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INNOVATION ARTICLE

The IT-BME Project: Integrating Inclusive Teaching in Biomedical Engineering Through Faculty/Graduate Partnerships

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Abstract

To broaden efforts for improving diversity, equity, and inclusion (DEI) in biomedical engineering (BME) education—a key area of emphasis is the integration of inclusive teaching practices. While BME faculty generally support these efforts, translating support into action remains challenging. This project aimed to address this need through a 3-phase inclusive teaching training, consisting of graduate students, faculty, and engineering education consultants. In Phase I, graduate students and faculty participated in a 6-week learning community on inclusive teaching (*Foundational Learning*). In Phase II, graduate students were paired with faculty to modify or develop new inclusive teaching materials to be integrated into a BME course (*Experiential Learning*). Phase III was the implementation of these materials. To assess Phases I & II, graduate student participants reflected on their experiences on the project. To assess Phase III, surveys were administered to students in IT-BME-affiliated courses as well as those taking other BME-related courses. Phases I & II: graduate students responded positively to the opportunity to engage in this inclusive teaching experiential learning opportunity. Phase III: survey results indicated that the incorporation of inclusive teaching practices in BME courses enhanced the student learning experience. The IT-BME project supported graduate students and faculty in learning about, creating, and implementing inclusive teaching practices in a collaborative and supportive environment. This project will serve to both train the next class of instructors and use their study of inclusive teaching concepts to facilitate the creation of ideas and materials that will benefit the BME curriculum and students.

Keywords Experiential learning · Inclusive teaching · Learning community

Introduction

Biomedical engineering education (BME), like engineering education broadly, aims to impart key knowledge and *know-how* for subject matter often thought of as rigorous and quantitative. While the calculative approaches we impart to engineers remain key elements of our classroom learning objectives, the broader societal impacts of engineering reverberate across scales—from the learning community we establish, to the patients for whom we develop technologies for. Acknowledging the significance of these broader impacts, the goal of inclusive teaching in biomedical engineering is to improve classroom pedagogy by adopting approaches that acknowledge student identity (background, learning preferences, and abilities) and patient identity (gender, genetics, ethnicity) as key elements of equitable engineering. In so doing, inclusive teaching aims to establish a sense of buy-in and community (inclusion), understand students' varied backgrounds, remove potential roadblocks to success (equity), and highlight the lenses through which biomedical engineering impacts can be understood (diversity). Inclusive teaching can create learning environments that positively impact student learning [1–4]. Establishing these inclusive practices is critical for promoting student success both in their course learning and in their eventual practice as engineers.

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While inclusive teaching practices hold the potential to improve education in biomedical engineering, barriers to adoption and implementation persist. While training materials, literature, and courses [5] are available, many are opt-in, requiring faculty to electively engage. This is particularly challenging in engineering, where pressures on faculty time can often divert attention from learning new pedagogy toward other endeavors. This is particularly pertinent for seasoned faculty, for whom, adopting these practices would necessitate a substantive change in instructional style. Compounding these issues is the *myth* or perception of engineering as apolitical or agnostic to social issues deemphasizing inclusive teaching pedagogy [6, 7]. These perceptions underscore a deeper misconception about inclusive teaching, highlighting the need for greater dissemination of principles and clear examples of changing practices that can serve as exemplars for instructors.

To address these challenges, in this paper, we outline the Inclusive Teaching in BME (IT-BME) project, started at the University of Michigan. The IT-BME project aims to integrate inclusive teaching training and practices into the BME curriculum through a partnership between engineering education teaching consultants, BME faculty, and graduate students. Through IT-BME, faculty, and graduate students underwent training through the NSF-funded Inclusive STEM Teaching massive open online course (MOOC) and collaborative learning communities. After training, faculty and students worked in joint mentor/mentee teams to revise BME courses to address key gaps in inclusivity, equity, and diversity. These collaborative teams served to lower the energy barrier for faculty to make substantive revisions in their courses while simultaneously providing graduate students with valuable pedagogical training and mentorship. These individualized experiential learning opportunities enabled the IT-BME project to impart the concepts of inclusive teaching to the next generation of biomedical engineering educators and build examples that can serve to further engagement.

In this paper, we review the literature behind inclusive teaching practices in engineering education as well as experiential learning practices—a key element of IT-BME (Literature). We then outline the structure of the IT-BME project, it's implementation, and metrics used to evaluate efficacy and success (Implementation). Results from graduate student reflections are highlighted and sense of belonging surveys are compared across biomedical engineering curricula. Finally, we finish by discussing the key implications of the project and its relevance for advancing engineering education in biomedical engineering (Findings).

Literature

This literature review focuses on two bodies of literature namely inclusive teaching and experiential learning. In what follows, we define these terms and highlight how this literature informs the design of our project. Specifically, in this project, participants engaged in an experiential learning opportunity to apply inclusive teaching practices in BME courses.

Inclusive Teaching

Teaching in a manner that supports all students' ability to learn most effectively is important to the mission of higher education. When considering the best ways to teach inclusively, there is no one definition that describes this form of pedagogy. Hogan and Sathy [8] define inclusion as "a culture in which all learners feel welcome, valued, and safe, and it requires intentional and deliberate strategies." Hockings [9] describes inclusive teaching and learning as "the ways in which pedagogy, curricula, and assessment are designed and delivered to engage students in learning that is meaningful, relevant and accessible to all. It embraces a view of the individual and individual difference as the source of diversity that can enrich the lives and learning of others." The Inclusive STEM Teaching Project focuses on the background, experiences and responsibilities of the instructor to implement inclusive practices with their definition, which states that inclusive teaching is "an approach in which instructors reflect critically on all aspects of their courses, rethinking their curricular choices, their teaching methods, activities and assessments as well as the intersections of their own identities and those of their students. Additionally, inclusive teaching approaches can guide instructors to reflect on how power, privilege and positionality play out in different learning environments" [10]. Further, the Center for Research on Learning and Teaching at the University of Michigan, the oldest teaching center in the U.S., infuses an equity-lens in their definition which states that "Inclusive teaching involves deliberately cultivating a learning environment where all students are treated equitably, have equal access to learning, and feel valued and supported in their learning [11]. Such teaching attends to social identities and seeks to change the ways systemic inequities shape dynamics in teaching-learning spaces, affect individuals' experiences of those spaces, and influence course and curriculum design." In all, these definitions describe inclusive teaching not just in terms of the intentional practices that instructors must engage in to cultivate a welcoming environment (e.g., course design, assessment, & and pedagogy), but they also consider

students' experiences and perspectives within that learning environment. Inclusive teaching requires a mindset shift and a commitment to lifelong learning to continually question and refine an instructor's practices.

