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Designing, Codifying, and Implementing Social Justice Content in a Required Course on Engineering and Research Skills for First-Year Graduate Students

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POSITIONALITY STATEMENT

We acknowledge that the authors are all in varying positions of privilege. The university at which we are implementing this initiative is a primarily white, private institution in the United States. We are also located in a state in which such topics are relatively open for discussion in educational settings. Although the authors hold different identities in gender identity, race, ethnicity, sexual orientation, socioeconomic status, and more, we are far from representative of the larger population and recognize the need for many more voices in this type of work.

INTRODUCTION

Engineering and research have profound impacts on issues of equity

Engineering and research, while crucial for technological advancement, cannot exist in a vacuum, divorced from the society that those advancements impact [1]–[5]. The work of engineers and researchers has human implications, both beneficial and detrimental, as well as equitable and inequitable [2]. Artificial intelligence, for example, is an area of research in which advancing technology can perpetuate harm when development is not paired with rigorous equity standards. A 2019 study found that a popular healthcare algorithm used to assess risk levels of patients was racially biased; sicker Black patients were measured as equivalent to healthier white patients, resulting in reduced levels of care for some Black patients [6]. The algorithm used healthcare costs as a measure of need, which does not correlate the same for Black and white patients, as more money is spent on white patients overall. The result is a false equivalency between cost and risk level, a dangerous result of a lack of context in the development of the algorithm. This example highlights one of many instances of the long-reaching impacts that research and engineering can have on broader populations.

Consideration of these implications on populations holding marginalized identities requires intentional consideration of concepts in the realm of anti-racism, diversity, equity, and inclusion (ARDEI). It is important to begin with an understanding of key terminology in order to engage meaningfully in this discussion [7], thus key terms are defined in Table 1. In addition to considerations of ARDEI, we want to interrogate how research promotes or impedes social justice. While there are many definitions of "social justice" available, we chose to use one from Donna Riley—"the struggle to end different kinds of oppression, to create economic equality, to uphold human rights or dignity, and to restore right relationships among all people and the environment" [8]. Because of engineering's human connection, it is important for researchers to consider the impact their work may have on various communities, especially those that have been historically marginalized.

Table 1. Definitions of key terms in ARDEI.

Word	Definition	Reference
Diversity	The presence of people with differences that may include race, ethnicity, gender, sexual orientation, (dis)ability, socioeconomic status, among other classes, especially groups that have been historically marginalized.	American Society of Anesthesiologists (ASA) Medical Student Component (MSC) [9]
Equity	The promotion of justice and fairness through actions that affect the root cause of societal disparities.	
Inclusion	The outcome where individuals holding diverse identities (especially those that have been historically marginalized) feel welcomed and are fully able to participate within a group	
Anti-Racism	Opposing racist policies (societal rules that create or sustain inequities between racial groups) and racist ideas (ones that suggest that one race is superior or inferior to another) with a goal of changing the root problems that produce and normalize racial inequities	*How to Be an Antiracist* (Kendi) [10]
Social Justice	The struggle to end different kinds of oppression, to create economic equality, to uphold human rights or dignity, and to restore right relationships among all people and the environment	*Engineering and Social Justice* (Riley) [8]

Existing engineering courses are often missing acknowledgement of social context, but some efforts have been made to rectify these omissions

There is a growing body of work exploring the role of social context in engineering education, though the authors find that it is lacking in most curriculum [2], [8], [11]–[13]. Many engineering courses have a heavy emphasis on the technical, mathematical, and scientific aspects of problem solving. Additionally, those lessons are often crafted in ways that use simplifying assumptions that break problems down to a specific characteristic engineering calculation [8]. For example, a student may be able to narrowly define the scope of their work to calculate the number of stages in a hydrocarbon separation column, but they may not consider how modifications to that column may impact the process's polluting emissions or the potential impact on the community that resides near that process. Moreover, when humanities and social science courses are taken separately from engineering courses, it further solidifies the boundaries between engineering and societal concepts and issues. With exposure to only the technical aspects of engineering, students' perception of engineering's connections to society and public welfare decreases throughout the course of their education [1]. If context is missing from educational experiences, students may not be prepared to enter the workforce and develop technologies that consider societal context.

