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Addressing Societal Challenges through Graduate-level Community-engaged Design Projects (Traditional Research Paper)

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Introduction

Engineering students will often complete design projects to solve a problem for an identified population in need, resulting in an engineered product such as a novel medical device or new assistive technology [1]. However, adequately addressing major societal problems (e.g., opioid addiction, mental health disorders, physical disability, etc.) will require more than just an engineered product or device, it will require solutions that span individual, community, and societal systems across many different disciplines [2]. The next generation of leaders charged with addressing these complex challenges must know how to work across traditional academic disciplinary boundaries and meaningfully engage with stakeholder individuals, communities, and policymakers [3], [4]. Thus, there is a strong need to train students in the necessary research and design philosophies and skills that will best prepare them to address these complex problems across a variety of users, communities, and disciplines.

We have implemented a graduate-level training program that prepares trainees to address societal challenges beyond their scientific discipline. Our goal is for students to gain a deep understanding of the physical, physiological, environmental, and social-ecological factors that surround major issues [5] and develop technological solutions to overcome these barriers. This is especially important for training a future generation of engineers who are empathetic to user experiences and understand that technological feasibility is only one part of successfully implementing a societal solution. Our traineeship model of STEM graduate education uses community-engaged design projects as a training mechanism that brings together students from different disciplines to creatively solve real-world problems at the intersection of health, society, and technology. A key feature of these year-long community-engaged design projects is that trainees get to work in multi-disciplinary teams while being immersed within the actual communities affected by these societal problems, where they benefit from learning about the lived experiences of actual community members. Working with these community partners, student teams co-create solutions that directly address the needs of that specific population, rather than trying to implement a one-size-fits-all solution. By following an iterative design process [6], these design projects have a high likelihood of being implemented within the local communities to create a strong impact for the people in need. Further, the co-creation with community partners provides insight into the realities and challenges of bringing technological solutions to real-world users, which can foster new convergence research grounded in practical application. We anticipate that these essential interdisciplinary skills will support a future STEM workforce capable of addressing major societal problems.

The purpose of our study was to investigate the effectiveness of our community-engaged traineeship model in achieving three objectives: 1) prepare trainees to address major societal challenges, 2) foster new convergence research opportunities, and 3) enhance our institutional capacity to produce STEM professionals with essential skills for innovation-related careers.

Methods

Traineeship program

Our model of STEM graduate education places community-engaged design projects at the core of the traineeship experience (**Fig. 1**). We believe that community-engaged design projects are an effective mechanism to provide trainees with interdisciplinary expertise (i.e., *principles*) to apply their skills toward major societal goals (i.e., *purpose*) through immersive hands-on experiences (i.e., *practice*) [7]. Our model emphasizes that the mere accumulation of disciplinary expertise is not sufficient but needs to be carefully contextualized and organized around important contexts to create "usable knowledge". This enables trainees to take control of their learning and apply it through structured activities to support the design process.

