Course-based Adaptations of an Ecological Belonging Intervention to Transform Engineering Representation at Scale

Abstract

This project uses an ecological belonging intervention approach [1] that requires one-class or one-recitation/discussion session to implement and has been shown to erase long-standing equity gaps in achievement in introductory STEM courses. However, given the wide social and cultural heterogeneity across US university contexts (e.g., differences in regional demographics, history, political climates), it is an open question if and how the intervention may scale. This project brings together an interdisciplinary team across three strategically selected universities to design, test, and iteratively improve an approach to systematically identify which first and second year courses would most benefit from the intervention, reveal student concerns that may be specific to that course, adapt the intervention to address those concerns, and evaluate the universality versus specificity of the intervention across university contexts. This systematic approach also includes persuasion and training processes for onboarding the instructors of the targeted courses. The instructor onboarding and the intervention adaptation processes are guided by a theory-of-action that is the backbone of the project's research activities and iterative process improvement. A synergistic mixture of qualitative and quantitative methods is used throughout the study.

In this paper, we describe our theoretical framing of this ecological belonging intervention and the current efforts of the project in developing customized student stories for the intervention. We have conducted focus groups across each of the partner institutions (University of Pittsburgh, Purdue University, and University of California Irvine). We describe the process of developing these contextually relevant stories and the lessons learned about how this ecological belonging intervention can be translated across institutional contexts and for various STEM majors and systemically minoritized populations. The results of this work can provide actionable strategies for reducing equity gaps in students' degree attainment and achievement in engineering.

Introduction

While the participation of women in science has increased overall, engineering remains heavily dominated by men. Men account for roughly 80% of engineering bachelors across the United States, and little overall progress in gender representation has been made the last 20 years [2]. Even more problematic from a gender- and racial-equity perspective is undergraduates' choice of major degree field. For example, several of the larger engineering majors (such as mechanical engineering) have had only between 11% and 15% of bachelor's degrees awarded to women [3]. Additionally, particular engineering majors (such as biomedical engineering) attract and retain more students at the intersections of systematically minoritized identities [4], which for engineering we define as Black, Latinx, and Indigenous (BLI) students as well as women, non-binary and third-gender students. Efforts are needed to broadly change the diversity of students pursuing and graduating from these engineering majors.

We believe a significant source of inequity in engineering is traceable to students' experiences within gateway courses during the first two college years. Within the common first-year curriculum, in physics, mathematics, and programming course sequences, we have found that

women engineers tend to have lower achievement than men, despite having similar or better prior preparation for STEM coursework [5,6]. Gender stereotypes among students, faculty, and TAs shape students' and instructors' experiences in these classes, leading women students to feel they do not belong, experience stereotype threat during class and exams, and negatively influence performance, which then further shape decisions about engineering majors [7]. Further, these first-course challenges are compounded with a concern about belonging when first attending college [8]. In the second year, the first-year challenges begin to snowball, as courses continue to increase in difficulty while the percentage of women in the courses decreases. Such changes can make women feel less attracted to the engineering domain [9] and exhibit lower expectations of themselves in the domain [10] by reinforcing masculine academic norms that often make women and people with non-binary and third-gender identifications feel marginalized [10, 11, 12].

Project Description

Our project, titled "Collaborative Research: Strategic Course-based Adaptations of an Ecological Belonging Intervention to Broaden Participation in Engineering at Scale" (NSF DUE 2111114/2111513), builds on prior social-belonging interventions [13, 14] by adapting the intervention to different science classroom contexts (first in introductory physics and biology courses at the University of Pittsburgh, and now directed specifically to engineering), and training instructors to deliver it as part of a social "ice-breaker" activity at the beginning of the term [1]. This study examines how the intervention can be translated to different institutional contexts, scaled for widespread impact, and how faculty engage in, influence, and are influenced by administering the intervention in their courses.

Participating Institutions

This project has three university partners: University of Pittsburgh (Pitt), Purdue University, and University of California, Irvine (UCI). We intentionally chose the partners of Purdue and UCI for scaling because each of these two institutions allow us to explore the effects of differences in race/ethnicity in the undergraduate student body, institutional size, and cultural norms.

