integration). While more diverse models of thinking and learning, these models still assume the primacy of established academic institutional structures for creating, using, and evaluating knowledge. The current need of researchers to move outside of higher education's structures, both practically and theoretically, necessitates the development of new modes of knowledge creation.

As such, transdisciplinary theories of learning push researchers and students to make just such a move beyond the boundaries of disciplinarity and toward the co-creation and co-use of knowledge that is the result of interactions between the academic disciplines and society: government, industry, and civil society. More specifically, theories of transdisciplinary learning are characterized by four features: (1) it relates to contemporary social issues and challenges, (2) it involves those stakeholders who are affected by such problems, (3) it transcends and integrates disciplinary structures, and (4) it involves a deep search for a unity of knowledge (McGregor, 2017; Pohl 2011). Additionally, its emphasis on the co-creation of knowledge requires students to develop collaborative problem solving skills, an understanding of their own positionality and the positionality of their collaborators, and reflexive, open communication strategies (McGregor, 2017; Park & Son, 2010; Stahl et al., 2011).

What Does this Mean for How We Teach?

Theories of transdisciplinarity offer innovative solutions to many of the challenges that manifest themselves in traditional disciplinary environments, yet contemporary research on collaborative, innovative pedagogical practices is still rooted in disciplinary structures. In undergraduate education, methods to teach and assess interdisciplinary learning are supported by the Association of American Colleges and Universities' LEAP Initiative's emphasis on integrative learning. Defined by the Carnegie Foundation as "an understanding and a disposition that a student builds across the curriculum and co-curriculum, from making simple connections among ideas and experiences to synthesizing and transferring learning to new, complex situations within and beyond campus," integrative learning provides faculty with a framework to structure student learning outcomes and corresponding activities for active learning (AAC&U, 2005). Integrative learning asks for students to bring established disciplinary perspectives together to develop new solutions. More recently, the call for T-shaped professionals, or individuals who have deep disciplinary knowledge coupled with the ability to collaborate across a variety of disciplines, embodies the challenges of teaching transdisciplinary skills: how can we create transdisciplinary STEM researchers when students are constantly defined by, and grounded in, their "home" disciplines (Austin et al., 2018)?

One such solution has been the creation of new locations of research and scholarship. The National Academies report *Facilitating Interdisciplinary Research* (2005) highlights the value of transdisciplinarity specifically for applied research initiatives. The report suggests a research model of "scientists, engineers, social scientists, and the humanities… addressing complex problems that must be attacked simultaneously with deep knowledge from different perspectives." Major universities have traditionally implemented this model in two ways: the development of entirely new stand-alone transdisciplinary schools, or the development of transdisciplinary research centers. Recent examples of such institutional structures include the School of Earth and Space Exploration at Arizona State, the Center for Human-Computer Interaction at Virginia Tech, the Institute for Information Security and Privacy at Georgia Tech, and the Center for the Prevention of Obesity Diseases at the University of Nebraska – Lincoln. All of the previously mentioned institutions are classified as Highest Research Activity by the Carnegie Classification of Institutions. Often, resources for such initiatives come from budget reallocations in response to a university's strategic plan, a partnership with an external business or corporation, or a specific endowment. As such, these models of transdisciplinary research are most often well-funded and central to the university's public face and mission. Additionally, multiple universities often pool together their resources to form transdisciplinary centers. One example of such a center is the Transdisciplinary Research on Energetics and Cancer Center (TREC Center) where UC San Diego, University of Pennsylvania, Harvard University, and Washington University in St. Louis work collaboratively on multiple cancer research projects. Similarly, the Center for Structured Organic Particulate Systems (C-SOPS), headquartered at Rutgers University and partnered with Purdue University, NJIT and the University of Puerto Rico at Mayaguez, investigates the ways pharmaceuticals, foods, and agriculture products are manufactured. These centers provide opportunities for new and established scientists who can carry out integrative research on the specific problem but do not have formal training programs for graduate students. Additionally, these programs are generally limited to specific research topics and, as such, are not available for the general graduate student population.