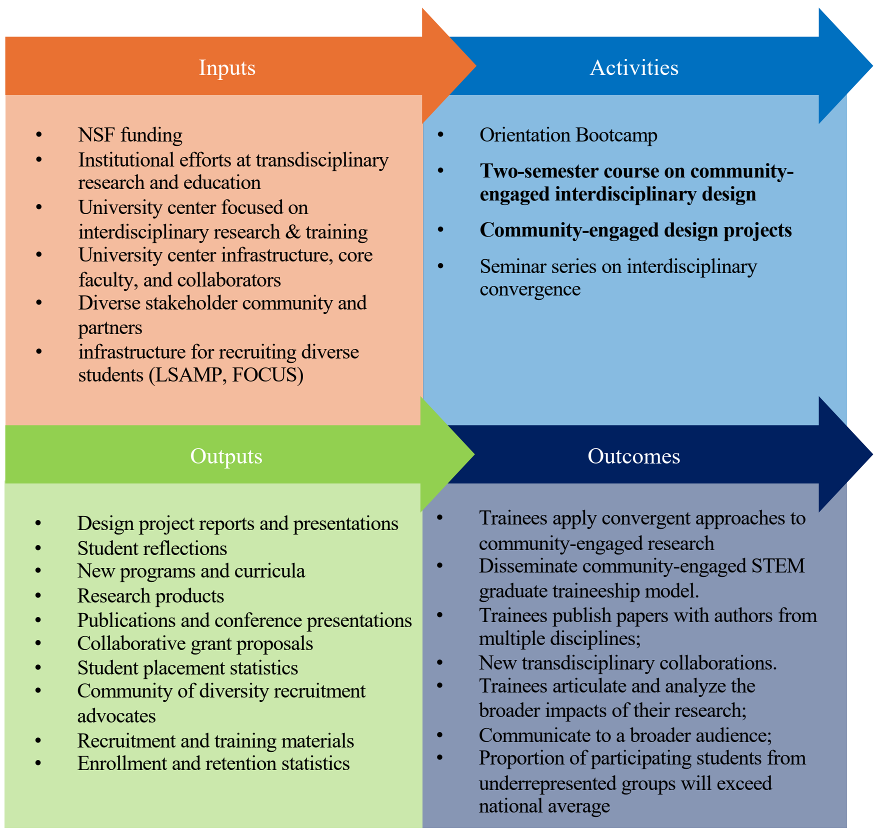

Figure 1. Logic model of our training program to achieve innovate community-engaged graduate STEM education.

This training is rooted in two complementary design philosophies: Design Thinking to provide students with a human-centered approach to solving real-world design problems [8], and Community-Based Participatory Research to develop intentional relationships with community partners and work together as a team in problem-solving [6]. Our training approach is also well-aligned with the How People Learn framework because it leverages learner-centered, knowledge-centered, assessment-centered, and community-centered learning environments [9].

The traineeship program aims to teach graduate students of various disciplines to:

1. Define a problem from multiple perspectives based on disciplinary knowledge, lived experiences, and community knowledge.
2. Utilize design thinking principles to break down open-ended problems.
3. Develop creative solutions by adapting and applying theories and methodologies from different disciplines.
4. Communicate effectively with stakeholders and broad audiences.
5. Work productively on diverse multidisciplinary teams.

This training involves an individualized interdisciplinary curriculum, scaffolded by laboratory rotations and hands-on workshops, a year-long community-engaged design project, and training in entrepreneurship, communication skills, and team science. Individualized curriculums are tailored to trainees to comply with the requirements of their home graduate degree programs.

Our traineeship program began in the 2019-2020 academic year as a result of a National Science Foundation Research Traineeship award. This traineeship program is meant to prepare at least 100 STEM graduate students to address major societal challenges within our local community through integrated research and interdisciplinary training in engineering, data science, and social sciences. The long-term vision of the program is to improve the quality of life for people in our communities by co-creating data-driven solutions alongside community partners. By leveraging the technical expertise of the graduate students in collaboration with the feedback and direction of the community partners, our training program is attempting to make profound and impactful changes within communities in need. To achieve this vision, we have developed and are iteratively refining our community-engaged graduate STEM traineeship model to prepare trainees to address major societal challenges (Objective 1). By bringing together interdisciplinary student teams to work on real-world problems in our community, we also anticipate that this traineeship program will foster new convergence research opportunities (Objective 2). Further, by strategically bringing together students recruited from various departments on campus, we hope to increase our university's capacity to produce diverse cohorts of interdisciplinary STEM professionals with skills essential to a range of research and innovation-related careers within and outside of academia (Objective 3).

Recruitment and Orientation

Trainees participate in the training program using a cohort model. Each year we recruit around 20 students to participate as a cohort, intending to recruit at least 100 students over 5 cohorts. Trainees must be enrolled in a graduate program (either a master's or Ph.D.) at our university. We prefer to recruit a wide diversity of students across a range of STEM fields who are interested and who are committed to participating in the program. We primarily recruit using faculty across various departments that participate in our university center for interdisciplinary design and convergence research. Trainees must have approval from their academic advisor and department. A limited number of eligible students will receive a year of graduate funding in exchange for their participation, distributed as part of an NSF Research Traineeship program award, although many students choose to participate in the program without funding because it aligns with their own professional development goals.

Training activities start with an orientation bootcamp in which the incoming cohort watches the departing cohort present their year's work to their community partners. This takes place at the beginning of the summer term. The new cohort then uses the summer to identify and choose potential community-engaged design projects for the year and start identifying potential community partners. Proposed projects come from various community partners with existing relationships with our university and from faculty who have identified promising areas for interdisciplinary convergence using community-engaged design. As the diverse teams start working on their project, the cohort meets together weekly during the summer to discuss project management and other professional skills necessary for interdisciplinary collaboration. The summer training is more about relationship building and reviewing literature surrounding the issues of the potential projects. We then conduct a formal panel review, similar to an NSF review process, to evaluate the potential community projects in terms of feasibility, impact, scope, relationships, and timeline. The highest-scoring projects are then chosen for student teams to pursue, and relationships with the community partners are initiated. Student teams are chosen based on student interests and an even distribution of necessary skills.