In an effort to rectify this existing gap, there is an emergent trend of adding context to engineering education. The following paragraphs highlight a small fraction of this new body of work, where students begin to engage in discussion of ARDEI concepts and ARDEI context is taught explicitly in engineering courses or is included in engineering problem solving.

Some educators have begun adding context to show the connections between engineering and society to engineering examples, homework, and textbook problems that have traditionally focused on the technical aspects of engineering problem solving. Hirschfield and Mayes capture student interest in a chemical engineering kinetics course by using tangible examples of baking, antifreeze, and flame retardants, and asking students to reflect on the ethical considerations present in the design and use of these chemicals [14]. Riley's thermodynamics textbook supplement introduces traditional thermodynamic homework problems with an energy context which helps to bridge the gap between the technical and the societal [15]. Through these contextualized examples and reflective questions, students use their critical thinking skills by considering the impacts (both intended and unintended) of global warming and energy consumption on marginalized groups, how those groups can be included in engineering solutions to the climate crisis, and how structural changes can happen. Catalano et. al., combine numerical methods and modeling with concepts of social justice in bioengineering [16]. Students explore concepts of sustainability, wealth distribution, and health care disparities while using various numerical techniques for solving complex bioengineering system models. Lucena and Leydens developed a framework for incorporating social justice in the classroom, as well as tips for how it can be used to increase students' understanding of social justice context in engineering problem solving. However, they also discuss the challenges associated with the addition of this context, namely that students who are seeing social justice context for the first time in an engineering course may be resistant, and that biases may influence how students interpret the information presented in the context. Regardless, they still found that the benefits of adding context outweighed the challenges [17]–[19].

Some faculty are developing full courses or curricula with a focus on social justice in engineering. In environmental sciences and engineering departments, such as those at University of California (UC), Berkeley and UC Davis, courses on engineering's impact on the environment are being developed. UC Berkeley has a course called "Engineering, Environment, and Society" where students read scholarly works on social justice, examine case studies for impact and injustice, and work with community clients on projects developing solutions to environmental issues that disproportionately affect members of historically marginalized groups [20], [21]. Hendricks et. al., provided the structure and objectives for their course "Science and Engineering for Social Justice," as a blueprint for other faculty. Their course is designed to engage students in discussions and projects around the ethical and societal considerations surrounding engineering solutions and technology, such as CRISPR gene editing technology, where issues with inequitable access to the technology and the potential for discrimination against people are concerns [22]. Loyola University Chicago incorporates social justice content through their core engineering curriculum. [23] In a first-year course, undergraduate students participate in an introduction to social justice that includes terminology and introductions to microaggressions and biases. This is followed by social justice case studies on the impact of technology on society in upper-level classes. The case studies connect justice to technical content relevant to the course topic but focus discussion on societal impact.

Nevertheless, implementing social justice into courses and curriculum cannot be done in a vacuum. The classroom climate can dictate whether these changes will be successful or not. There are some strategies that can help in cultivating the environment necessary for productive engagement with social justice concepts. Inclusive teaching practices can set the tone for

conversations about ARDEI in the classroom. Incorporating strategies such as Universal Design for Learning (UDL), diverse perspectives and course materials, and peer learning activities help make the classroom climate accessible to all learners [24]. In addition, having instructors reflecting on their own identities and biases can help with challenging their assumptions about students from diverse backgrounds [25]. With culturally relevant pedagogy, instructors learn from the various students in their classrooms, gain a strengths-based understanding of what their diverse learners bring to the classroom, and realize that students from any given background are not a monolith, all of which help instructors engage with students from all backgrounds, thereby improving student interest in their education [26]. In the classroom, inclusive and culturally relevant pedagogies establish that everyone is valued and belongs in the learning environment. When students feel a sense of comfort and belonging, they are more likely to be engaged [27]. A positive classroom climate is especially important when it comes to engaging in challenging discussions around social justice in the classroom.