Preparing instructors to teach inclusively has the potential to create a learning environment that supports students' sense of belonging and impacts their learning outcomes. In terms of classroom climate, Lovett et al. [3] provide a detailed literature review describing the ways that course climate impacts students' sense of belonging and how climate is shaped by the instructor's tone and social presence. Several studies connect student's sense of social belonging with student persistence and learning [1–4]. For instance, Walton and Cohen's [4] intervention helped African American students understand that struggle is a critical part of the learning process, rather than a sign of student deficiency that would indicate that they didn't belong in the field. Ultimately, their intervention led to an increased grade point average relative to multiple control groups and reduced the achievement gap by half. When instructors become aware of evidence-based practices, they can more readily support all students.

Research has shown that while workshops may raise awareness, it may not necessarily lead to consistent change in practices [12]. For instance, as a part of an engineering orientation, student instructors examined classroom scenarios and learned about inclusive teaching practices; however, they still wanted "more time and focus dedicated to practicing their [inclusive] teaching strategies and receiving feedback" [13]. Learning communities are designed to empower instructors to institute best practices through reflection, peer discussion, and applications [12, 14–16]. For this project, graduate students and faculty participated in The Inclusive STEM Teaching Project, an NSF-funded initiative, which aims to advance the awareness, self-efficacy, and ability of STEM instructors to cultivate inclusive learning environments for all their students [17]. Grounded in educational literature, this course centers the impact of power, privilege, identity, and positionality within the STEM teaching and learning environment. The content of this online course incorporates embodied case studies and vignettes, reflection, and discussion questions around topics of equity and inclusion in a multitude of STEM learning environments. It consisted of 6-modules and participants were expected to take one module each week, over the course of 6 weeks. Participants were able to engage in synchronous learning communities to delve deeper into the module content and explore applications to their teaching context.

Experiential Learning

Experiential learning is a process of learning that occurs through action and has become an important component of engineering education [18–21]. It is considered to contribute to student learning in a meaningful and long-lasting way, due to the emphasis on hands-on learning [22, 23]. Experiential learning aligns with other works that promote active learning, shifting from learning through traditional lecture-style mechanisms to learning by doing and engaging in thoughtful and meaningful experiences [23–26]. In engineering education, experiential learning can help students develop and enhance their problem-solving skills, gain practical experience, build relationships, and understand stakeholder needs [27]. In higher education, experiential learning opportunities can include engaging in community service, service-learning, research, internships, student teaching, and capstone projects.

The concept of experiential learning in higher education is often attributed to David Kolb [20, 22, 23, 28]. Kolb defines experiential learning as a 4-stage process. This process, known as Kolb's Experiential Learning Cycle, consists of (1) concrete experience, (2) reflective observation, (3) abstract conceptualization, and (4) active experimentation, taking place in a continuous learning loop [23]. In the concrete experience stage, the learner practices the application of prior knowledge by engaging in a new task, activity, or experience. This is followed by the reflective observation stage, where the learner reflects on that new task, activity, or experience by discussing and analyzing it. This stage allows learners to identify any discrepancies between their understanding of prior knowledge and the experiences themselves. The third stage of this cycle, abstract conceptualization, involves making sense of and drawing conclusions about the experience through reflecting on existing knowledge, ideas, and concepts, and engaging in discussions with peers. Finally, in the fourth stage, active experimentation, the learner applies their learning in new or similar settings.

In biomedical engineering education, experiential learning traditionally takes the form of research and laboratory experiments, design courses, industry-sponsored design projects, clinical settings, or internships to name a few [21, 26, 29, 30]. Although the literature focuses heavily on the benefits of experiential learning for undergraduate student learners, recent work also highlights the importance of it in graduate student training [31]. In this project, IT-BME participants, engaged with experiential learning through an internship-like opportunity in inclusive teaching course design. Biomedical engineering graduate students interested in teaching careers, worked collaboratively with a faculty member to modify, revise, or design elements of a BME course (e.g. syllabus, assignments, content), applying inclusive teaching strategies they learned in the Inclusive STEM Teaching MOOC (*refer to* section "Inclusive Teaching"). In addition to the known benefits of experiential learning, faculty-graduate student collaborations have also been shown to enhance graduate student training in course design and

instructional practices [32], further enriching this learning experience for IT-BME graduate students.

Implications for Program Design

In this paper, we present the design and outcomes of this year-long project in which BME graduate students, alongside a faculty partner, engaged in an experiential learning experience, applying inclusive teaching strategies in BME courses. First, BME faculty and graduate students participated in a 6-week online course and a learning community, facilitated by Engineering Education Teaching consultants (EET) consultants, to gain foundational knowledge of inclusive teaching, understand how it improves teaching and learning outcomes, and learn different strategies for incorporating it into a course. To get hands-on experience with the application of inclusive teaching practices, graduate students were partnered with a faculty member. Together, each faculty-graduate student team identified course elements that they wanted to modify (or create new) to be more inclusive, and each graduate student worked on making those changes. To support the various aspects of the experiential learning process, in particular, the reflective observation and abstract conceptualization phases, graduate students had scheduled regular meetings with their faculty members (individually), and with each other (as a group) to ideate inclusive teaching strategies, discuss progress, challenges, and brainstorm solutions. We defined three learning objectives for this IT-BME project (Table 1).

1. To train faculty and graduate student instructors in best practices for inclusive teaching in STEM.
2. To engage in hands-on training that applies inclusive teaching best practices for BME course design.
3. To foster an inclusive learning environment in undergraduate BME courses.

Implementation

Overview of the Project

The IT-BME project consisted of a team of BME graduate students ($n=5$), BME faculty members ($n=7$), and engineering education teaching consultants ($n=2$). Graduate students were all candidates and ranged from 3rd to 5th years. Faculty members engaged in the project were teaching lecturers (with 1–3 years experience) and tenure-track faculty (assistant to full professor). Consultants involved in the project both held PhDs in Engineering or STEM education fields and work in the Center for Research on Learning and Teaching in Engineering (CRLT-Engin) and are part of the Inclusive STEM Teaching MOOC.

This year-long project was comprised of three major phases focused on *foundational learning*, *experiential learning*, and *implementation* (Fig. 1). In Phase I (*foundational learning*), the graduate students and faculty participants took part in joint training using the Inclusive STEM Teaching MOOC and an accompanied inclusive teaching learning community. In Phase II (*experiential learning*), graduate students were paired with faculty members to work on specific courses in the biomedical engineering curriculum. To support the pairing of faculty-graduate teams, at the conclusion of the learning community, faculty were asked to give a short presentation on their desired goals for the project and indicate the type of support they would need from graduate students. During these presentations, graduate students asked questions of the faculty members on their proposed projects and were given a form to complete ranking their faculty project preferences. In the *implementation phase* (Phase III), the faculty delivered the revised/newly created materials in their IT-BME course. The inclusive teaching strategies were implemented across 6 IT-BME courses—ranging from sophomore level to graduate level.