Interdisciplinary community-engaged design courses

During the fall and spring semesters of the academic year, the student teams continue their design project and also participate in a two-semester course sequence about community-engaged interdisciplinary design. The students also participate in a weekly seminar series with various speakers on the theme of interdisciplinary convergence to address major societal problems. The students will finish their cohort participation by giving their final presentation at the annual retreat (i.e., the start of a new cohort's bootcamp). Students are invited to continue their design project after their formal year of training, and funds are available to support their continued non-mandatory participation.

The two-semester course on community-engaged interdisciplinary design instructs the students in design thinking and community-based participatory research. Each course is 3 credits each, for a total of 6 credits for the sequence. This course continues the discussions/trainings that started in the summer term. The assignments are scaffolded to support the design process they undergo with their community partners. For example, the fall semester is focused on user-centered ethnographic research to develop empathy and understanding of the community members they are working with in an effort to identify the specific problem to solve that will best help their community. The spring semester is focused on methods for creating technological solutions to solve the specific problem statement they previously identified. Students are trained by faculty from several fields (e.g., Engineering, Computer Science, Mathematical Sciences, Social Work, Education, Psychology), who offer workshops covering data science, the design cycle, minimal viable products, stakeholder interviews, community partner introductions, qualitative interviews, focus groups, and Institutional Review Board applications. Trainees develop and use both data-collection devices and data-analysis techniques to promote data-driven solutions with major social, public health, and economic consequences. In the courses, the trainees also participate in a variety of communications activities, including developing an iterative peer grant proposal with community partners, rehearsal presentations, and panel presentations to community stakeholders.

The goal of these two courses is three-fold: (1) explore new frameworks for addressing scientific and social challenges through deep integration of knowledge and techniques from data science, engineering, and social sciences (2) ensure that all trainees irrespective of their background have a baseline exposure to the themes of the traineeship program spanning the biological, psychological and social domains, the underlying research challenges, and are aware of the tools to address these challenges; and (3) to disseminate the themes of the traineeship program across the university community and engage both faculty as well as students to develop common terminology and exposure to diverse research methods. For example, through this interdisciplinary training we are teaching engineers to think like social scientists and teaching social scientists to think like engineers, which will better prepare all of them to develop solutions for major societal problems.

Community-engaged design projects

The integrative capstone experience is the yearlong design project, where multidisciplinary teams work together with community partners on problems at the intersection of health, society, and technology (**Fig. 2**). Teams are composed of 4-5 graduate students from different disciplines and local community partners invested in solving big societal challenges. Graduate students are immersed within community settings, challenging the traditional hierarchies between researchers and participants by engaging community stakeholders as full participants in the research process [10]. Over the year, these teams work with community partners to identify the specific challenges, issues, and needs within their local communities based on multiple perspectives and lived experiences, formulate research questions, and engage in participatory design to develop and test ecologically-valid multi-disciplinary solutions. Each team also works with at least one project mentors that are faculty in the university and have subject matter expertise on their design project topic. Teams work with their community partner to start building a respectful relationship for collaboration using the principles of community-based participatory research.

Figure 2. The community-engaged design project is the primary mechanism driving our traineeship model of interdisciplinary graduate STEM education.

To navigate the complexity of these projects, teams use the design thinking framework to:

1. Develop empathy for community members and learn more about societal problems.
2. Define a specific and actionable problem within the community that can be solved using their collective team expertise in a feasible timeframe.
3. Ideate a vast array of solutions to explore to solve this defined problem.
4. Create prototypes of solution components.
5. Iteratively test these prototypes with community members to gather feedback and improve their design.

Note that design thinking is a non-linear process and provides freedom for teams to focus efforts on only the necessary aspects of their current design efforts [8]. For example, teams can go through multiple rounds of ideating, prototyping, and testing their designs to iteratively develop a solution that is co-created with community members. As another example, during product testing the teams may learn more about the users and the community that may support an updated definition of the problem statement. Thus, teams must document their design process to create a compelling set of evidence to support their design decisions and tell an impactful design narrative.

Community stakeholder participation is crucial for a successful design project. Students are taught to use a stakeholder map to identify how individual community members are involved in the design process. For example, some community members are highly involved in weekly conversations about the design process and other community members are available to share their personal experiences surrounding the design problem and provide their feedback on proposed solutions. The goal is to involve a wide range of community members across various stages of the design process, from user experience interviews and defining specific community issues to user testing of prototypes for proposed solutions. Students are encouraged to visit with community members in their community environments to better understand how the environment affects their experiences. Students are taught ethnography methods to understand the community, as well as product concept testing methods when recruiting feedback on the solutions. After collecting this data, the key community partners (i.e., community leaders) are included in making the key design decisions and determining the next steps of development.