All three universities are public and all three are research-intensive. Pitt has approximately 3,000 engineering undergraduates: 30% women, 8% combined BLI students. Women make up 15% of the engineering faculty, but they rarely teach first-year students. Purdue has almost 10,000 engineering undergraduates: 26% women, and 9% BLI students. Compared to Pitt, 60% of first-year engineering courses at Purdue are taught by women. UCI has approximately 4,000 engineering undergraduates: 24% women, and 25% BLI students. All institutions have low, but typical-for-the U.S. representation of women, but Pitt and Purdue are at or above the national average for enrollment in engineering of undergraduate women. UCI is noticeably different by race/ethnicity, being both a Hispanic-Serving (HSI) and Asian American and Native American Pacific Islander-Serving Institution (AANAPISI). Additionally, half of UCI's students are first-generation college students. Correspondingly, UCI engineering faculty are also more diverse, although not in gender diversity. The broader academic foci are significantly different across the three universities: UCI and Pitt are dominated by arts & sciences and health disciplines, and Purdue is dominated by STEM fields, and engineering in particular.

The Ecological Belonging Intervention (Base Form)

Here we describe the base form of the in-class intervention that has already proven to close demographic performance gaps [1]. As noted, the intervention was developed from prior social belonging interventions [13, 14], which taught students a mindset that adversity in college is both normal and surmountable. The ecological approach attempts to instill the same message, not just within individual students, but within the social ecology of the classroom. Namely, rather than being delivered in a lab setting as in prior work, the ecological-approach targets carefully selected populations—classrooms with specific, known demographic disparities in performance. The intervention is adapted to these classrooms via focus groups. Rather than being delivered by an experimenter, course instructors or TAs are trained to deliver the intervention and to engage their students in peer discussion around the intervention. These peers are not random strangers but rather classmates with whom they will work together over the term. The intervention is delivered early in the term, during the first or second week of classes.

The intervention begins by the facilitator (usually instructor or TA) telling the class that they will be shifting gears to discuss some of the students' ongoing college experiences. Facilitators describe some common issues that students frequently face. For first-year courses, this often involves adjusting to college, such as feeling homesick, wondering where they fit in, and figuring out how to structure their time. For second-year students, this often involves adjusting to the increasing demands of the major and deciding which major path to pursue. Students are then asked to work alone to complete a brief, anonymous writing exercise in which they describe a current struggle or challenge (e.g., adjusting to college, worries about a difficult course). To get students to view their circumstances as changeable and to shape the tenor of the upcoming classroom discussion, they are encouraged to consider how their challenge was resolved or how it may be resolved in the future.

During the second phase (normalizing struggle and growth), facilitators reinforce the focal message of the intervention: struggles are normal, college is not easy, but students are generally successful over time if they persevere through adversity. The facilitator then presents students with a series of stories attributed to upper-level students that convey this message. The stories are modeled on materials developed by Yeager and colleagues [15] but we have and continue to customize them for each target course following focus groups with prior students in that course (at that university). Below we present two context specific testimonials for a first-year engineering course that were developed so far labeled with pseudonyms:

> *If you don't know anything about coding—like me—you're probably feeling like you did something wrong. You didn't. The class is just tough sometimes. And that's okay! You're more than capable to get through this. Stack exchange is your friend. Don't be afraid to ask other groups for help, and never think you're not good enough. Have faith in yourself and your teammates. Learn to rely on yourself sometimes, but you gotta have a support system, both academically but more importantly emotionally. You got this! Signed, a fellow engineering idiot.*
>
> - Kara, Junior Biomedical Engineer

> *I literally failed the first exam. I spent so much time re-watching the videos and working through problems, and I still failed. I was like, why am I even here? I ended up reaching out to my instructor, and she gave me some great advice. She helped me think about the exams in terms of the learning objectives and using those to guide how I was studying. For the second exam I started studying earlier, but I focused on really understanding the important concepts and how they applied in each problem instead of breaking down each and every problem step for hours on end. And I got an A! Figuring out how to study and putting in the work really paid off, and I learned that I can do it. If I can, you can too.*
>
> - Amare, Senior Electrical Engineer

Going beyond prior belonging interventions, the next phase lets students practice and reinforce this new belonging and growth mindset through collaborative learning with their peers. In small groups of 3–5, students are given two discussion questions to answer. These questions are carefully designed to require students to attend to the knowledge generated in the conversation. One discussion question asks why so many students do not realize that other people are struggling. This way of asking the question forces students to accept the premise that others are regularly struggling in order to answer the question. Another question asks how being a senior might be different from being a (first/second) year student. To answer this question, students must similarly accept the premise that life as a senior will in fact be different. By answering the questions as a group, students get to hear and see their peers' perspectives and thereby know what their peers know. Although the intervention is only delivered in a single class session, the embedded nature of the intervention in the classroom at the beginning of the term means the core message can be reactivated in subsequent social interactions with those peers and continue to shape the meaning that students make of their experiences in that class.