Such university research centers and stand-alone schools are the cornerstones of transdisciplinarity at major research institutions. Students in these programs are given opportunities to participate in innovative, funded research, partnering with established mentors in academia and industry, to develop specific, yet adaptive, problem-solving strategies. These students are given the opportunity to not just find answers to problems from different areas of expertise but re-define the problems themselves through a transdisciplinary lens.

What about Schools That Cannot Create Such New Locations?

Importantly, researchers and scholars must note that STEM graduate researchers are educated at a variety of types of institutions. Institutions classified as having higher research activity may have individual projects that are transdisciplinary in nature, but do not have resources (location, personnel, space, etc.) that can support broad-based transdisciplinary skill education centers. As an example, the Otto H. York Center for Environmental Engineering and Science at NJIT is a central facility for material characterization, which can be utilized as a transdisciplinary learning space, but it is not currently providing any training for graduate students to tackle transdisciplinary problems. This phenomenon is common in many universities, especially the ones that are not listed as having the highest research activities.

At the same time, STEM graduate researchers from schools classified as having high or mid-level research activity will be just as likely to face the types of large-scale societal challenges as their peers at the highest-research university. The need for these students to learn

transdisciplinary problem solving, collaboration, and communication still exists. In many ways, the need is even greater: at our mid-sized, high research level institution, over 90% graduates go into research and development in industry while less than 10% of them hold academic positions. In effect, such graduate students are more likely than others to find themselves working outside traditional academic disciplinary structures and on problems with multiple, diverse stakeholders. Hence, they need more exposure in solving transdisciplinary problems in order to be successful in their careers, especially in an ever-changing world.

We Believe Cohort Learning is the Answer.

For graduate programs like ours—those with limited financial resources, faculty resources, and collaborative working spaces—cohort learning models may ameliorate the practical "costs" of transdisciplinary research and education while providing precisely the environment in which they may flourish. Learning cohorts facilitate collaboration, investigate problems from multiple perspectives, and focus on individual and group transformation (Donoldson & Peterson, 2007; Holms et al. 2010).

Building on theories of social constructivism and "communities of practice," cohort style learning operates on the assumption of the benefits of cooperative, immersive, and recursive learning. Generally, a cohort shares five characteristics:

- They have a defined, long-term membership who commence and complete together.
- They share a common goal that can best be achieved when members are academically and emotionally supportive of each other.
- They engage in a common series of learning experience.
- They follow a highly structured and intense meeting schedule.
- They form a network of synergistic learning relationships that are developed and shared among members (Imel, 2002).

These characteristics help facilitate not only individual learning, but also learning among group members and among members and their advisors/mentors. In graduate education, these cohorts usually take one of two forms:

- A cohort-with-one, or a group of students sharing a common research area or theory and assigned to a single supervisor with expertise in the research topic, theory or methodology; or cohort-with-team, or
- A group of students assigned to a team of advisors whose complementary expertise in the research topic, relevant theory or methodology broaden the scope of support for the group (Glover, 2010; Holms et al., 2010).

As such, a transdisciplinary cohort both builds on and disrupts these two models. Traditionally, a successful cohort requires a recognizable structure, a shared set of goals, and an understanding of disciplinary norms. In a transdisciplinary cohort, graduate STEM researchers from multiple fields work with the mentor and advisors from multiple fields, necessitating the creation of new, collaborative working structures, goals, and norms. Instead of requiring new locations of research and significant additional financial resources and human capital, such a transdisciplinary cohort would happen in already established locations: the face-to-face graduate classroom.

The Cohort Learning Program

Cohort Program Objectives

Because of these practical and theoretical issues in graduate education our university is piloting a cohort learning program for graduate students. More specifically, we are investigating the effectiveness of cohort learning on the graduate researcher competencies transdisciplinary communication and transdisciplinary problem solving. We believe that transdisciplinary communication skills are vitally important to the next generation of graduate students for continued innovation. When researchers move outside of academia they must be able to work with, listen to, and address multiple stakeholders, as well as convey information in a public or alternative setting. This emphasis on communicating in new environments, along with a focus on critical argumentation and multidisciplinary perspectives, will create researchers with better developed critical thinking skills (Dezure, 2017; Hayne, 2014). Additionally, we believe that a pedagogical focus on transdisciplinary problem-solving skills will provide researchers with new strategies for practicing and revising disciplinary methods and methodologies. By combining established interdisciplinary problem-solving practices like Repko's (2012) model of integrated research with a focus on contemporary social challenges and diverse audiences, transdisciplinary problem-solving strategies will allow STEM graduate researchers to succeed beyond the academy.