When introducing concepts of ARDEI in the classroom, instructors and students need to be prepared to engage in those conversations in a way that is safe and productive [28], [29]. Using community guidelines or discussion norms can establish a framework for respectful communication. For example, the guideline, "avoid assumptions" discourages speakers from generalizing actions, behaviors, or thoughts that perceived social groups might have, or treating perceived social groups as monoliths. In addition to norms, an instructor will also want to be ready to handle microaggressions or other "hot moments" in the classroom that could further traumatize students holding marginalized identities [30]–[32]. There are examples and frameworks for how to begin conversations on race, gender, and social justice in the classroom [33], [34]. These efforts are not without challenges [35]. Students holding a majority identity may resist engaging in conversations or may balk at confronting their positionality or privilege [36]. Faculty holding a majority identity may feel ill-equipped to engage in these conversations [37] or unable to intervene in a classroom incident of microaggression or bias that may further traumatize a student holding a marginalized identity [38]. Meanwhile, faculty holding an identity that has been historically excluded in STEM may be subject to microaggressions from students holding majority identities when they initiate these conversations in their courses [39], [40]. Use of the frameworks described above and other models for engaging in these discussions in an effective way [41] may help to allay some instructors' concerns.

Formalizing social justice content into coursework solidifies its importance in engineering

These examples illustrate that it is possible, and even beneficial, to include social justice topics in engineering courses. These examples, along with resources like "Advancing Inclusion and Anti-Racism in the College Classroom: A rubric and resource guide for instructors" [42], "Toward an antiracist engineering classroom for 2020 and beyond: A starter kit" [43], and Inclusive Teaching pedagogies [44], [45] provide a framework for helping students engage in discussions of engineering research's impact on society. However, we have yet to find an example of an introductory level course that discusses these topics geared toward the professional development of graduate engineering students within a broad range of career and research interests. Thus, we sought to develop a course that would help graduate student researchers understand the terminology around inequities and justice; interrogate well-known cases of engineering research across a range of applications, technology, and higher education

bias and discrimination; reflect and discuss how their own research areas impact society; and form a plan for how they may address or actively prevent potential injustices. The course also featured opportunities to develop a shared lexicon for ARDEI concepts and interrogate one's own identity and positionality.

By making this a required course, we set the expectation that considering the societal impacts of research is an important and natural part of the entire research process. We chose to expand an existing professional development course for graduate students that originally solely covered topics like laboratory safety, library use, grant writing, and communication, to include ARDEI and social justice content. Into this predominately passive content, we added active and complex reflections and discussions of identity, bias, and (in)justice. We believe that developing this reflective skill early sets students up to think about social justice and the impacts of their research throughout grad school, and hopefully beyond. Our main goal was to help graduate student researchers feel equipped to interrogate how their engineering research projects impact society and how their work promotes or impedes social justice.

Our methods and preliminary findings aim to encourage and enable other engineering departments to adopt a similar approach

What we present in this work-in-progress paper is the effort to create and mandate this course as well as the findings from our initial dataset. While it is early in this endeavor and we have insufficient data at present to form final conclusions about the success of the course, we aim instead to speak to our approach and our preliminary–but encouraging–findings. In addition, we understand that the path to becoming an anti-racist and socially just researcher is not completely linear; it is complex and nuanced as students challenge their ways of knowing. Regardless of what the path looks like, or how circuitous it is, our goal remains to provide graduate students with the skills to become socially just engineering researchers. This paper outlines the process of creating a course for graduate students that helps prepare them for engineering research with equity and justice in mind. By outlining the course development, structural components, and the initial findings from the first offering of the course within our 3-year longitudinal study, we hope to provide other engineering departments with encouragement and a starting point to adopt a similar approach to training future engineers.