The design projects will have matured by the end of the year, but this does not mean that the teams will necessarily deliver a working prototype of a solution. Although this is the ultimate goal, we tell the teams it would be better to deliver a well-defined community problem statement that has been validated by community members and has garnered buy-in from key stakeholders than to deliver a rushed prototype that attempts to solve the wrong problem (consistent with design thinking principles). In this way, students are encouraged to follow the non-linear design process to develop feasible and impactful mechanisms for societal change, and their work can continue to mature either by a future design team or by the original team after their traineeship period is over (both of which are common). This de-emphasis on rushing to prototype also demonstrates the importance of building/maintaining relationships with the community partners, who will continue to face these problems long after the student teams are involved. Nonetheless, student teams have successfully delivered innovative ideas (in various stages of development) and identified promising and specific mechanisms to promote change using technology in their local community.

Community-based participatory research is a mechanism for researchers to improve health and well-being and promote social change through taking action [11]. We have seen 44 graduate students over three cohorts complete the training program, and a new cohort of 18 students began in Summer 2023. Students have come from a variety of disciplines, including engineering, psychology, neuroscience, computer science, computational data science, and social work. The community-engaged projects have sought to address a variety of societal challenges, including improving the agency and resilience of individuals with opioid addiction in northern Virginia, connecting incarcerated individuals to reentry services, improving accessibility of mental health care to new patients, accessible navigation in public spaces for people with mobility impairments, improving communication between patients with Parkinson's disease and their caregivers and clinical providers, improving mental health for our community firefighters, preventing domestic violence in our community through partnership with religious institutions, and supporting students in our community with disabilities during the COVID-19 pandemic. Community partners came from a variety of non-profit organizations and community advocacy groups who are now invested in continued long-term collaboration to help address these community issues.

Evaluation approach

We sought to investigate the effectiveness of our community-engaged traineeship model. To remain objective and reduce bias, we used an external evaluator (The Mark, Newport Beach, CA) to conduct an evaluation related to our three primary objectives. This evaluation answered the following questions related to the program objectives:

- (Objective 1) Use a community-engaged traineeship model to prepare trainees to address major social challenges.
    - To what extent does participating in the program increase trainees' **convergent research skills**?
    - To what extent does participating in the program increase trainees' **community engagement and socio-skills**?
- (Objective 2) Use a community-engaged traineeship model to foster new convergence research opportunities
    - To what extent does participating in the program increase trainees' **interdisciplinary scientific knowledge**?
    - To what extent does participating in the program increase the **number of trainees' research projects integrating multiple disciplines**?
- (Objective 3) Use a community-engaged traineeship model to enhance our institutional capacity to produce STEM professionals with essential skills for innovation-related careers.
    - To what extent does the program facilitate **recruitment and retention of diverse trainees** in the program, specifically underrepresented minorities?
    - To what extent does participating in the program increase **interpersonal skills** (i.e., leadership/team skills, general professional skills, and communication skills) for trainees?
    - To what extent does the program increase a trainee's **intentions to pursue a research or innovation-related career**?
    - To what extent does the program increase a trainee's **preparedness to perform professional skills related to obtaining a job**?

To address the evaluation questions, we gathered data from surveys and student reflections. The baseline/post-survey assessed research skills (e.g., problem identification, hypothesis construction, research design, data analytics, products), socio skills (e.g., ethics, socioeconomic implications, policy/regulatory challenges, dialogue), professional skills (e.g., leadership, teamwork, and management), communication skills (written, translational, and presentation), community engagement, and interdisciplinary scientific knowledge (e.g., core competencies and applications). The surveys included Likert scale items and open-ended questions. Student reflections were recorded at the end of each semester, where they reflected on their personal growth over the past year in the areas of knowledge integration, procedural learning, transfer of learning, communication, and team science.

We analyzed the quantitative data using response frequencies. We used inferential statistics (paired-sample t-tests or Wilcoxon signed rank test) to test for statistically significant changes in trainees' knowledge and skill levels as measured by the baseline and post surveys. To assess changes in knowledge and skills, survey items were categorized by concept, and composite means were calculated. Statistical significance was set a priori as $p < .05$ and we only included responses in these analyses from students who completed both the baseline and post-survey. Qualitative data were coded for themes and summarized.

We use the evaluation feedback to iteratively improve the traineeship model each year. To avoid confusion from the previous year's attempts, we only report the results of the most recent implementation of the traineeship model, which was the third year of executing our traineeship program. A future study will describe the efficacy of the traineeship program over all cohorts, describe the final curriculum of the design courses, and provide recommendations for implementing this program at another institution.

Results

Program participants

We recruited 19 students as trainees in our year 3 cohort (**Table 1**). The majority of trainees identified as female (n=11; 58%). Most trainees identified as being either Caucasian or White (n=9, 47%) or Asian (n=6, 32%). Close to three-fourths of trainees (n=14; 77%) reported pursuing a doctoral degree. Only 15 of the 19 trainees completed the evaluation surveys and student reflections.