To normalize the message even more broadly, the instructor (or recitation/discussion TA) ends the exercise by asking for volunteers to raise a hand to share with the whole class what they had discussed in their group. Students' voluntary comments typically reinforce the exercise's general message. For example, in an engineering class, a student reported that several people in her group had concerns about coding in MATLAB when they were also learning other programming languages in their other science courses. Students often are seen continuing to talk about their experiences as they leave the classroom, and the instructors regularly receive several spontaneous "thank you" messages from students who were grateful for the activity.

Research Questions

The first part of our research plan focuses on deeply understanding how the ecological belonging intervention for first-year courses translates to second-year courses, and from the Pitt course contexts to the Purdue and UCI course contexts. We pose three research questions:

RQ1 (the course contexts): How do students, with a focus on minoritized students (i.e., Black, Latinx, and Indigenous women and non-binary students), describe their lived experiences in courses that show demographic-based achievement differences?

RQ2 (the immediate effects on students): How does the ecological belonging intervention change students' feelings of belonging in the course, their disciplinary-based growth mindset, and perceptions of academic norms in the course, major, and engineering overall?

RQ3 (the broader effects on students): What effect does the intervention have on short- and long-term academic success as measured by achievement (course-specific, overall GPA) and choice (retention, engineering career pathways)?

The overarching research objective for this aspect of the grant is to understand the efficacy and mechanisms by which the course onboarding strategies involving leadership messaging and community learning processes are successful across course, departmental, and university contexts in transforming each targeted course. Without broad and sustainable adoption, no meaningful overall change will occur in the representation of minoritized students in the engineering pathways historically resistant to change. In addition, we examine whether implementing the intervention itself changes instructor beliefs: there is extensive research showing that attitudes tend to change after behaviors change [16, 17]. Changes in instructor beliefs have the potential for positively changing other courses they teach, clubs they advise, and students they mentor in capstone design; however, changing instructor beliefs remains a challenge. Even when instructors know about more effective teaching techniques, there are numerous barriers to implementation [17]. Our research questions are:

RQ4 (context effects on onboarding strategies): What are the key disciplinary and institutional factors that demand adaptation to the onboarding strategies?

RQ5 (impact of onboarding strategies on instructor beliefs): What are the effects of the onboarding strategies on instructor beliefs that are key to intervention implementation?

RQ6 (impact of instructor beliefs on intervention implementation): What are the instructor beliefs most critical to implementation (initial and sustaining implementation) of the intervention?

RQ7 (impact of implementation on instructors): What impact does implementing the intervention have on instructors' mindsets, attitudes, and practices?

Contextualizing Interventions

Our efforts to contextualize the interventions [RQ1**]** per course have involved: 1) using institutional data to identify specific first-year engineering courses at each university that have pervasive demographic disparities in course grades (before and during COVID-19); 2) conducting focus groups with past students in two of the identified classes (to date) to identify issues and to create customized intervention stories. The focus groups were contextualized to the context of the engineering course the students had completed. A common pattern in the institutional data that has emerged thus far is that race/ethnicity is a particularly common basis for 0.5 grade points or greater pervasive demographic disparities in engineering course grades at the three universities, rather than gender, first-generation status, or family low-income status. Further, the demographic disparities in course grades by race/ethnicity were not found in all engineering courses within a given engineering department, but rather appeared in a subset of courses, highlighting that the causes of performance differences were not attributable to the students and not only from the institutional environment.

With these quantitative considerations in mind, we designed a focus group protocol by adapting a series of discussion exercises and activities from previous focus groups to extract stories for the belonging interventions. These exercises include: 1) opening the focus group by having students talk about their challenges; 2) transitioning to an index card activity where students write good and bad things they have experienced in their context; 3) shifting the conversation from challenges to how students resolved some of the challenges they faced; 4) students completing a journey map of their experiences in their context and subsequently have them present to the group; 5) and finishing up by having the students engage in a reflective writing exercise where they write a postcard to a past self about a time they didn't belonging in the context and how they overcame that.