METHODS

ARDEI content was readily incorporated into an existing graduate student course

The two options for introducing ARDEI content into the graduate student curriculum were to create a new course or integrate content into an existing course. We chose to integrate content into an existing Professional Development Course in order to minimize extra time first-year graduate students would spend in class and to emphasize the importance of learning ARDEI concepts alongside traditional professional development topics such as research safety, university library usage for research, presentation and writing skills, and fellowship writing. Finally, changing an existing course is logistically easier from the program- and university-approval process standpoint than creating a new course. Each class is held for one hour each week. The pre-existing course was split into two sections, providing more opportunities to

incorporate ARDEI content while simultaneously exposing students to the course material at more relevant times during their graduate career. This structure creates continuity for students by offering Part 1 during the first quarter of their initial year of study and Part 2 is offered during the first quarter of their second year of study. The course was also codified into the required curriculum for Ph.D. students and made optional for M.S. students. This codification means that the content is mandatory and truly a part of the training the program provides. Thus far, one instance of Part 1 of the course has been completed. This study received IRB exemption; consent was obtained from student participants, and student data was provided anonymously.

The instructor and teaching assistant were carefully selected and trained

For the first iteration of the course, we chose a faculty instructor who was and continues to be involved in the development of the course. The teaching assistant (TA) was chosen through an application process and assessed with a rubric. Applicants provided their resume and answered an essay response on why they would like to hold the position and what they would bring to the class. This application process ensured the chosen TA had a demonstrated desire to engage in ARDEI related discussions. This TA-ship is counted as equivalent to a technical course as one of the required TA-ships for Ph.D. program completion. The faculty instructor, faculty co-lead of the ARDEI Committee, and department chair determined the best candidate. Both the instructor and TA were required to attend personalized training sessions held by the teaching and learning center on campus. Sessions included content on how to create an inclusive teaching environment, how to foster discussion, and how to handle "hot moments."

Course assignments were minimal and in-class discussion was prioritized

The vast majority of learning in the course took place during class time. Students were encouraged to actively listen to lectures and participate in discussions. Outside of class, the sole submitted assignment each week was a journal entry. Journal entries were completely anonymous and consisted of two parts: one submitted and one private, unsubmitted reflection on the week's topics.

Various types of data were collected to assess the effectiveness of the course

Different types of data were collected to assess the effectiveness of the course and the comfort of students in the class. Three surveys were conducted: prior to the start of the course (pre-course survey), at the midpoint of the course (mid-course survey), and after the course (end-of-course survey). The pre-course and mid-course surveys were open for approximately two weeks, while the post-course survey was open until a month after completion of the course. We chose to continue collecting responses for the post-course survey to have adequate data to compare to the other surveys, as students were less responsive at first, likely due to final exams and the winter recess. Surveys were collected anonymously. Students had a unique identifier unknown to the analysis team that was then matched to prior survey responses throughout the quarter to track each individual's sentiments over time.

In addition to the surveys that we developed, data from the university course evaluations were used as well. University course evaluations are distributed to students for every course at the end

of the quarter and contain questions regarding the course, instructor, and teaching assistant. The results of the university course evaluations are anonymous and publicly available for viewing.

The journal entries that students anonymously submitted throughout the course were also used for analysis. These provided immediate reactions to the content with guiding questions and encouraged honest responses.

Content was constructed to meet course objectives over the two quarters

Course objectives:

1. Provide new graduate students in the Department of Chemical and Biological Engineering with some of the skills they will need to be successful in graduate school.
2. Define terms related to ARDEI such as anti-racism (white supremacy, abolition, militarization), diversity, equity, inclusion, implicit bias, intersectionality, positionality, identity, systemic racism.
3. Explain how inequity, injustice, and exclusion impacts STEM in contexts such as developed technology, scientists, funding, etc.
4. Collect 3-5 scholarly resources on a chosen topic and demonstrate how the resources fit within ARDEI to aid in their and others' learning to determine the extent/depth of racism in STEM and STEM outcomes.
5. Analyze intersections between technological development and systemic racism through the use of case studies.
6. Recommend tangible actions for combating racism in given research applications and work environments.
7. Develop an action plan for how they (the student) will practice anti-racism in their science, work, and daily life considering their identity and positionality.

