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Encouraging a supportive learning environment in chemical engineering education

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Introduction

The classroom and academic environment play an important role in undergraduate students' academic success and retention in engineering majors. Ineffective teaching and advising, curriculum difficulty, and lack of belonging (the feeling of being connected, accepted, and valued) can contribute to students' decisions to leave engineering majors [1,2]. Fostering supportive classrooms is an important step towards addressing these concerns. Supportive classrooms can not only enhance students' learning experiences but also increase their sense of belonging in classroom, which can be associated with self-efficacy, intrinsic motivation, as well as belonging in engineering major [3,4]. Self-efficacy is believing in one's ability to complete tasks or accomplish goals, and intrinsic motivation is the inherent stimulus to perform tasks or activities out of joy or interest rather than external pressures or rewards. Creating supportive classrooms would be highly beneficial for chemical engineering students due to the difficulty of the chemical engineering curriculum and the rigorous learning expectations, which could cause significant mental stress [5]. This would be particularly advantageous for marginalized students, for whom curriculum challenges might be combined with feelings of isolation due to their social identities [6]. Having a supportive learning environment could relieve a significant amount of mental stress for these students and promote their overall well-being, which would positively impact their academic experience.

As part of an IRB-approved study to assess the sense of belonging in major for the students in the Chemical and Biomolecular Engineering (ChemBE) program of our institution, we implemented some interventions in an elective "Cell Biology for Engineers" course. The primary objective of the course is to understand the structures and functions of cells. The course also discusses dysfunctions in different parts of the cells and their relations to various diseases (e.g., cancer, neurological disorders, etc.), and the basics of tissue engineering. It is generally taken by undergraduate ChemBE students of different levels (e.g., sophomores, juniors, and seniors) who are interested in future careers related to biotechnology or medicine. The interventions that we applied in the classroom were inspired by various theoretical frameworks. A qualitative analysis of students' reflections about the course, obtained from the course offered in two Spring semesters in 2023 and 2024, helped us to identify the factors that positively influenced students' learning experiences and mostly answered our primary research question: "Did the classroom interventions impact students' feelings about their major?"

We mentioned the research question was answered mostly because not all the participants mentioned the impact of the course on their feelings about the major directly in their responses. The students primarily focused on their experiences in the course in the qualitative responses. During the next iteration of the course, we would be interested in finding the impact of the course

on students' belonging in classroom and the correlation between belonging in classroom and belonging in major through quantitative analysis.

Background

Theoretical frameworks

Our interventions for creating a supportive classroom were inspired by three theoretical frameworks: Culturally Responsive Teaching (CRT) [7,8], Universal Design for Learning (UDL) [9,10], and Self-Determination Theory (SDT) [11-13]. While both CRT and UDL highlight inclusive and student-centered instruction, SDT emphasizes the importance of intrinsic motivation, which could be enhanced by effective and supportive instruction. We included a summary of the frameworks below.

CRT is respectful of different cultures and aims to create a common culture that all students can accept. This educational approach has four key aspects: establishing inclusion, developing attitude, enhancing meaning, and engendering competence [7,8]. The first aspect focuses on creating a learning environment in which both students and teachers feel respected and connected to each other. The second aspect emphasizes creating a favorable disposition or positive outlook of the students toward learning through personal relevance and choice. The third aspect highlights promoting thoughtful and meaningful learning experiences that consider student perspectives and values. Finally, the last aspect focuses on building opportunities so that students can effectively demonstrate their understanding of the learning they value.

UDL helps to design classrooms that accommodate diverse learners and remove barriers to learning [9,10]. It has three basic principles: Representation, Expression, and Engagement [9]. The first principle is multiple ways of representing knowledge or instructional materials (e.g., text, visuals, audio, interactive demonstrations, etc.) to make the content accessible to the greatest number of learners. The second principle is multiple ways of demonstrating students' understanding (e.g., multiple assignment formats, projects, written reports, presentations, etc.) as no single option works for all students. The final principle is multiple ways of engaging students. Within the UDL framework, student engagement is generally a result of using the first two principles to improve the learning process [10].

SDT considers autonomy, competence, and relatedness as the fundamental psychological needs that are necessary for developing intrinsic motivation [11-13]. Autonomy is the feeling of being in control of one's behaviors and actions. Competence aligns with self-efficacy and relatedness aligns with belonging. Educators can fulfill these psychological needs of the students by minimizing evaluative pressure and including student voice and choice in academic activities, incorporating optimally challenging activities and providing necessary tools and feedback to facilitate students' academic capabilities, and encouraging a sense of belonging in classroom [13]. In classrooms that

include all these elements, the students tend to be more intrinsically motivated and demonstrate higher-quality learning outcomes as well as enhanced wellness [13].