The planned Transdiplinary Learning Cohort will provide vital data on the ability of a well-organized cohort learning program to support and improve transdisciplinary research and communication skill development in graduate students. As such, our work has been broken down into four tasks: 1) university transdisciplinary research and communication skills needs assessment, 2) development

and implementation of the transdisciplinary learning cohort, 3) program assessment, and 4) development of guidelines and information for transference of program to other universities.

Task 1: University Transdisciplinary Research and Communication Skills Needs Assessment

In order to properly develop and support the cohort, the project has begun with a series of needs assessment surveys to provide baseline information. We are using this to understand the following: (1) student and faculty knowledge of how transdisciplinary research differs from inter- or multidisciplinary research, (2) faculty needs for graduate student transdisciplinary problem solving and communication skills, and (3) employer needs for new transdisciplinary problem solving and communication skills. This needs assessment takes the form of a series of surveys, focus groups, and panel discussions, thus taking advantage of our existing relationships with companies and industry advisory boards that hire and employ our graduate students.

Task 2: Development of the Transdisciplinary Learning Cohort (TLC)

The TLC will be a cohort-based program where students will work together, along with faculty facilitators and their faculty advisors, to develop transdisciplinary research skills and communication skills. This program will be administered as a combined effort through our Engineering College and our College of Science and Liberal Arts but will be open to students across the university. An outline of the TLC program is presented below.

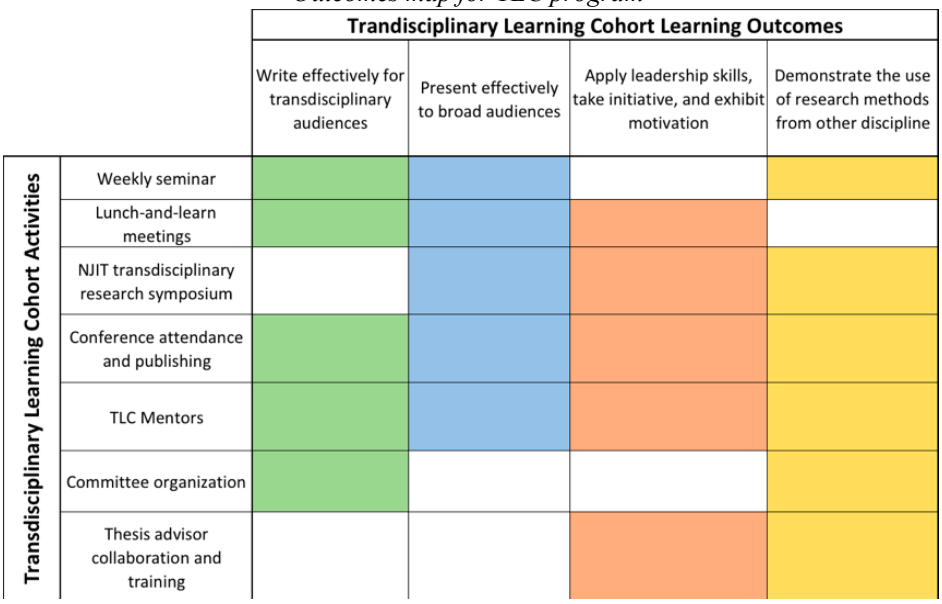
TLC Program student and faculty recruitment. Students will be recruited through active and regular contact with college deans, department chairs, and university faculty. The TLC administrators will ask these stakeholders to identify highly motivated, inquisitive, and interested students across our graduate programs who have at least two years remaining in their graduate programs. Many of these stakeholders have already agreed to participate in this aspect of the TLC program. From recommendations and research areas, a cohort of no larger than 20 students will be chosen by a review panel. We are seeking a balance between different disciplines, backgrounds, and genders to enhance the access to transdisciplinary learning for a diverse group of students.