The schedule for the course is shown in Table 2 and Table 3, where each class lesson is one hour in length. Only classes related to ARDEI concepts are included. For Part 1, incidental objectives are those which we observed to be included in the class session after its implementation; a more in-depth discussion can be found in the Results section of this paper. These are not included for Part 2 since an instance of the class has not yet occurred (Table 3). All course materials were available to students on Canvas. A page was created for each week with optional pre-class reading material. After each class, resources were added to the page depending on the class discussion in order to further provide students with materials.

Table 2. Northwestern University CHEM E 520-0 Professional Development Course in Chemical and Biological Engineering 1 ARDEI-related lesson and assessment plan.

Week	Lesson Plan	Assessments		
		Activity	Intended Objective(s)	Incidental Objective(s)
Ongoing /Weekly	All	Journal reflections	7	N/A
2	Why this course? Definitions	Groups of 3-4 students were given a set of 3-4 ARDEI-related terms. Students provided definitions on sticky notes and then rotated to other groups to include their own thoughts. Definitions from cited sources were then shared with the class.	2	N/A
4	Identities	Students completed two identity wheels	2-3	N/A
6	Case studies/ Examples (provided) on impact of tech, hiring process, etc.	A case study on bias in artificial intelligence (AI) was presented to the class with discussion questions interspersed throughout. Students discussed real-world examples of such bias and explored how technology can be improved to minimize negative effects.	2-3	4-6
7	Case studies/ Examples (provided) on impact of tech, hiring process, etc.	Groups of 3-4 students were assigned a different part of a case study regarding inequities in academia. The four sections were: entrance to college, entrance to graduate school, post-doc/faculty hiring, and the tenure process. Students progressed through their sections on Canvas pages and shared final thoughts to the whole class at the end.	3	4-6
10	Review ARDEI	Students proposed discussion topics on a discussion board in Canvas prior to class. These topics included some discussed in class, and some not. Instructors prepared material to help guide conversation.	2-3	N/A

Table 3. Northwestern University CHEM E 520-1 Professional Development Course in Chemical and Biological Engineering 2 ARDEI-related lesson and assessment plan.

Week	Lesson Plan	Assessments	
		Activity	Intended Objective(s)
Ongoing/ Weekly	All	Journal reflections	7
1	Review of ARDEI Quarter 1	N/A	2-3
3	Literature review on chosen topic	Gather sources and reflect	4
6	Case studies (provide information, minimal guidance on analysis so students do analysis themselves) on impact of tech, hiring process, etc.	Analyze and reflect on case studies individually with little guidance	5
8	Recommend actions for combating racism in given research applications and work environments	Discuss provided scenarios in class all together	6
9	Recommend actions for combating racism in given research applications and work environments	Discuss provided scenarios in breakout rooms in smaller groups	6
10	Develop individual action plan for practicing anti-racism in science, work, and daily life	Complete guided worksheet to develop action plan and interview rotation PIs about anti-racism and DEI in specific labs	7