While Phase I and Phase II of the project included 7 IT-BME courses, in Phase III, one faculty member chose to integrate developed inclusive teaching strategies into two of their courses. Additionally, another faculty member who participated in the first two sessions did not offer their course the subsequent year. Therefore, seven courses were included in this study (refer to Table 2). All 7 IT-BME

Table 1 Learning objectives (LO) of the IT-BME project with associated activities.

Relevant *student learning or professional development objectives* in a BME classroom, course, curriculum, or extracurricular activity	Activity/events/item associated with LO
• To train faculty and graduate student instructors in best practices for inclusive teaching in STEM	Phase I—foundational learning (MOOC & learning community)
• To engage in hands-on training that applies inclusive teaching best practices for BME course design	Phase II—experiential learning
• To foster an inclusive learning environment in undergraduate BME courses	Phase III—implementation

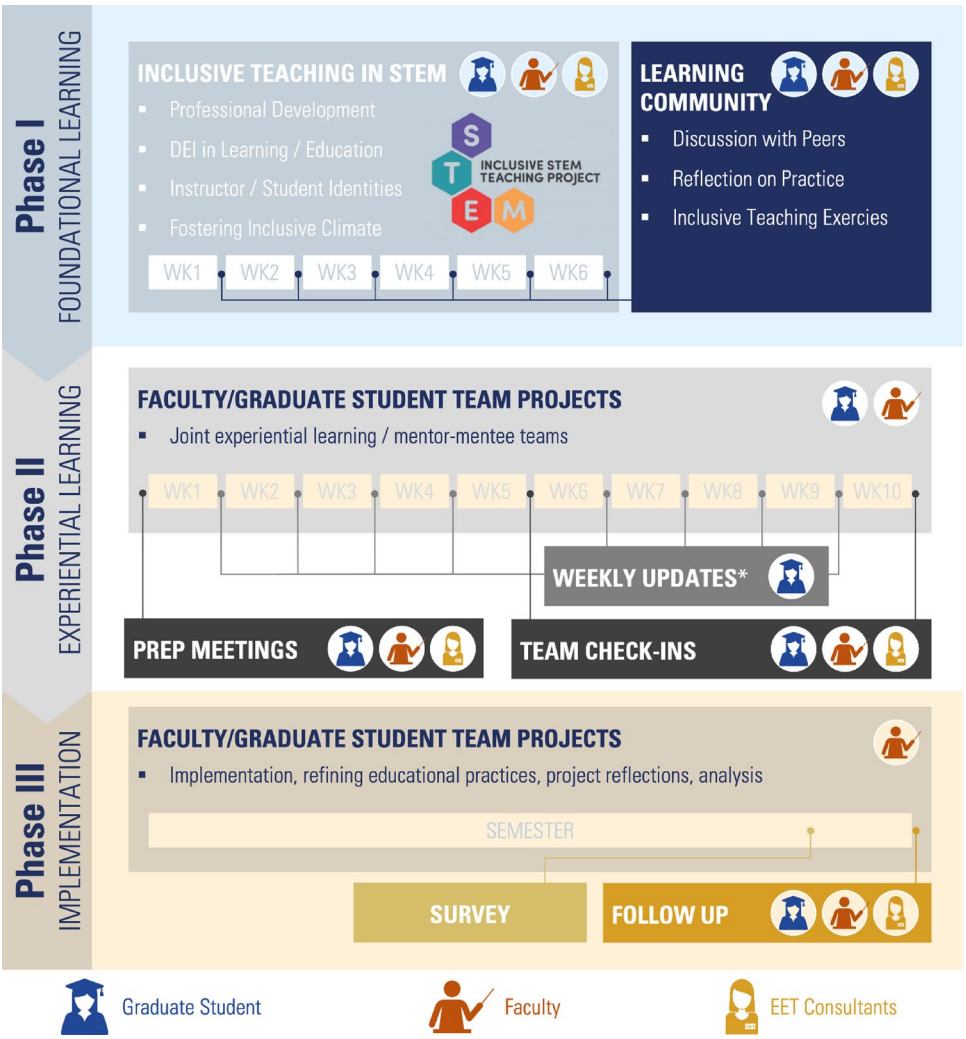

Fig. 1 Overview of the IT-BME project timeline split into three sequential phases. (Phase I) Joint training through the Inclusive STEM Teaching MOOC and dedicated learning community. (Phase II) Experiential learning through adaptation of current curriculum to integrate inclusive teaching practices. (Phase III) Implementation in undergraduate and graduate courses and follow-up evaluation

Table 2 Overview of the content covered in the 6-week MOOC and learning community (Phase I)

Module	Module and learning community content
Week 1: course overview	Orientation to the course content, community, and expectations
Week 2: DEI in higher education	Understanding of DEI concepts and vocabulary and engaging in conversations on hesitations and concerns for promoting inclusive teaching
Week 3: instructor identity	Understanding of how instructor identity, power and experience influence their approach to teaching and their expectations of students
Week 4: student identity	Understanding how students' learning experiences can be informed by their identity and lived experiences
Week 5: course design	Incorporating diversity, equity, and inclusion in the development of STEM courses
Week 6: climate in the STEM classroom	Identifying the impact of, and the roles instructors play in creating an inclusive and welcome classroom climate on student learning

courses were for undergraduate or masters-level students. Three of the courses were Design-based, three were Lecture-based, and one was Lab-based.

Phase I: Foundational Learning

Phase I of this project is directly related to Learning Objective 1: *To train faculty and graduate student instructors in*

best practices for inclusive teaching in STEM. During this phase, graduate student and faculty participants took part in the Inclusive STEM Teaching MOOC which was complemented by an inclusive teaching learning community facilitated by consultants. Each learning community session was designed to complement weekly modules within the MOOC, providing an extension of what participants learned as well as opportunities for community engagement.

Table 2 summarizes the MOOC and learning community content covered in each of the 6 weeks. Week 1 focused on orientation to course content, setting expectations for working together, and community-building activities. In Week 2 participants gained a foundational understanding of DEI concepts and vocabulary, engaged in conversations about hesitations and concerns about promoting inclusive teaching, and discussed tips and strategies for navigating them. In Week 3, participants engaged in a self-reflection activity and small group discussions to deepen their understanding of how instructor identity, power, and experience influence their approach to teaching and their expectations of students. In Week 4 participants examined student demographics, sense of belonging, and campus climate data from the University of Michigan and discussed how students' learning experiences can be informed by their identity and lived experiences. In Week 5 participants began thinking more about inclusive course design strategies and how to incorporate them into their specific course context. Finally, in Week 6, they examined group work scenarios and discussed the impact of and the roles that they, as instructors, play in ensuring inclusive learning environments in student group work.