Demographics		N
Gender	Male	5
	Female	11
	Other	3
Race	African American or Black	1
	Asian	6
	Caucasian or White (non-Hispanic)	9
	Hispanic or Latino	1
	Native American	0
	Native Hawaiian or other Pacific Islander	0
	Do Not Wish to Specify/Other	2
Degree Type	Doctorate	14
	Master's	4
Field of study	Bioengineering	1
	Education/Kinesiology	1
	Computational Data Sciences	1
	Psychology	8
	Computer Science	4
	Electrical and Computer Engineering	1
	Information Science and Technology	1
	Social Work	1

Table 1. Demographic overview of the year 3 trainees. Note that one respondent dropped from the program and this is reflected only in the count for Degree Type and Field of Study.

Satisfaction and usefulness of the design courses

Overall, 8 of 15 (53%) respondents were very or extremely satisfied with the community-engaged interdisciplinary design courses we provided. The majority of respondents (9 of 15; 60%) also found the courses very or extremely useful for improving their team science skills, improving their research skills, and engagement with community stakeholders. Major themes were that respondents enjoyed the way the course was organized around team activities, exposure to other disciplines, and introduction to design thinking processes. Respondents provided several suggestions for improving the program, including setting realistic expectations for the project timeline (e.g., IRB process, what to expect in focus groups) early on in the process, and having prerequisites (e.g., introduction to statistics) so students come in with the same foundational knowledge and so more time can be devoted to team activities.

Self-reported pre-post assessments

Trainees reported significant improvements in their abilities after the training program, as seen in the matched responses from the baseline survey to post survey (**Table 2**). Note that these assessments were conducted in parallel with the post-training student reflections, which help provide an interpretation of these changes.

Survey	*Items*	Baseline Survey *Mean (min – max)*	Post Survey *Mean (min – max)*	
Convergence research skills	10	3.1 (1.9 – 4.2)	3.7 (2.9 – 4.6)	*
Convergence learning skills	10	2.9 (1.3 – 4.0)	3.9 (2.4 – 5.0)	*
Community engagement & socio-skills	4	2.9 (1.3 – 4.3)	3.7 (1.5 – 5.0)	*
Interdisciplinary scientific knowledge	3	2.2 (1.0 – 3.3)	3.0 (1.7 – 4.3)	*
Leadership & team skills	17	4.1 (1.8 – 4.6)	4.4 (3.5 – 5.0)	
General professional skills	9	2.6 (1.4 – 3.9)	3.5 (2.1 – 4.9)	*
Communication skills	8	3.2 (2.3 – 4.3)	4.0 (2.5 – 4.9)	*
Communication confidence	6	3.4 (2.0 – 4.2)	4.1 (2.8 – 5.0)	*
Communication comfort	6	3.3 (2.0 – 4.3)	4.1 (2.7 – 5.0)	*
Career preparedness	14	3.0 (1.5 – 4.3)	4.0 (2.5 – 5.0)	*

Table 2. Respondents' (n=15) baseline and post mean scores for self-reported skills and abilities. All survey items were evaluated on a five-point scale (e.g., ranging from 1: *no experience* to 5: *expert*). The asterisk (*) denotes a statistically significant increase in the post survey score from the baseline survey score.

Interdisciplinary research projects

The trainees contributed to one of four community-engaged design projects (**Table 3**). In the post-survey, when asked how the traineeship program impacted their knowledge and/or skills, nine respondents shared that the program helped them understand how to do research with community partners. Five respondents shared that it increased their familiarity with multidisciplinary research. Two shared they learned about design thinking, one said the program improved their leadership and teamwork skills, and one said they generally learned new skills.

Post-survey respondents also reported how their participation in the program impacted their learning in fields outside their area of expertise. The students valued the interdisciplinary experience they gained from the program (6 respondents), the ability to communicate with diverse audiences (6 respondents), having the ability to take new opportunities because of the broadened horizon the program gave them (2 respondents), and learning about new technologies (1 respondent).

Community-engaged design project	Number of trainees	Disciplines represented
Improving messaging between patients with Parkinson's disease and their care team in our community	4	Psychology, Social Work, Education/Kinesiology
Improving accessibility on campus for community members with mobility impairments	5	Psychology, Computer Science, Bioengineering, Electrical & Computer Engineering, Health Services Research
Supporting individuals in our community during re-entry after incarceration to reduce substance abuse	4	Psychology, Computer Science
Improving access to mental health resources for our community	5	Psychology, Computational Data Science, Information Sciences & Technology

Table 3. Description of the year 3 cohort's community-engaged design projects.