RESULTS

Students reported an increased ability to meet course objectives over time

Students were asked directly about their ability to meet each of the six course objectives in the pre-course, mid-course, and end-of-course surveys in order to directly assess student perception of these important skills over time. We found that there was improvement over time in all objectives, with the majority or highest frequency response shifting from “somewhat agree” to “strongly agree” in all cases (Fig. 1). However, there were more significant and earlier shifts in self-assessed performance for objectives 2, 3, and 5 compared to objectives 4, 6, and 7. We attribute these differences to the inherent course structure, which guides which objectives are the explicit focus of each quarter (Tables 2 and 3). In the first and second quarter, ARDEI-related objectives 2-5 and 4-7 are the focus, respectively. The first quarter of this course creates the foundation on which students will build. This is done explicitly through providing definitions and walking through several examples and case studies of the impacts of inequity in STEM, which parallels objectives 2, 3, and 5. These case studies contain a variety of scholarly resources for further exploration, but students are not necessarily asked to seek out any themselves until the second quarter portion of the course (Objective 4). Similarly, within the case studies or journal

reflections, students were asked to think about possible corrective actions or solutions to address the inequity highlighted in the case study; however, this will be covered more significantly and with direct relation to student lives and work in the second quarter of the course (objectives 6 and 7). Thus, we believe the structure of the course enabled explicit learning of objectives 2, 3, and 5 while the increase in ability to perform objectives 4, 6, and 7 was due to implicit learning from exposure, which can be further enhanced in the second quarter of the course with explicit coverage.

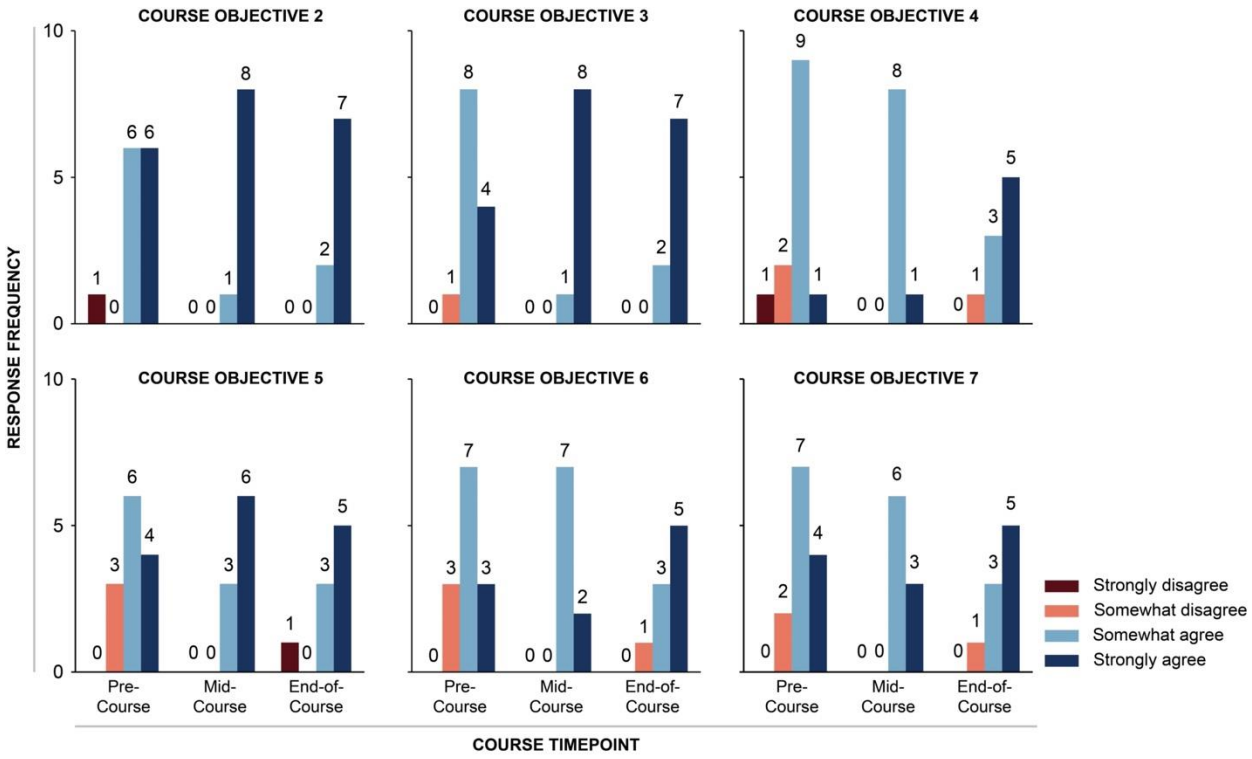

Figure 1. Student self-assessment of ability for each of the six ARDEI-based course objectives over time. Number of students at each time point (pre-course, mid-course, and end-of-course) who indicated the degree to which they agreed with statements asserting that they are able to do each of the ARDEI-related course objectives (2-7) using a 4-point Likert scale ranging from “strongly disagree” to “strongly agree”.