Phase II: Experiential Learning

Phase II of the project focused on our second learning objective: *To engage in hands-on training that applies inclusive teaching best practices for BME course design*. This part of the project is where the experiential learning took place (Fig. 1). In this phase, graduate students were paired with faculty mentors to work on courses the faculty would be teaching (IT-BME course). Working for 10 weeks, faculty-student teams met individually to discuss, review, and revise/create course materials and ideate plans for integrating inclusive teaching practices into the curriculum. Please note that due to an uneven number of graduate students ($n=5$) to faculty ($n=7$) ratio, two faculty did not work with graduate students in Phase II and instead received consultation support offered by the Teaching and Learning Center staff.

Prior to the start of this phase, consultants facilitated two additional sessions to (1) prepare graduate students for working effectively with faculty and (2) support faculty in their inclusive teaching goals. The first session focused on teaching best practices for collaborative work [33–35]. Consultants emphasized the importance of graduate students engaging in conversations with their faculty mentor to establish guidelines for collaboration, including discussing communication preferences, modality and cadence of meetings, and expected responsibilities of each other. This information was also shared with faculty to facilitate collaboration and mentorship.

The second additional session focused on supporting faculty in identifying inclusive teaching goals they had for integrating into a Fall 2022 course. Prior to the session, faculty were given a Google Slides presentation template to complete. The template asked faculty to consider the following: (1) course background and learning objectives, (2) inclusive teaching practices they would like to implement, and (3) the graduate student support they would need. During the session, faculty presented these slides to consultants and graduate students. Consultants offered feedback on the faculty's inclusive teaching goals. Graduate students were given the opportunity to ask questions of the faculty members on their proposed projects. Following the second session, graduate students were asked to complete a form ranking their faculty project preferences.

Once paired, graduate students met regularly with their faculty members to solidify ideas for the specific strategies, tools, or content the faculty members wanted to incorporate into their course as well as discuss pedagogical ideas and share experiences. Using the tools and knowledge they gained in Phase I, graduate students typically worked individually on researching, revising, or creating new materials and content. This is an example of the *concrete experience* stage of experiential learning. However, they would continue to meet regularly with their assigned faculty member to discuss progress, and challenges and adjust planning as needed. In addition to regular meetings with their assigned faculty member, graduate students also participated in weekly meetings. In these meetings, attended by graduate students and facilitated by a faculty member, each graduate student presented weekly updates on their respective projects, shared challenges and barriers they encountered, received and provided feedback, and problem-solved together. They would also discuss readings on best teaching practices and share resources with each other. Support from consultants was also available to student-faculty teams throughout the 10 weeks. Broader team check-ins were performed at the halfway and 10-week time points. During these check-ins, the whole group (faculty, graduate students, and consultants) met to provide updates on their project status (via presentation) and solicited feedback and resources to support their project. With faculty member support, graduate students led these presentations, allowing them to articulate their team's synthesis of inclusive teaching practices. Preparing for these check-in meetings (with individual faculty, graduate students, and the whole team) are all examples of the *reflective*

observation and *abstract conceptualization* stages of experiential learning. To prepare for these meetings and updates, graduate students (and their assigned faculty members) had to reflect on their work, articulate what they did and why, identify barriers and challenges, and ask specific questions of their peers, faculty members, and consultants. Through discussing their projects in these various check-ins, graduate students were able to progress on their projects, eventually resulting in a final product(s) at the end of Phase II (e.g. the active experimentation stage).

Phase III: Implementation

Phase III of the project focused on the implementation of inclusive teaching strategies in IT-BME courses, addressing our third learning objective: *To foster an inclusive learning environment in undergraduate BME courses*. Faculty instructors used the concepts, strategies, and materials created by our teams and applied them in their IT-BME courses (Fig. 1). While graduate students were not directly involved in this phase, some did participate with their faculty mentors.

Faculty/graduate student teams incorporated a range of inclusive teaching concepts, strategies, and materials in these courses that fell under three overarching categories: "Course Element Revisions, DEI Course Content, and Improving or Incorporating Group Interactions (Table 3).

Courses that incorporated "Course Element Revisions" typically updated their syllabus language to be more learner-centered, inclusive, and welcoming or made modifications to assignments. For example, some faculty members added language to their syllabus about Title IX, and religious observances, and included information on the various resources available to students, including mental health and well-being, and for those with housing/food insecurity, or who are caregivers. Another faculty member shared that they created grading rubrics, that they gave students, to increase transparency on how they were being assessed [36]. Another faculty member included more assignments as lower-stakes assessments in their course and worked with students to develop grading criteria (e.g. how much clicker quizzes would be graded vs attendance only). Several faculty also indicated that they revised their course learning objectives [37], both for the overall course and for each class session.

Courses that incorporated items related to "DEI Course Content" included DEI-focused engineering case studies, classroom discussions on the socio-technical implications of biomedical engineering, or vignettes of modern-day researchers engaging in state-of-the-art research related to course content. For example, one faculty member had their students listen to podcasts on the topic of "Engineering for Change and Designing for Social Justice" and assigned homework questions on the podcast. They also exposed students to some of the historical context behind policies

Table 3 Overview of the courses, course type, and specific strategies incorporated in each IT-BME course

Course & course type	Inclusive teaching category	Specific concepts, strategies and materials implemented
Course 1: design	DEI course content	Included DEI case studies in the curriculum
Course 2*: lecture	Course element revisions	Updated syllabus language
	Improving or incorporating group interactions	Incorporated group-based assignments
Course 3: lab	Improving or incorporating group interactions	Students took a leadership style assessment to improve collaborative work
		Introduced group contracts for students to outline norms and expectations
		Allocated class time for dedicated group work
Course 4: design	Improving or incorporating group interactions	Introduced group contracts for students to outline norms and expectations of each other
Course 5*: lecture	DEI course content	Incorporated content and discussions on the socio-technical implications of biomedical engineering
Course 6: lecture	Course element revisions	Developed lecture-specific learning objectives
		Created coursework questions touching on the social impacts of engineering
Course 7: design	DEI course content	Included DEI case studies in the curriculum
	Improving or incorporating group interactions	Introduced group contracts for students to outline norms and expectations of each other
Course 8**: lecture	DEI course content	Included DEI research vignettes
		Incorporated content and discussions on the socio-technical implications of biomedical engineering

Here, * indicates courses that did not have a graduate student mentee facilitate inclusive teaching development, and ** indicates courses that did not partake in Phase III

that led to current-day health inequities and incorporated discussions that had students think about the intersections of the technical course content they were learning about and societal impact [38]. Instructors that included case studies in their courses worked with the Center for Socially Engaged Design, a unit in the College of Engineering that has a case study initiative developing original case studies for engineering courses highlighting the impact of engineering work on engineers and the broader society. This initiative is specific to this institution and instructors worked closely with the unit staff to integrate existing case studies into their courses in ways that align with the course context.