Recruitment of diverse trainees

Our traineeship program aimed to recruit diverse cohorts of students (**Table 4**). Our program appeared to do well at recruiting female trainees but was less successful in recruiting trainees from underrepresented minority groups. Our program aimed for 27% of the recruited students to be considered diverse, which is the percentage of graduate students at our university that come from underrepresented groups. Our program did meet its goal, with most of its trainees coming from at least one underrepresented group.

Diversity demographics	N
Female trainees	11
Trainees with underrepresented minority status	2
Trainees with a disability	6

Table 4. Trainees' (n=19) diversity demographic information.

Career intentions

Respondents were asked about their intentions to pursue research- or innovation-related careers. Respondents' ratings of their likelihood to pursue a research- or innovation-related career did not significantly change in matched responses. On the baseline survey, 95% of respondents (18 of 19) indicated that they were very or extremely likely to pursue a research- or innovation-related career and 93% of respondents (14 of 15) indicated the same on the post survey. These findings suggest those who stayed in the program persisted in their interest in these careers.

Trainee reflections

Trainees provided reflections on their growth in the areas of knowledge integration, procedural learning, transfer of learning, communication, and team science attitude. Thirteen out of 15 trainees submitted reflections.

When asked about their knowledge integration, all trainees (13 of 13) reported gaining new knowledge or skills. Commonly reported skills included application and integration of knowledge (e.g., applying new approaches to research) from across disciplines (9 of 13) and communication with and across disciplines (10 of 13). One trainee explained, "*These experiences were essential to me… knowing the processes of my other disciplined team members, made me realize how efficiently I can prepare these resources, which is a valuable addition to my knowledge integration.*" Other responses included engaging the community and stakeholders in research, applying multiple perspectives and approaches to preparing materials, incorporating technology into developing treatments, and learning about design thinking and different frameworks/visualizations of problems. The majority of trainees (8 of 12) expressed interest in further developing skills in data science and data analysis, including data cleaning, training in advanced statistical analyses, testing computer-based interventions, and creating interactive dashboards.

In terms of procedural learning, experiencing the research process appeared to be impactful for trainees. All trainees (13 of 13) described their experience with the research process. More than half of the trainees described developing skills related to qualitative analysis and addressing open-ended questions. The trainees described techniques they learned, such as critical thinking techniques, such as brainstorming, the 5 Whys, design thinking, and learning to break down ideas into steps. As an example from a trainee who discussed using a stepwise procedure to address an open-ended problem, one trainee wrote, "*I usually find open-ended problems challenging and confusing, however, working in such a multidisciplinary team improved my understanding and problem-solving skills. Based on the feedback from one of our stakeholder meetings, I wanted to know my teammates' opinions about designing a system acting as a centralized hub for mental health resources. These are all step-by-step procedures we have tried to maintain regularly, which was very helpful for my process learning skill*."

All trainees (13 of 13) described how they have already or would be able to transfer their newly acquired knowledge and skills to other situations. Examples included learning how to involve and consider the needs of community partners and stakeholders' (including those from vulnerable and marginalized communities), applying specific techniques and methodologies to other settings (such as mental contrasting and implementation intention techniques), and applying their knowledge and skills to future presentations and research. For example, one trainee wrote, "*For instance, I knew about the mental contrasting and implementation intention (MCII) technique for quite a time, but I never thought it could be applied in other settings than clinical work. When our team discussed that we could use MCII as an interview strategy for the stakeholders I was surprised how we never thought of using this approach outside clinical work. So, I think examining the feasibility of MCII for community-stakeholder interviews is a good example of applying a methodology in a unique setting to address a very different problem*."

Communication was an area in which most of the trainees (12 of 13) reported they had grown over the semester. Two students stated that the traineeship program helped them improve the most in terms of communication skills. Most trainees (9 of 13) noted that the interdisciplinary nature of their team projects facilitated growth in their communication skills through learning to use a common language accessible to stakeholders and teammates from different fields. For instance, one trainee explained, "*My teammates and I have at times struggled to find common language – technical terms, concepts, and themes that one or two of us may take for granted we soon realize are completely novel to the rest of us! We have all gotten practice at using understandable language to communicate our own expertise and are steadily improving our communication. I'm so grateful to be able to learn from my team members!*" One trainee, who was an international student whose first language was not English wrote, "*Being an international student and not having English as my first language, oftentimes I find it very difficult to speak up and express my thoughts. But during my [training] journey, with the help of my team members and faculty mentors as well as the whole cohort, I improved a lot. Although I still need a lot of improvement in this area, I feel my overall communication skill got better over time throughout the [training] procedure.*" Six out of 13 trainees wanted to continue to build their communication skills. For example, one trainee wrote, "*I look forward to learning how to present our findings effectively to a non-scientific audience*." Another trainee wanted to learn more about *".... storytelling skills because that is something that my degree does not touch on*."