Project context

We aimed to create an inclusive classroom environment based on mutual respect and learning. We highlighted real-world applications of the concepts to help students develop a positive attitude toward learning and understand the relevance of the coursework. To promote cooperative learning [14], we included meaningful group projects that would help students to find meaning in learning. We utilized active learning strategies like retrieval practice and two-minute pause strategy to facilitate reflection and retention of the content [15,16]. Getting some time to process information during lectures and reviewing content regularly by recalling information from memory can help students feel more prepared and competent.

We provided recorded lectures and course notes to the students to accommodate the learning pace of different students. The recorded lectures also offered flexibility for those students who might miss in-person lectures for health reasons or other circumstances. The students also had the opportunity to attend lectures online if they were feeling unwell or traveling. Through active learning strategies, group discussions, and meaningful group projects, we promoted various means of expression and engagement. The exams were part of the course, but they were not the only way of assessing learning. As all students might not feel comfortable speaking up during the class, due to being an introvert, being afraid to be wrong, or coming from a culture where assertiveness is not the norm, we used online polling and online discussion boards to engage all students. The group projects had oral and written components, which allowed the students to demonstrate their verbal and technical writing skills, which are often not demonstrated in traditional exams.

We emphasized developing connections that can facilitate belonging. We focused on building connections between students and four other factors: the professor, the course content, the peers, and the ChemBE major. Connection between students and the professor can be fostered through the professor's display of care and support [17]. Understanding the relevance of the coursework through real-world applications can promote connections with the course content and the major. Participating in cooperative learning can provide opportunities to interact with peers and facilitate peer connections.

Supportive Classroom in Cell Biology for Engineers

During the course introduction, the professor introduced herself by sharing her preferred pronouns and hobbies and encouraged the students to introduce themselves on a Canvas discussion post, if they felt comfortable. The professor also encouraged the students to respond to other students' posts to welcome them to the course. While discussing the expected classroom

environment, the professor emphasized the importance of mutual respect and learning. A portion from the syllabus, adapted from teaching policies and guidelines of our engineering school regarding the classroom environment, is included below:

I am committed to creating an inclusive classroom environment, which values mutual respect and learning. Everyone here has the right to be treated with dignity and respect. You are encouraged to interact with peers from different backgrounds as it facilitates understanding of different perspectives as well as obtaining tangible learning outcomes. The classroom is also a place for mutual learning. You should feel free to share new knowledge and understanding about the course concepts with me, the TAs, and your peers.

The professor additionally explained the course accommodations available for the students in case of any health concerns, disability, emergencies, or other commitments. The professor also provided information about various student communities in the university to encourage the students to find their own community.

The professor recorded the in-person lectures so that the students could review the materials again after the class or catch up on the content in case of missed lectures. During each lecture, the students responded to questions from previous and ongoing lecture contents on iClicker. To allow students sufficient time to absorb the lecture materials and think about the content, the professor paused twice during the lectures. Multiple real-life applications were included in the lectures for specific concepts. Additionally, the connections between chemical engineering principles and cell biology concepts were highlighted. For instance, during the lecture on nuclear transport of proteins, an example of COVID-19 infection was included as it can negatively impact nuclear transport [18]. While discussing the passive transport of molecules through the cell membrane, a discussion of steady-state mass transport was included, which is a fundamental chemical engineering principle.

The professor took the initiative to show care and support for the students. The professor encouraged the students to attend office hours regularly to build connections with students. Through anonymous feedback surveys throughout the semester, the professor checked on the learning progress of the students as well as their overall well-being. The professor occasionally shared stories of experiencing failures and overcoming setbacks from her academic journey to promote growth mindsets in students.

Students participated in cooperative learning in the form of weekly online group discussions and group debates. While through group discussions the students could test each other's understanding of the course content, through the group debate the students could develop awareness regarding their social and ethical responsibilities as engineers. Through the debates, the students learned to consider the pros and cons of controversial topics like gene editing, human-animal chimera, brain organoids, and so on, and got the opportunity to learn how to be respectful to those with different perspectives. Before beginning the group activities, the students submitted a teamwork contract. The students read online articles and watched a YouTube video on effective

teamwork before filling out the contract, where they discussed their individual roles in the team, preferred methods of communication, strategies to ensure the team's progress and a safe team environment, and steps for mitigating any possible conflict. The students participated in peer evaluation through two teamwork surveys during the semester, evaluating themselves and their team members individually. The first survey was not graded and included the option of intervention from the instructor to facilitate teamwork or mitigate any conflicts if required. The students were encouraged to share their feedback with each other so that everyone could get the opportunity to reflect on the team's performance and individual accountability. The second teamwork survey was submitted at the end of the semester, and it was graded.