TLC Program organization and structure. The TLC program will be centered around cohort learning activities in which the students help to lead the activities with the support of faculty facilitators, and this will enhance their transdisciplinary learning skills. In addition to cohort learning activities, the TLC students' dissertation advisors will be actively engaged with the program administrators to help facilitate transdisciplinary research skill development in their individual research projects. Students will participate in the program on a two-year cycle. Specific cohort learning activities will be:

- Weekly Seminar: Students will be required to attend weekly seminars that are facilitated by the TLC program administrators. These seminars will focus on basic interdisciplinary communication skills including presentations, writing, and conversations. Students will focus on the metacognitive styles of each of their own disciplines and discuss how these styles differ among disciplines. Students will explore how to communicate their methodologies, results, and thought processes to people outside of their discipline.
- Lunch-and-Learn: Lunchtime meetings will also be provided, and transdisciplinary researchers working on a variety of topics will be invited to discuss their research, as well as their process for developing appropriate methodologies, their learning of new techniques, and their challenges and techniques for communicating their research to multidisciplinary audiences.
- Transdisciplinary Research Symposium: We are planning a yearly research symposium, hosted by the TLC. All students participating in the TLC will be required to present their research through a poster and in written conference proceedings that will be published by the university. The second-year students will be selected to give oral presentations at the symposium. Other students and faculty who are also working on transdisciplinary projects at our or nearby universities will be invited to participate. Researchers from local universities, as well as government agency and industry professionals, will be invited to attend. Students will be able to use this symposium as a way to showcase their communication skills, as well as to learn new techniques and ideas from other disciplines.
- Conference Attendance and Publishing: Several scholarships to attend and present at conferences will be provided each year by the TLC administrators[1]. Scholarships will be awarded to students who have presentations or

[1] Student travel will be funded through a mix of internal (the graduate school) and external (STEM funding agencies currently working with affiliated program faculty) programs.

Figure 1
Outcomes map for TLC program



papers accepted at a conference outside of their specific discipline, but still within their particular research topic. This will provide students with the ability to learn from other disciplines as well as put their communication skills to work. Beyond presentations, students will be encouraged and supported in publishing their work in journals that may not be typical to their field.

- TLC Mentors: Each second-year TLC student will be paired up with a student from the new cohort of first year TLC students as a transdisciplinary mentor (for the first year of the program, the TLC administrators will pair the cohort with a separate faculty mentor). Students will form a writing and research group. They will be expected to meet regularly, discuss their research and its processes, and both support each other and hold each other accountable throughout the graduate school process. This will help facilitate connections between each cohort year, as well as support transdisciplinary learning by providing opportunities for each student to teach a fellow student directly.
- Committee Organization: Students who participate in the TLC will be required to have one committee member from outside of their home department that can help to improve hypothesis development, provide outside methodologies, and enhance the transdisciplinary nature of their research project. Students will work with TLC facilitators and their thesis advisor to identify a good candidate for this position on their committee.
- Thesis Advisor Training and Collaboration: Training on transdisciplinarity will also be provided to the thesis advisors of the graduate students in the TLC program. These workshops will discuss the concept of transdisciplinary research, its relation to interdisciplinary and multidisciplinary work, and methods to incorporate transdisciplinary concepts within their own projects. Additionally, the thesis advisors will be part of the team that reviews the TLC students' progress and learning.

Task 3: Program Assessment

Student learning outcomes. The TLC program structure is designed to help students reach four main learning outcomes. By the end of the program, students will be expected to be able to do the following: 1) write effectively for transdisciplinary audiences; 2) present effectively to broad audiences; 3) apply leadership skills, take initiative, and exhibit motivation; and 4) demonstrate the use of research methods from other disciplines. The program activities map directly to these learning outcomes, as is shown in Figure 1, which shows that there is significant overlap between the types of activities that will support students meeting each outcome. This will support student engagement with program initiatives through a variety of methods and techniques.