Similar to communication, team science was an area in which most trainees (10 of 13) described how they had grown over the semester. For some trainees (5 of 13), this was their first experience working on an interdisciplinary team and they reported this experience to be valuable. The majority of trainees (10 of 13) described cross-disciplinary collaboration with teammates. One trainee explained, "*Whenever we try to address an issue, we aim to solve it collaboratively, which leverages each of our individual strengths… Our collaboration and agreement on executing these steps enhanced team bonding in terms of team science*." Specific skills learned through working on an interdisciplinary team included conflict resolution skills, adjusting to others' working styles, and leadership skills. Four of 13 trainees described the comfortable, positive climate of their teams and the positive impact it had on their group dynamic, communication, and teamwork. One participant stated that working on an interdisciplinary team increased their confidence. Two trainees mentioned challenges including struggling to fit in and find their place/role within the group and struggling with allowing others to take on leadership roles. Three trainees wanted to continue to learn from an interdisciplinary team. For example, one trainee noted, "*I am most looking forward to expanding on problem-solving and communication skills as we go into making our final product and being able to test and* *troubleshoot as a team.*” Two trainees wrote that they looked forward to continuing to work with community partners.

Discussion

In this study, we investigated the effectiveness of our community-engaged traineeship model. First, we found evidence that our training program was successful at preparing trainees to address major societal challenges by increasing their convergent research skills and community engagement skills. Second, we found evidence that our training program could foster new convergence research opportunities by increasing their interdisciplinary scientific knowledge and kick-start community-engaged research and design projects. Third, we found that our training program can enhance our institutional capacity to produce STEM professionals prepared to use the skills necessary for innovation-related careers. We believe that this community-engaged traineeship model has strong potential to prepare graduate-level students to address societal challenges beyond their own scientific discipline.

We find this training is especially useful for engineering students, who have expertise in the technical aspects behind new technology but may lack the experience of a social scientist. This training gives students an extended opportunity to constantly think about engaging with community members and end-users. This helps engineers transition from a technology-centered design philosophy to a human-centered design philosophy [12]. Along these lines, this experience can help an engineer to first examine the needs of users in their design process, which may not be their default approach when designing solutions [13], [14]. By having students work on real-world problems with actual community members, this training also fosters an entrepreneurship mindset and provides insight into the difficulties facing startup companies. The training also helps engineers communicate with people outside their discipline and outside of STEM fields, supporting the need to develop “T-shaped” engineering graduates who bring broad knowledge across domains, deep expertise within a single domain, and the ability to collaborate within a diverse workforce [15].

Our findings related to our first objective suggest that the program has been successful in increasing trainees’ convergent research skills as well as their socio-skills, which will help prepare them for engaging with the community [6]. This finding is aligned with the identified competencies needed to drive innovation across a wide range of industries [16]. In particular, the program has especially helped trainees identify the ethical and socioeconomic implications of their research and findings. Trainees have shown improved inclusivity of diverse stakeholders' perspectives in their research, but there is still room for improvement in their ability to listen to community stakeholders and understand their perspectives and needs. For example, students expressed a need for more training on policy research methods, and we are considering bringing in faculty from university departments related to government and policy to help fulfill this need. However, our overall results suggest that our program is on track to meet its goal of preparing trainees by equipping them with the knowledge and skills needed to address major societal challenges at the intersection of health, technology, and society.

Our findings related to our second objective suggest that all trainees gained valuable experience working on team-based interdisciplinary and community-engaged research projects. By increasing the interdisciplinary scientific knowledge, the trainees are better prepared to foster new convergent research [17]. This finding is also aligned with past studies that have shown that community-based participatory research and human-centered design can advance inclusion, diversity, and access to innovation [14], [18]. However, we are aware that there may be a large amount of interdisciplinary scientific knowledge required to conduct these projects, which may not be feasible during the time spent in the training program. We are considering offering specific trainings of in-depth scientific topics à la carte, so that students can access online recorded lectures as needed for a given project. This would require a considerable investment of the instructors' time, but could be done slowly each year in a cumulative fashion. To enable new convergence research opportunities, students are also given opportunities to identify new areas for design projects in the next cohort, and can propose new projects based on their design experiences that can explore new and promising community-engaged research. For example, a previous design team worked on developing autonomous rovers to detect obstacles and report accessibility options for community members on campus in wheelchairs. This inspired a new design team to continue this research area by designing a smartphone application that could enlist a network of volunteers to clear reported obstacles for their local community members.