Methods

Researcher Positionality

The first author (She/her) is a teaching-focused faculty in chemical engineering in the United States who navigated her undergraduate and graduate studies in North American Universities as a woman of color. Her motivation to create a supportive learning environment for her students originated from her own feelings of isolation as a student. The second author (she/her/ze/zir) is a gender-expansive woman of color, a first-generation college graduate, and the first in her working-class immigrant family to attend school in the United States. She has interdisciplinary training in Biology, Ethnic Studies, and Education. Zir passion for cultivating inclusion and belongingness in higher education stems from positive and adverse experiences navigating STEM classrooms and research labs. The third author (She/her), a first-generation college student, is currently a graduate student in school counseling. She is interested in promoting students' belongingness and mental well-being as a future counselor in training.

Site

We conducted this study at our institution, which is a private R1 university with high research activity in an urban metropolitan area in the Mid-Atlantic region of the United States.

Participants

We categorized the undergraduate participants in terms of academic level (at the time of the course enrollment), gender, racial/ethnic background, and first-generation status. Based on the students' responses, the Black/African American, African, Hispanic/Latino, and mixed-race (e.g., White and Hispanic/Latino) students were considered under "Black, Latine, and Multi-racial" group. We assigned the non-Hispanic White and non-Hispanic Asian students to the "White and Asian" group. The non-first-generation students had at least one parent completing a college education, a bachelor's degree, or any postgraduate degree (Master's/Ph.D.).

Out of the 20 participants, 6 students were sophomores, 13 students were juniors, and 1 was a senior student. In terms of demographic background, the distribution was as follows: 40% women

(N=8), 60% men (N=12), 50% Black, Latine, and Multi-racial (N=10), 50% White and Asian (N=10), 15% first-generation (N=3), and 85% non-first-generation (N=17).

Survey

The undergraduate students enrolled in the Cell Biology for Engineers course were invited to participate in an online survey at the end of the semester during the Spring 2023 and Spring 2024 offerings of the course. We initially aimed to use a mixed-methods approach for our research [19]. Thus, the online survey contained both quantitative and qualitative portions. For the quantitative part, we used a previously validated 4-item belonging in major scale, focused on feelings related to acceptance, comfort, support, and being part of the major [20,21]. The qualitative portion of the survey involved an open-ended question, enquiring about the effect of the course on students' feelings about their major.

The quantitative part of our survey evolved over time. In the first semester, we used a 6-point Likert scale to avoid neutral bias in student responses. In the following semester, we switched to a 5-point Likert scale to ensure the use of a verified belonging scale [20,21]. Through our analysis in a separate part of our research project, which considered belonging in major for students who were not enrolled in the course, we learned some important things. We realized that belonging in major is a broad domain. It is impacted by multiple factors and classroom experience is one of the factors. Therefore, using the belonging in major scale to evaluate the efficacy of the classroom interventions would not be effective. A better approach would be to assess the belonging in classroom along with the belonging in major and analyze their correlations. This would help us to understand how strongly belonging in classroom is associated with belonging in major. We hope to accomplish this in the next iteration of this class. Since the qualitative responses were more useful for understanding the impact of the interventions implemented in the course, we chose to report the results from the qualitative analysis in this paper.

Analysis

A total of 20 undergraduate students (combined from both semesters) voluntarily responded to the qualitative portion of the survey. While some students explicitly mentioned the impact of the course on their feelings about the major, the majority included information about their experiences in the course. The second author anonymized the responses before sharing the data with the first author (the professor of the course) and the third author by following the IRB protocol. All authors individually read all the responses and assigned codes (words or phrases that capture essence or meaning) [22] to specific excerpts of the qualitative data using an inductive approach [23], in which no prior assumptions were made, and the interpretations were derived directly from the data. Two rounds of qualitative coding were performed using in vivo and descriptive coding; a codebook was created to organize assigned codes and descriptions [22]. In the first round of coding, codes were generated by analyzing qualitative data line-by-line. At the end of this round, authors 1, 2, and 3 assigned 49, 51, and 53 codes respectively—with some codes being similar to each other. Inter-rater reliability was 100%, which we calculated by comparing the overlap of codes between

three authors for approximately 25% (or five) of the samples, which were randomly selected. Each of the five data points had a 100% overlap of codes between the three authors.

After the first round of coding, the second author, who performed the analysis using qualitative data analysis software NVivo, conducted a second round of coding in which thematically similar codes were collapsed into three primary categories [22]. In this second round of coding, three overarching themes emerged: intentional curricular design (codes that related specifically to pedagogy and curriculum design, such as curriculum that promotes big picture thinking, interdisciplinary approaches, and sound structure and organization of lessons); positive affect (codes that related to student perceptions and affective domains of learning, such as associated feelings from being in the course: enjoying learning, acquiring beneficial effects, and feeling comfortable and accepted); and beloved professor (codes that specifically mention the professor). The second author then discussed these emergent themes with the first author. Finally, both authors agreed on these final themes to develop an overall interpretation: (1) professor's caring qualities and inclusive teaching practices, (2) course structure and content, and (3) positive learning environment. We included specific student responses while describing each theme in the results and discussion. We pseudonymized the names of the respondents to protect their anonymity.