Student Learning Outcome 1: Write effectively for transdisciplinary audiences. First and foremost, students in this cohort program are required to learn how write effectively for transdisciplinary and multidisciplinary audiences. In order to assess this outcome, each student will first work with their research advisor to identify a topic that is transdisciplinary in nature or a portion of their research that may benefit from transdisciplinary research skills. Each student will read articles related to the topic from journals in various fields and write a review paper. Workshops on writing as a process will be provided to enhance students' writing skills, as well as to allow them to reflect on their writing processes. During these workshops, students will also read each other's papers and write in groups to improve their writing skills and to develop strategies that work best for them. TLC facilitators will lead the discussions of writing as a process, and students' thesis advisors will provide feedback to the students' writings. The program will also invite mentors whose research is transdisciplinary in nature to discuss what are the challenges they face when they communicate with a broader audience, how those challenges can be addressed, and how best to communicate across disciplines. These activities will be structured with student reading and writing groups, faculty feedback session, and short reflective essays and discussions.

Student Learning Outcome 2: Present effectively to broad audiences. Second, students in the cohort will be educated on effective methods to present their research to broad transdisciplinary audiences. Specific activities include attending conferences and presenting to peers in the cohort and beyond, as well as participating in group/lunch meeting presentations. These activities will be structured such that feedback is given by the faculty involved, the cohort, and any general audience members that are willing and able. In addition to this, the TLC program will host a yearly research seminar where the students will present to the university, industry partners, and a broad group of peers. During this seminar they will be asked to present not only on how their research can be impactful for their specific topic, but also on how the methods and tools they are using or developing may have a broad impact across disciplines, as well as how they may be able to apply this work to other transdisciplinary problems.

Student Learning Outcome 3: Apply leadership skills, take initiative, and exhibit motivation. Third, students in the cohort will be encouraged to take on leadership roles, to maintain their initiative, and to keep motivated through their time in graduate school. Specific activities include having the students organize the workshops and lunch meetings noted in Outcome 2, send abstracts for presentations at conferences, communicate their results to the broader public, and devise plans to manage and publish on their research projects. These activities will be structured around lunch meetings, networking sessions, and outreach activities with the local community.

Student Learning Outcome 4: Demonstrate the use of research methods from other disciplines. Lastly, students in the cohort will be evaluated on their ability to work in a transdisciplinary manner. Specific activities will include having members of the cohort identify a knowledge gap in a different discipline for which their discipline specific research methods may help, solving complex problems collaboratively, and developing the ability to spin off their research into new areas. These activities will be structured around group discussions involving all members of the cohort and collaborative proposals with their respective advisors. Students will also be encouraged to publish their work in peer reviewed journals that are outside of their discipline, to find areas where they can publish or present on techniques with a cohort member of a different discipline, and to include a faculty member from outside of their discipline on their thesis committee whose methods may be valuable to creating a transdisciplinary project.

Assessment of students. A variety of tools will be used to assess each student's ability to meet the learning outcomes. These will include written artifacts, presentation artifacts, reflective essays, peer-reviewed journal paper and presentation acceptances, student self-assessment surveys, and faculty advisor assessment surveys. Assessment will occur continuously throughout the program on individual artifacts, as well as at the end of each term and after the two-year-long program cycle through assessment surveys.

The TLC Seminar Facilitators will be responsible each term to assess the written and presentation artifacts for each student. A performance rubric will be created that will support this assessment. Self-assessment surveys will be created and administered to the students each term, and we will track how students feel about their ability in each skill throughout the course of the program. TLC mentors and mentees will also be asked to provide assessments on how well the mentorship progressed and the value it added for them individually. Assessment surveys will also be distributed to faculty thesis advisors at the beginning, after the first year, and after the second year of the students' involvement in the TLC program to assess the impact of the transdisciplinary research and communication skills developed, as well as how well the student has been able to incorporate them, within their own work.