Finally, almost all the IT-BME courses had some collaborative elements to them and most faculty tried to integrate techniques related to teamwork, often focusing on creating group assignments or improving dynamics through team contracts or establishing working norms. In one course, to encourage students to build their networks and get to know other students in the class, the faculty member changed their first homework to a group work assignment, instead of an individual one. Other faculty members supported their students in learning about best practices when engaging in collaborative work via presentations and Canvas modules. One faculty member emphasized the importance of having their students split up the managerial work of note-keeping, editing assignments, etc. so that it did not fall on one person (typically happens to women in engineering). Some had students create group contracts to hold each other accountable. Many also engaged their students in creating norms and guidelines for communicating and interacting with each other in classroom discussions.

Evaluation

Learning objectives for Phase I and Phase II of this program were evaluated through a series of self-reflection questions asked of the graduate students. Specifically, they reflected on what they gained from this experience in relation to instructional knowledge, working with a faculty member, and the value of the MOOC and learning community. Graduate students are included in this manuscript as co-authors, writing about their experiences on this project through self-reflection. Learning objectives for Phase III were evaluated through a department-wide climate survey, disseminated to graduate and undergraduate students, specifically probing for students' sense of belonging in the department and perceptions of inclusive teaching practices in BME courses. Data collection for Phase III was approved by the Internal Review Board (HUM00226313).

Evaluation of Phases 1 & 2

Self-reflection is an important component of experiential learning because it allows participants to self-evaluate their knowledge, skills, and experiences on this project [39]. Following the completion of Phase I and Phase II, graduate student participants were invited by consultants (TPG & PJ) and faculty member (DN) to be included as co-authors on this manuscript by sharing their experiences on this project through self-reflection. Of the 5 IT-BME graduate student participants, four chose to be included as co-authors and agreed to respond to a set of reflection questions (developed by consultants TPG, PJ, and faculty member DN). The fifth student did not respond to our inquiry. Upon confirmation of their interest in being included in this manuscript as co-authors, participants were asked to submit their responses via an anonymous Google Form to ensure thoughtful and honest responses. Specifically, they were asked to respond to the following questions:

1. How have your ideas of instruction changed by participating in IT-BME?
2. What do you feel you gained from this experience?
3. How valuable was working with a faculty mentor for your IT-BME experience?
4. How did the learning community (with faculty and graduate students) shape your understanding of Inclusive teaching?
5. What aspects of this experience did you find most valuable?
6. Do you have any suggestions for how we could make the IT-BME experience better for graduate students?

Their responses were synthesized and documented in the "Findings" section of this paper.

Phase III Evaluation

A department-wide climate survey, disseminated to graduate and undergraduate students, evaluated Phase III (Learning Objective 3) of the IT-BME project. The survey was distributed to all students (undergraduate and graduate) via email in the last 3 weeks of the Fall 2022 semester. To assess the effect of the inclusive teaching strategies on IT-BME courses vs. non-IT-BME courses, we conducted a dept-wide climate assessment specifically probing for student perceptions of sense of belonging and inclusive teaching in their courses (see Fig. 2 and "Appendix"). The survey collected information on three categories: (1) *students' sense of belonging in the department*, (2) *student perceptions of inclusive teaching practices in BME courses*, and (3) *demographics* (Appendix). Students were also asked to indicate whether or not they took an IT-BME course. To encourage responses, we

Fig. 2 Summary of sense of belonging survey questions (Q1 through Q16). See Appendix for more details

Based on your experience in the U-M BME, please indicate the degree to which you agree that your BME instructors do each of the following when teaching:	
Q1	Create a classroom environment that is conducive to student participation
Q2	During class, use activities that encourage all students to participate
Q3	Elevate student learning using multiple types of assessments (e.g. homework, quizzes, tests, presentations)
Q4	Include details about course policies, requirements, schedule, and deadlines in the syllabus or general course information.
Q5	Remind students of upcoming course deadlines (e.g. upcoming exam and assignment due dates, help sessions, and office hours)
Q6	Try to ensure that all students feel a sense of belonging in the classroom
Q7	Present examples, resources, images, etc. that reflect a diverse population
Q8	Design assignments that have clear instructions
Q9	Convey the idea that all students can learn and improve
Q10	Create an atmosphere of respect for all students
Q11	During class, give instructions about appropriate group interactions
Q12	During class give instructions to promote equal participation within groups
Q13	Provide useful feedback on student assessments
Q14	Use inclusive language (e.g. do not always use the pronoun 'he')
Q15	During class, establish explicit ground rules for appropriate classroom conduct
Q16	Teach in ways that do not reinforce negative stereotypes

offered a $10 gift card incentive to the first 100 respondents. Upon completion of the survey, students were redirected to another form, separate from the survey responses, to enter their email information to receive the gift card.

The sense of belonging questions were compiled from Ingram [40] and Good et al. [41] and adapted by Hirshfield and Khan [42] (Fig. 2). These ten survey items asked students to rate their level of agreement with the sense of belonging statements such as "I feel comfortable asking an instructor for help if I do not understand course-related material" and "I feel excluded in my BME classes." Students were able to respond using a 6-point Likert Scale with answers: *Strongly disagree, Disagree, Slightly Disagree, Slightly Agree, Agree, Strongly Agree*. Students were also asked two open-ended questions to indicate what factors would make them feel as though they belong or did not belong in a classroom.

To evaluate the impact of the IT-BME courses, students were asked to indicate if they took one or more IT-BME courses in Fall 2022. If they indicated "yes", they were prompted to specify the IT-BME courses they took and respond to a series of statements about their perceptions of inclusive teaching in relation to those IT-BME courses. If students responded "no" to taking an IT-BME course, they were redirected to the same set of questions but were not asked to specify the courses they'd taken. Instead, those students were asked to respond to the statements in relation to their BME courses in general. Specifically, survey items consisted of 16 inclusive teaching statements focusing on students' perception of teaching practices such as using "activities that encourage all students to participate" and "present[ing] examples, resources, images, etc. that reflect a diverse population" [43]. All students were asked to rate their agreement with those statements answering, *Strongly disagree (1), Disagree (2), Slightly Disagree (3), Slightly Agree (4), Agree (5), Strongly Agree (6)*.