During this process, we witnessed how these focus groups can serve as a microcosm of what students experienced in the classroom context. Not only is this reflected in how students discuss the challenges, but we also see this in their body language and how they respond to each other. We have also seen that some students hold themselves from admitting that they faced challenges within the classroom context and/or discussing how they struggled. However, if a student in a group 'breaks the mold' and does discuss their personal struggles, this allows for other students in the group to express if they had similar experiences or open up about their own experiences. We saw this dynamic playout in several groups where students tend to follow the 'tone' set by the student who had participated early in the discussion. Thus, a challenge we have faced as facilitators is getting participants to feel that the space is safe enough so that they open up genuinely about their experiences within the course context. In successfully doing so, we are able to extract information to construct authentic stories that reflect the landscape of context and students' struggles and triumphs within that context to share with future students. Within the intervention, students are presented with stories that normalize struggle and challenges and that provide the psychological resolutions that previous students in the context have used to overcome those challenges. From a short anonymous survey, we have students fill out after these groups, we learned that these groups can act as a safe space for students to express their experiences, that students feel heard and valued during the session, and they feel that they benefited from their participation.

To date, we have conducted six focus groups, three at Purdue and three at UCI. The sociodemographic characteristics of these groups are listed in Table 1. Within the specific course contexts, we have studied to date, we identified a number of concerns related to classroom climate and belongingness. The contextualized stories that have been developed center around feeling overwhelmed and getting behind, learning to work in teams, being surrounded by peers who have previous experience in the context, staying motivated in dealing with content you dislike, overcoming identity-based performance stereotypes/myths, and dealing with early failure on exams.

Table 1.

Sociodemographic Characteristics of Participants in Focus Groups (n = 29)

Institution	Purdue	UCI
	n	*n*
Gender		
Man	8	6
Woman	4	11
Non-binary	0	0
Race/Ethnicity		
African American/Black	1	0
Arab, Middle Eastern or Persian	0	1
East Asian	3	7
Mexican American/Chicano or Mexican	1	1
Southeast Asian	2	5
White/Caucasian	5	3
Pell Grant Recipient	1	4
First Generation Student	0	1

Current and Future Work

The contextualization work we have completed thus far has allowed us to implement an intervention in our studied course contexts at Purdue and UCI. We will be conducting focus groups at Pitt during the Spring 2022 term and plan to launch our first intervention there during the 2022-23 academic year. We are also currently in the process of developing, testing, and revising surveys to test our theory of action about the immediate effects of our intervention (RQ2) and how those translate into longer-term impacts (RQ3). In the case of some of our theoretical constructs (e.g., inclusive classroom norms), no existing survey existed. For other theoretical constructs (e.g., disciplinary mindsets), some surveys existed, but had not yet been adapted to the engineering context. Quantitative validation work will make sure the scale items cohere as a scale, differentiate from other motivational constructs, and do not show biases/mismeasurement by race/ethnicity, gender, first-generation status, or low-income status. Once the scales have been validated, then structural equation modeling will test our theories of how the constructs relate to one another and to student midterm behaviors and outcomes, and how our interventions change student motivations and longer-term outcomes. RQs 2 and 3 will also be addressed through a comprehensive and longitudinal set of individual interviews with students. We aim to follow a cohort of students at

each institution across their undergraduate engineering experience. This approach will allow us to understand not only how various doses of the intervention relate to the student experience but also how they relate to career goals, aspirations, and early career starts. This work will investigate how and where students at the intersections of race/ethnicity and gender diverge in their experiences, identity development, and meaning-making. We plan to use interpretive phenomenological analysis [18] for our analysis. This method focuses on understanding "lived experience" from the participants' first- (i.e., descriptions of tangible events) and second-order (i.e. socio-emotional reactions) to lived experience. This extensive set of interview data will be leveraged fully with the quantitative data streams (described above) within a mixed-methods design using a concurrent partially mixed methods approach [19]. These data and our approach with them will provide a richer and more comprehensive understanding of the student experiences and the engineering culture than would have been possible otherwise [20].

Efforts related to RQs 4-7 focus on instructors and departments. Research on RQ4 involves analyzing the adaptations to the onboarding strategies, RQ5, RQ6, and RQ7 involve understanding instructor beliefs related to onboarding and implementation of the intervention. In the term following the initial deployment of the intervention in a course and at an institution, we will interview the department chair, the course champion, and one (additional) implementing instructor, using a cued-reflection protocol [21]. We seek to learn the details of the onboarding strategies as they were experienced by each role group and reasons for any adaptations to the base scripts. The analysis protocols will focus on identifying changes and then reasons for changes. We will produce analytic memos and then do member-checks with interviewees [22] to cross-validate our observations and conclusions. Because of the open-ended nature of the interview questions, there will be an opportunity to revise the theory of action to include other kinds of instructor beliefs beyond the ones highlighted in the current theory of action. These data will be collected for every course and will be systematically analyzed each summer to guide improvements to the base scripts/approaches that are being iteratively changed each year.

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