Results and Discussion

The primary themes that emerged from the qualitative data analysis were (1) professor's caring qualities and inclusive teaching practices, (2) course structure and content, and (3) positive learning environment. Supportive and effective teaching along with a well-structured course positively impacted students' learning experiences, peer interactions, and feelings about the major. The observation aligned well with the study by Freeman and colleagues, which determined that students' sense of belonging in classroom was enhanced by encouraging, warm, and organized instructors as well as the implementation of well-designed instruction [3]. We used some responses from selected students (details in Table 1) while describing the themes.

Table 1: Demographic information of students whose responses are included in the results.

Pseudonym	Academic level	Gender	Racial/ethnic background	First-generation background
Allen	Sophomore	Man	Asian	Non-first-generation
Stephanie	Senior	Woman	Multi-racial	Non-first-generation
Liam	Junior	Man	Asian	Non-first-generation
Aidan	Junior	Man	White	Non-first-generation
Paulo	Sophomore	Man	Multi-racial	Non-first-generation
Dave	Junior	Man	Latine	First-generation
Lena	Junior	Woman	Multi-racial	Non-first-generation
Alicia	Junior	Woman	White	Non-first-generation
Megan	Junior	Woman	Multi-racial	Non-first-generation
Anika	Junior	Woman	Black	First-generation

Theme I. Professor's caring qualities and inclusive teaching practices

Most of the students emphasized the professor's qualities and teaching practices that comforted students.

Allen highlighted that "*[his] professor was very accepting and understanding. This made [him] feel more comfortable within the class and allowed [him] to be more open with [his] opinions and thoughts*." Meanwhile, Stephanie mentioned:

"The professor is very understanding and willing to provide help when needed, as well as provides encouragement to the students, while still checking in with them and seeing how they are doing."

Additionally, Liam appreciated that the "*[professor] emphasizes having her students feel welcome and accepted. Since this is such a big part of her class, it has affected how [he feels] about the major*."

The professor's supportive nature made the students feel comfortable not just with how they were learning but also with how they were feeling about their major.

Theme II. Course structure and content

The intentional design of the course along with the incorporation of connections between chemical engineering principles and cell biology concepts helped students learn the content better. Aidan focused on the real-life implications of the course content:

"*The course has helped me to learn the ways that ChemBE principles can be easily applied to many other systems*."

Paulo emphasized that "*the class has enabled [him] to take a very rigorous content-dense course in a less stressful environment, allowing [him] to enjoy it for what it has to offer*."

Dave appreciated that "*[the professor] made the curriculum easy to understand and study and gave [him] more understanding of the bigger picture: allowing [him] to get knowledge about stuff [he] usually wouldn't study.*"

Making the class more structured and less stressful and the content more applied made the learning more relevant and enjoyable for the students.

Theme III. Positive learning environment

Multiple students commented on their positive experiences in the course. Lena highlighted that "*the course allows [her] to get to know [her] ChemBE peers more and makes [her] feel more*

accepted and comfortable with the people [she sees]in class everyday. Also, [she] got to work with new people which was a good way to get out of [her] comfort zone."

Alicia mentioned that "*[she has] loved this course. It has made [her] feel so much more comfortable and accepted*."

Both Megan and Anika specified the impact of the course on their feelings about the major. Megan mentioned that "*[she] really enjoyed this class and it makes [her] feel more secure in [her] choice to be a ChemBE."* Anika emphasized that *"Cell biology for engineers has had a positive impact on how [she views] chemical engineering."*

Students appreciated the opportunities for peer interactions within and outside their regular cohort and experienced more positive feelings toward their major.

Conclusions

The goal of the study was to assess the effectiveness of the interventions applied in an elective course "Cell Biology for Engineers", offered in the Chemical and Biomolecular Engineering (ChemBE) program of a large R1 University, for promoting a supportive learning environment. The interventions were based on three theoretical frameworks: Culturally Responsive Teaching (CRT), Universal Design for Learning (UDL), and Self-Determination Theory (SDT). We collected qualitative responses from 20 students over two semesters of the course, which aided in analyzing the effectiveness of the classroom interventions. Through thematic analysis, the positive influences of supportive and effective teaching and a well-structured course were determined. In the future offering of the course, we aim to utilize quantitative analysis to determine the effect of the interventions on students' sense of belonging in classroom and find the correlation between belonging in classroom and belonging in major.

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