Demographics

Demographic questions inquired on five main areas: (1) gender identity, (2) student status (graduate or undergraduate), (3) years in the department, (4) international student status, and (5) open-ended questions on other identities they'd like to share. For purposes of ensuring student anonymity, all questions, with the exception of student status and years in the department, were optional.

Analysis

To understand the potential impact of IT-BME project outcomes, sense of belonging survey results were sorted into two primary groups: students who did not participate in any IT-BME course during phase III ($n=93$) and students who participated in one or more IT-BME course(s) ($n=53$). This analysis excludes two IT-BME courses: course 6 and course 8 (see Table 3). Course 6 was excluded due to the fact that the course was taught by multiple faculty—the majority of whom did not participate in IT-BME. Course 8 was excluded as it did not run during phase III. Survey questions are listed in Fig. 2, the distributed responses are reported in Fig. 3, with the mean and standard error of Likert scale results calculated across responses from each group for each question

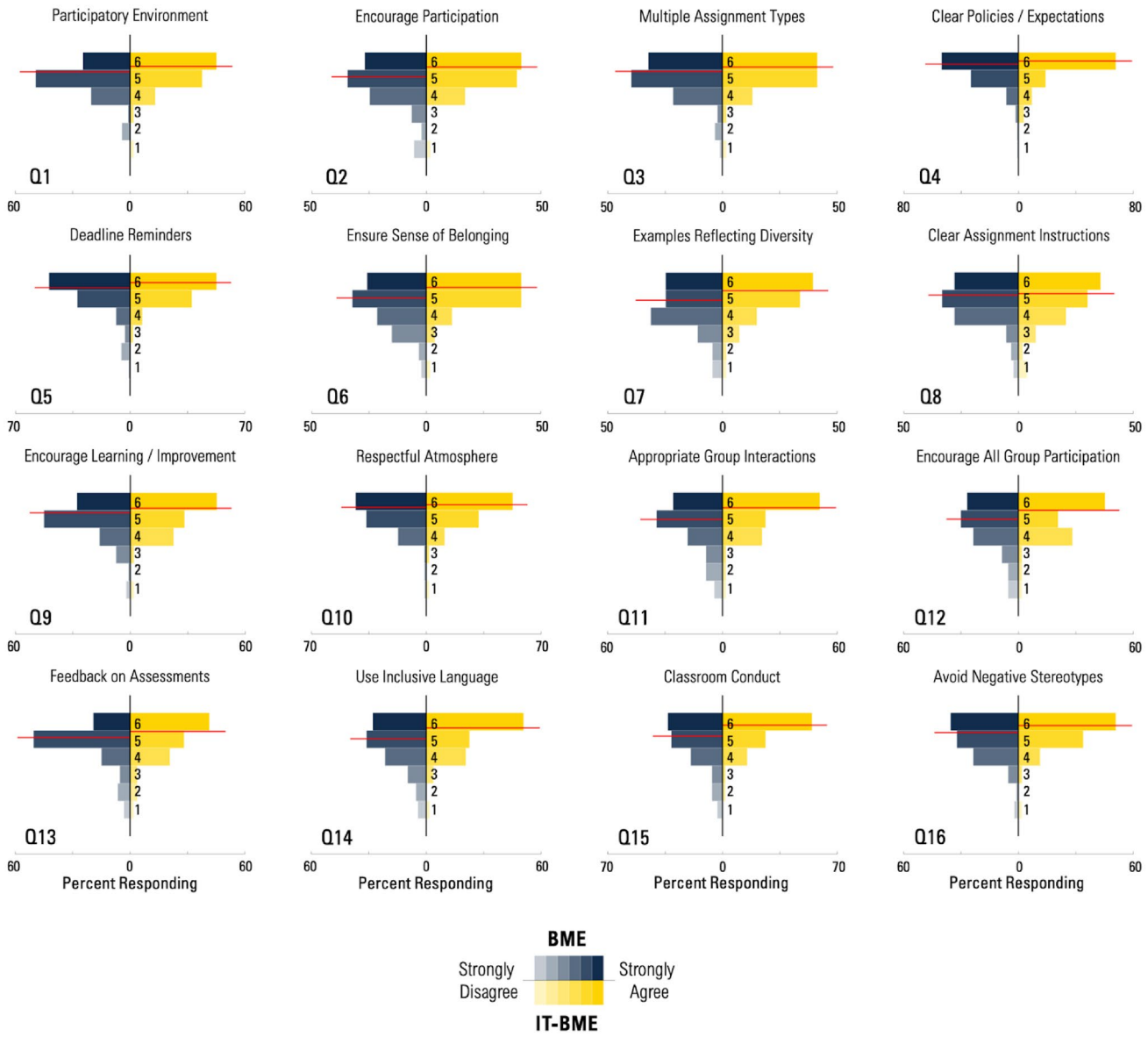

Fig. 3 Full distribution of student responses to the sense of belonging survey based on no participation in IT-BME courses (blue, $n=93$) or participating in one or more IT-BME course(s) (maize, $n=53$). Lighter shades indicate more disagreement, while darker shades indicate greater agreement. Red lines indicate the mean response in each group

in Fig. 4. Significance of the difference in responses between groups was assessed using a two sample *t*-test. Quantitative assessment was conducted in MATLAB.

Findings

Sense of Belonging Survey Results

The sense of belonging survey was completed by 146 active students (53 IT-BME, 93 non IT-BME) at the University of Michigan, accounting for a response rate of approximately ~20%. Respondents predominantly identified as female (68.3%), with males (29.2%) and non-binary (2.7%) comprising a smaller portion (with 2 individuals preferring not to respond). As the survey was sent to the entire student body, responses were received from undergraduate (54.3%), masters (14.8%) and doctoral students (30.9%). Student respondents also had a range of experience at the University of Michigan, with student respondents having (0–1 years: 29.6%, 1–2 years: 19.6%, 2–3 years: 23.5%, 3–4 years: 16.7%, 4–5 years: 8%, and 5+ years: 3%).

Responses to the sense of belonging survey are summarized in Fig. 3, with distributions illustrating the responses

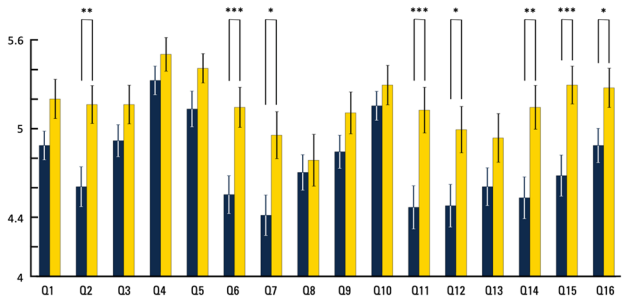

Fig. 4 Mean and (±) standard error of student responses to the sense of belonging survey questions (Q1 through Q16), based on no participation in IT-BME courses (blue, $n=93$) or participating in one or more IT-BME course(s) (maize, $n=53$). Questions are marked for significance (*p-value < 0.05, **p-value < 0.01, ***p-value < 0.001)

in IT-BME (maize) and non IT-BME respondents (blue). Here the hue indicates the Likert response, with lighter shades indicating disagreement with the stated questions and darker shades indicating more agreement. Comparing the two groups, for all questions the IT-BME group responded more or equally positive showing a tendency for the Likert distribution to skew more positive.