Assessment of the Cohort Program. For programmatic evaluation, an emphasis will be placed on a continuous evaluation cycle, including both formative and summative assessment methods

Table 1
TLC Assessment Matrix

Activities	Performance Criteria	Evaluation Methods
Student Learning Outcome 1: Write effectively for transdisciplinary audience		
Read articles Writing with peers Writing as a process Reflection on the writing process	Trainees are published authors Trainees and faculty report growing skill development and familiarity with the field	Annual trainee pre and post survey Number of papers published in high impact journals Writing rubrics Annual trainee focus group Reflective writings
Student Learning Outcome 2: Present effectively to broad audiences		
Attend conferences Present to peers Present at group/lunch meetings	Trainees present at conferences Trainees, peers, and faculty will report satisfaction with presentation skills at group meetings	Annual trainee pre and post survey Number of international conferences attended and presented Presentation rubrics Reflective exit interviews with trainees
Student Learning Outcome 3: Apply leadership skills, take initiative, and exhibit motivation		
Organize workshops Organize lunch meetings Project management	Trainees will take initiative to foster a diverse collaborative research community Trainee project will be successfully managed to completion	Annual trainee leadership skills pre, mid and post survey Annual trainee focus group Exit interviews with trainees Diversity counts
Student Learning Outcome 4: Demonstrate the use of research methods in other areas		
Identify a knowledge gap you can fill Problem solving assignments Spin off research into new areas	Trainees and faculty report growing scientific skills that can be applied in a transdisciplinary fashion Trainees report satisfaction with career advising and placement	Annual trainee pre and post survey Counts of Intellectual property and new ideas split off from PhD (Patents files) Job attainment in STEM Exit interviews with trainees Annual trainee focus group Faculty workshop rubrics Reflective writing

developed and adapted from skills-based research with quantitative and qualitative tools employed to assess the cohort project's success in meeting its goals and objectives (Gredler, 2009). Quantitative methods will include rubrics, pre-and post-surveys of expected outcomes, graduate trainee performance/testing data, and counts of relevant program data (Hernon, 2004). Qualitative assessment methods will include focus groups and advisory committee reviews (Krueger, 2000; Mabry, 2003; Olds & Miller, 2005).

Data will be collected from TLC faculty, trainees, committee members, staff, and associated participants. Data collection includes a specified timeline with annual pre- and post-assessments. Table 1 provides the assessment matrix with an overview of outcomes, performance criteria, and assessment tools (Lopez, 2006).

In addition, we plan to measure the effect of the TLC program on the doctoral completion rate. According to the Ph.D. Completion Project run by the Council of Graduate Schools (2008), previous studies suggest that no more than 56% of students who enter STEM doctoral programs at public universities complete their degrees in spite of having adequate academic abilities and highly favorable conditions. Six institutional and program characteristics are identified as key factors that affect the likelihood that a particular student will complete a Ph.D. program: (1) selection, (2) mentoring and advising, (3) financial support, (4) program environment, (5) research mode of the field, and (6) processes and procedures. Summative program assessment will include surveys and focus group data collection on the cohort's effect

on these key factors. Corresponding data will also be collected from the research advisors of the students participating in the TLC program.

Task 4: Development of Guidelines and Information for Transference of TLC Program

One important additional goal of the project will be to provide a transferrable program that can be implemented at other universities. Our team hopes to develop a set of guidelines and information on how to successfully implement a similar program at other schools. As such, the TLC program will be used as a case study for the guidelines.We hope our experiences will allow us to make program modules, assessment surveys, and example artifacts available to other universities.

Conclusions

Many institutions of higher education have limited opportunities for students to gain exposure to transdisciplinary learning and research activities. Such institutions have multi- and transdisciplinary research centers and other large-scale initiatives that would typically be used to foster transdisciplinary learning environments. The proposed cohort learning program aims to create an environment for graduate students to learn how to solve problems and communicate across traditionally discipline specific boundaries.

We believe this program will transform graduate student education at our university by providing avenues for students to explore research topics in a transdisciplinary context and to communicate effectively to a broad group of researchers with diverse backgrounds. Additionally, the hope is that the TLC program concept can be readily translated to other institutions with limited resources and that do not have large multi- and transdisciplinary research and education centers. Thus, this program has the potential to impact graduate students across a range of universities that do not have the resources to foster transdisciplinary centers in the traditional context.

Additionally, the research project will provide insight on how cohort learning programs can develop transdisciplinary research and communication skills. Beyond determining how well cohort learning can impact transdisciplinary skills, this research will add valuable information on the impact of cohort learning at the graduate level in general and provide a set of tested educational tools that universities can access nationwide for graduate program development.

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