Our findings related to our third objective suggest that our training program has been successful in preparing trainees for research- and innovation-related careers. For example, students reported a significant increase in being prepared to enter the job market. This finding is aligned with past studies using training programs to generate skills for innovation-related careers [19]. However, our training could be improved by providing more opportunities for trainees to work on their communication skills within the design courses. Trainees may benefit from having more formal feedback from professors and their peers when preparing for presentations to community members or writing to government leaders. Taken together with trainees' satisfaction and usefulness ratings, portfolio reflections provided further evidence that our courses helped trainees build knowledge and skills.

While most students were satisfied with the design courses we offered, there is still room for improvement in the courses. Feedback on the post-survey and course reflections suggests that requiring students to have completed prerequisites may help move the course along faster. For example, requiring a prerequisite in statistics may be useful so that our courses could include more advanced statistics and data science methods. To improve the time spent in class, we could also use course design techniques such as a flipped classroom model to ensure students have adequate prior knowledge [20]. This may also address some trainees' suggestions to provide more class time for project work, team activities, and in-class presentations. We also found that the course was particularly helpful in improving team science skills, specifically for learning to engage with community stakeholders. For example, a majority of trainees shared in their course reflections that they will use what they learned in the courses to better consider the needs of community partners and stakeholders, and they also appreciated the exposure to other disciplines through the courses.

In our effort to recruit a diverse cohort of students, we were surprised that we did not recruit more trainees from underrepresented racial/ethnic minorities. Studies show that historically disadvantaged groups in STEM tend to desire participating in projects involving social impact [21], [22], [23]. The diversity of our cohort may have been a result of inadequate recruiting methods, which was mainly via word of mouth and emails between faculty participating in our university center, and resulted in a relatively small number of applicants. Recruitment for future cohorts has been updated to include a wider reach through various university centers and graduate programs, aided by targeted flyers and referrals from past participants, and has garnered a much larger pool of applicants. However, for the cohort described in this paper, we were pleased to recruit a large percentage of female students. Women tend to show a greater interest in solving societal issues [24], and real-world design problems may help draw women to participate [7]. It is also worth nothing that we recruited a high number of trainees with a disability, who are also considered an underrepresented group in higher education [25]. This is aligned with a recent study finding that student researchers with a disability are drawn to the intersection of academia and community-based research [26].

There are limitations with this study that must be considered when interpreting our findings. First, the cohort examined in this study had a small sample size (N = 19). However, this cohort was the third cohort in a multi-year training program that iteratively improves based on the feedback of each cohort evaluation. We only report the results of the most recent cohort because the training model changes each year and want to best account for the current implementation approach. We plan to execute this traineeship model over five cohorts, and anticipate that iterative improvements to the traineeship program each year will result in a very compelling traineeship model with strong potential to make an impact in graduate-level training (and which we plan to publish at that time). By the conclusion of the fifth cohort, we anticipate to have trained over 100 students using this approach. Second, our evaluations have not yet formally considered the feedback of the community partners on this program. Our anecdotal evidence suggests that these communities feel more respected and recognized by academia and are more willing to participate in community action programs. However, formal assessment of the community reactions to these design projects has not been conducted. This feedback would be a very strong factor to guide the design of traineeship model. Third, our analysis is based on self-reported measures of improvement, and we cannot yet account for more objective assessments of student progress and interdisciplinary convergence within the teams. This is largely limited by the diverse nature of the various design projects, where the progress is not easily quantified and tracked during the non-linear process of design thinking. However, this is mitigated by investigating the documentation and design narratives generated by the trainee teams at the end of their year. The changes in self-reported measures may also be limited by response shift bias, in which students entering the training program do not yet know how to evaluate themselves in convergent skills because they are not as aware of the concepts until after completing the training program. The student reflections are meant to mitigate this effect, in which students can reflect on how they have grown over the course of the year and qualitatively evaluate any self-improvement via retrospection.

In conclusion, we hope that future traineeship programs will use community-engaged design projects as their central mechanism for training diverse cohorts of students and fostering new opportunities for convergence research. We believe that the best solutions for major societal problems cannot be addressed by any one discipline, and the future workforce of STEM professionals must be equipped with the interdisciplinary knowledge and team skills to navigate these complex issues. This workforce must possess a comprehensive understanding of the interconnected systems at play and retain the ability to collaborate across diverse disciplines. By instilling research and design philosophies that transcend traditional boundaries, educational opportunities like our traineeship program play a pivotal role in equipping students with the skills required to address complex challenges, paving the way for a more holistic and effective approach to major societal issues.

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