Figure 4 quantifies the mean response within each group (± the standard error). Here we can see that 8 of the 16 questions showed significant differences in the responses between groups, suggesting a meaningful, positive impact on the courses in the IT-BME group. Note that while many of the questions in the sense of belonging survey clearly relate to inclusivity in the classroom and material (e.g. Q14–Q16), others reflect the broad perspectives through which inclusive teaching principles can be incorporated. For example, Q1 and Q2 (p-value of 0.053 and 0.007, respectively), focusing on promoting classroom participation. While this is a goal for many instructors, within the inclusive teaching space, promoting participation goes beyond classroom dynamisms and uses participation as a way of building a sense of community and personal investment.

Graduate Student Reflections

Participating in this IT-BME experience provided IT-BME graduate students with a deeper understanding of teaching pedagogies and influenced their perception of course design and best instructional practices. Table 4 contains direct quotes from the graduate students describing their experiences on this project. In their reflections, they discussed how taking the MOOC and engaging in conversations with faculty and graduate students in the learning community enhanced their understanding of course design and exposed them to specific teaching strategies they could apply to their projects and carry with them into teaching careers. For example, one graduate student acknowledged understanding the importance of flexibility in the classroom. Additionally, several spoke about recognizing the importance of considering the identity and background experiences of an instructor and how that influenced the design of a course. Graduate students also found it valuable to partner with faculty and get hands-on experience in co-creating inclusive content including assignments, assessments, classroom norms, and lecture content, and appreciated being able to reflect and ask questions, learn about their teaching context, and gain a new teaching mentor. As intended in the design of this initiative, the experiential learning process was supported by having regular progress update meetings with their faculty member, other graduate students, and consultants to discuss ideas and solicit feedback from others. Finally, some graduate students mentioned that they were able to apply what they learned in this experience to their career aspirations.

Discussion

In this paper, we aimed to address the challenges associated with integrating inclusive teaching practices in biomedical engineering courses through IT-BME: a unique partnership between engineering education researchers, BME faculty, and graduate students. This collective learning, along with the experiential component of collaboratively modifying course materials, provided opportunities for both faculty and student development. In addition, this collaborative effort served as an incubator, enabling the sharing of ideas across courses at both the graduate and faculty levels. The consequences of this work can be seen in the positive responses to our sense of belonging survey, which highlights how students in courses involved in IT-BME felt a greater sense of engagement, inclusion, encouragement, and buy-in.

While the findings of this study suggest promising outcomes from the project, there are a few notable limitations. First, our comparison groups consisted of students (at all levels) who either participated in an IT-BME class or did not. This means that students in the two groups responded based on different classroom experiences. While we aimed to mitigate this by asking students more broadly about their experiences, a cleaner approach would be to profile courses prior to participation in IT-BME to illustrate the direct impact of the project (which was not possible during this project). Another potential confounder lies with the faculty instructors themselves. As participation in IT-BME was opt-in, faculty more focused on pedagogy and student experience may have elected to participate in the program, which could explain the improved results. However, this is unlikely to explain the deviations observed between groups, as approximately 30% of the faculty participating were new faculty. Further, course styles and instructor styles naturally vary. Delving into this variance in courses more in-depth would be

Table 4 Themes that emerged from IT-BME graduate students reflecting on their experiences on this project

Theme	Direct quotes
Learned about teaching pedagogies	• "The inclusive teaching concepts I learned through participating in IT-BME broadened the way I think of instruction as a whole."
	• "I gained a much deeper appreciation for pedagogy and all the work of preparing classroom material."
	• "IT-BME expanded my view of instruction by highlighting the need for flexibility in teaching."
Recognized how instructor identities influence course design	• "Now I recognize that teacher and student backgrounds factor heavily into the classroom, which is why it's important to prepare material in a variety of ways, such as written and oral."
	• "...my view of teaching was primarily based on my experience as a student, mainly what I thought worked well or wrong with the approaches different professors had. Thanks to the IT-BME project, I now know that as a future instructor, I can have an impact beyond the class content. I am more aware of the different identities and learning styles that are present in the classroom, and I have better tools to engage with students."
Found value in the hands-on experience of co-creating the course	• "The faculty member I worked with was open to incorporating inclusive teaching into several aspects of the course, including lecture content, group work norms, and final project assessments… they were also very collaborative, offering helpful feedback and insight into what was most needed in the course, what they thought would work well, and student responses to previous changes."
	• "Working with a faculty helped transform all the ideas and knowledge from the learning community into concrete interventions. Without this part of the project, all the things we gained at the beginning would have stayed as ideas, but now I have some clear experience of how they can be applied, especially as a first, moderate intervention in a class."
Appreciated the regular check-ins with peers, assigned faculty, and consultants	• "I was able to gain additional teaching strategies through hearing about what other grad student-professor teams were doing to increase inclusivity and get feedback and ideas on my own project."
	• "The meeting with my faculty mentor and the weekly updates we gave about the changes we were working on for each class were the most valuable to me during the program. The mentor meetings furthered my understanding of course design and the many elements that can be updated with inclusive teaching, and the weekly larger group meetings were helpful in providing feedback from multiple perspectives. The feedback in the group meetings helped refine the changes we were working on from both faculty and student perspectives…"
Applied knowledge to career aspirations	• "Not only was this a vital practice for my career, but it also was a talking point during interviews. The knowledge I gained about inclusive teaching is also very helpful for my career and understanding of teaching."
	• "My goal has always been to become a professor, but realizing that I can impact the students by making a more inclusive classroom and that this can translate into a more prepared workforce further boost my desire to follow this path. I now feel like I can contribute with knowledge and by motivating individuals with different backgrounds to become engineers and tackle society's challenges from their different perspectives."

of interest, course-specific analyses and comparisons were not conducted to ensure anonymity of surveyed participants. Additionally, areas for improvement for each course were based on the professor's perceptions of the needs and do not necessarily reflect the needs of students in the course.

While the focus of this project was targeted within the Department of Biomedical Engineering, the framework and concept of collective education and collaborative experiential learning for graduate students and faculty to develop inclusive teaching content could be generalized to other engineering degree programs or more agnostically to STEM. Direct mentor–mentee experiential learning benefitted by having a specific course to use as a focus for development; however, many of the concepts discussed were applicable to engineering program-wide. Indeed, the Inclusive STEM Teaching MOOC—a primary source for training in the early phases of the project—speaks to concepts affecting most engineering programs. A key to the success of the IT-BME

project, and likely others that may mimic this model, is investment from all participants. As inclusive teaching within the STEM classroom focuses on developing a sense of community, establishing this same community within IT-BME was critical for success. Achieving this was a collective effort, with engineering educators present to help facilitate and guide discussions, with faculty who prioritized establishing greater inclusion in their classrooms, and graduate students hungry to learn about pedagogy and gain experience beyond what the typical graduate student instructorship position affords. However, bringing these groups together creates a valuable ecosystem for learning, cultivating ideas, and advancing engineering education toward a more inclusive environment.

Considering the extensibility and scalability of the IT-BME framework raises a number of interesting considerations. Extension of this framework to other departments or BME programs would, invariably, raise new challenges and concerns reflective of the program or university environment. However, the IT-BME project is adaptable, providing flexibility to address key needs as identified by instructors. The scalability of this framework to involve greater graduate and faculty participation could be easily addressed assuming similar scaling in the number of engineering educators, enabling multiple small-to-medium groups for learning communities and discussion. Adoption of a large group model, while potentially viable, would require care. Most importantly, building an open collaborative learning community in IT-BME was facilitated by engineering educators through shared small group activities. However, broadening the reach of this program by in new groups, particularly across institutions with varied demographics and diversity, would provide an important opportunity for learning, dissemination, and advancement of inclusive teaching practices.

Appendix

Sense of Belonging

Rate your agreement with the following statements. (6 point scale: Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

- I feel comfortable asking an instructor for help if I do not understand course-related material [1].
- My instructors in my engineering classes know who I am [3].
- I can maintain a sense of perspective in the face of adversity [3].
- I am confident my peers would help me out if I encounter a problem [3].
- I feel excluded in my BME classes [2].
- I feel a sense of belonging in my BME classes [modified from 1].
- When I interact with instructors at this college, I feel they care about how I'm doing [1].
- I feel valued in my BME classes [modified from 2].
- I am confident that I can complete the required work in my BME classes [3].
- I have trust that I do not have to constantly prove myself in my BME classes [modified from 2].
- I feel respected by my BME classmates [2].
- My instructors in my BME classes treat students fairly [3].

Indicate Courses They've Taken in Fall 2022/Winter 2023

- List of IT-BME courses
- Course 1: design
- Course 2: lecture
- Course 3: lab
- Course 4: design
- Course 5: lecture
- Course 6: lecture
- Course 7: design
- Course 8: lecture

Inclusive Teaching (General)

Please indicate the degree to which you agree that the BME instructors of your course do each of the following when teaching the course (6 point scale: Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

- Create a classroom environment that is conducive to student participation
- During class, use activities that encourage all students to participate
- Elevate student learning using multiple types of assessments (e.g. homework, quizzes, tests, presentations)
- Include details about course policies, course requirements, course schedule, and course deadlines in the syllabus or general course information
- Remind students of upcoming course deadlines (e.g. upcoming exam and assignment due dates, help sessions, and office hours)
- Try to ensure that all students feel a sense of belonging in the classroom
- Present examples, resources, images, etc. that reflect a diverse population
- Design assignments that have clear instructions
- Convey the idea that all students can learn and improve
- Create an atmosphere of respect for all students

- During class, give instructions about appropriate group interactions
- During class give instructions to promote equal participation within groups
- Provide useful feedback on student assessments
- Use inclusive language (e.g. do not always use the pronoun 'he')
- During class, establish explicit ground rules for appropriate classroom conduct
- Teach in ways that do not reinforce negative stereotypes

Inclusive Teaching (IT-BME)

Please indicate the degree to which you agree that the BME instructors of your course do each of the following when teaching the course (6 point scale: Strongly disagree, somewhat disagree, slightly disagree, slightly agree, somewhat agree, strongly agree)

- Create a classroom environment that is conducive to student participation
- During class, use activities that encourage all students to participate
- Elevate student learning using multiple types of assessments (e.g. homework, quizzes, tests, presentations)
- Include details about course policies, course requirements, course schedule, and course deadlines in the syllabus or general course information
- Remind students of upcoming course deadlines (e.g. upcoming exam and assignment due dates, help sessions, and office hours)
- Try to ensure that all students feel a sense of belonging in the classroom
- Present examples, resources, images, etc. that reflect a diverse population
- Design assignments that have clear instructions
- Convey the idea that all students can learn and improve
- Create an atmosphere of respect for all students
- During class, give instructions about appropriate group interactions
- During class give instructions to promote equal participation within groups
- Provide useful feedback on student assessments
- Use inclusive language (e.g. do not always use the pronoun 'he')
- During class, establish explicit ground rules for appropriate classroom conduct
- Teach in ways that do not reinforce negative stereotypes

Open-Ended Questions

- What factors make you feel like you belong in a classroom.
- What factors most make you feel like you do *not* belong in a classroom?

Demographics

Please select your gender identity.

- Male
- Female
- Non-binary
- Other
- Prefer not the answer

Indicate your current student status (mandatory).

- Undergraduate student
- Master student
- Doctoral student

How many years have you been in the University of Michigan BME Department?

- 0–1 years
- 1–2 years
- 2–3 years
- 3–4 years
- 4–5 years
- 5+ years

Are you an international student?

- Yes
- No

Do you identify with a minoritized or marginalized group? For example, due to race, ethnicity, disability, LGBTQ+ etc. Feel free to answer just "yes" or "no". If you feel comfortable sharing, please specify.

Author Contributions Following the CRediT Taxonomy example (https://credit.niso.org/): PJ—conceptualization, project administration, methodology, formal analysis, writing—original draft. EB—writing—original draft. TH—writing—original draft. JJ—writing—original draft. JK—writing—original draft. MW—writing—original draft. MC—writing—review and editing. KJ—writing—review and editing. EM—writing—review and editing. AM—writing—review and editing. JW—writing—review and editing. MW—writing—review and editing. DN—funding acquisition, conceptualization, project administration, supervision, methodology, formal analysis, writing—original draft. TP-G—funding acquisition, conceptualization, project administration, supervision, methodology, formal analysis, writing—original draft.

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Data Availability Due to IRB agreement, survey data is unable to be shared publicly.

Code Availability Not applicable.

Declarations

Conflict of interest Not applicable.

Ethical Approval Data collection for Phase III of this project was approved by the U-M Internal Review Board (HUM00226313).

Consent to Participate All participants consented to participate in this project.

Consent for Publication All authors consent to the publication of this work.

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