Student comfort in engaging with social justice concepts reached a maximum midway through the course

It is important to gauge student comfort with ARDEI and social justice concepts throughout the course, as one goal of the course is to increase comfort in engaging with these topics to facilitate this engagement beyond the course setting. Thus, students were asked about their comfort in 1) discussing social justice concepts within the context of engineering/science with peers and faculty, 2) confronting their own biases related to race or other forms of identities, and 3) reflecting on their own past experiences with incidences of perpetuating or experiencing racism, inequity, or injustice at all survey time points. Interestingly, student comfort in all three categories increased by the course midpoint but decreased again by course end (Fig 2A). We primarily attribute this to two factors: (1) students reckoning with the scope of inequity and (2)

distance in time from the course. While the course gave students an initial increase in comfort level provided by a shared foundation of definitions and basic examples, we believe that as the discussions and material became more complex and highlighted the scale and scope of inequity in STEM, students realized the limitations of their knowledge and comfort with these topics. For example, one student noted in the Week 2 reflections that "*before I had only thought about equity, race, and racial justice; however, after the second week, I knew more about different terms that were related to the ones I had known before*". Another student noted that they "*[had] previous exposure to these terms*", yet they were "*particularly struck by the definition of privilege. I had some idea of what it meant, but I had never seen it formally defined before*", indicating that even students who have engaged with ARDEI concepts in the past were able to recognize gaps in their knowledge. This initial increase then subsequent decrease in comfort level parallels the framework of moving from unconscious novice to conscious novice in the stages of the development of mastery framework [27], [46]. The second influencing factor is the time during which they took the end-of-course survey, which was available immediately following the final class and stayed open for a few weeks. Those who filled out the survey right at the end of the quarter tended to have a higher rating for comfort (generally "strongly agree") compared to those who filled it out a later date. We believe it is likely that being asked these questions with time and distance from the course induced student reflection on their comfort with these topics more within the context of their lives, which perhaps presents additional discomfort compared to the course setting with which they had grown accustomed. Our hypotheses on the result of the plateau in comfort level in all areas are supported by the students' reported initial and continued belief that the course would and did increase their comfort in discussing ARDEI concepts (Fig. 2B). These data revealed an increased comfort even for those who reverted to an uncomfortable state by the end of the quarter, and provides evidence against interpretation that the course decreased their comfort level.

Further, qualitative responses provided additional evidence that this course supported students in engaging more comfortably in these discussions. We analyzed student journal entries to assess comfort levels with engaging with ARDEI concepts over time. For example, after the Week 2 lesson on ARDEI-related definitions, we asked students "How comfortable do you feel using these terms before and after this session?". Out of 15 students, 10 students indicated that they were more comfortable, some of which noted that their comfort was independent of having prior exposure to these terms. Four students indicated they were either already comfortable or did not specify whether there was a change before and after the lesson. Only one student indicated that they were still uncomfortable actively using the terms, but they noted that they did experience an increase in understanding. By the end of the quarter, when asked to reflect back on their learning, one student said "*I feel more confident in having conversations about topics like discrimination in academia.*" Additionally, when asked by the survey to summarize their reactions to the course, one student noted that "*the discussions offered in this course were very helpful in getting perspectives of challenging concepts to discuss amongst others. I am much more comfortable and aware of ARDEI in graduate school, which will be very helpful further in my studies".*

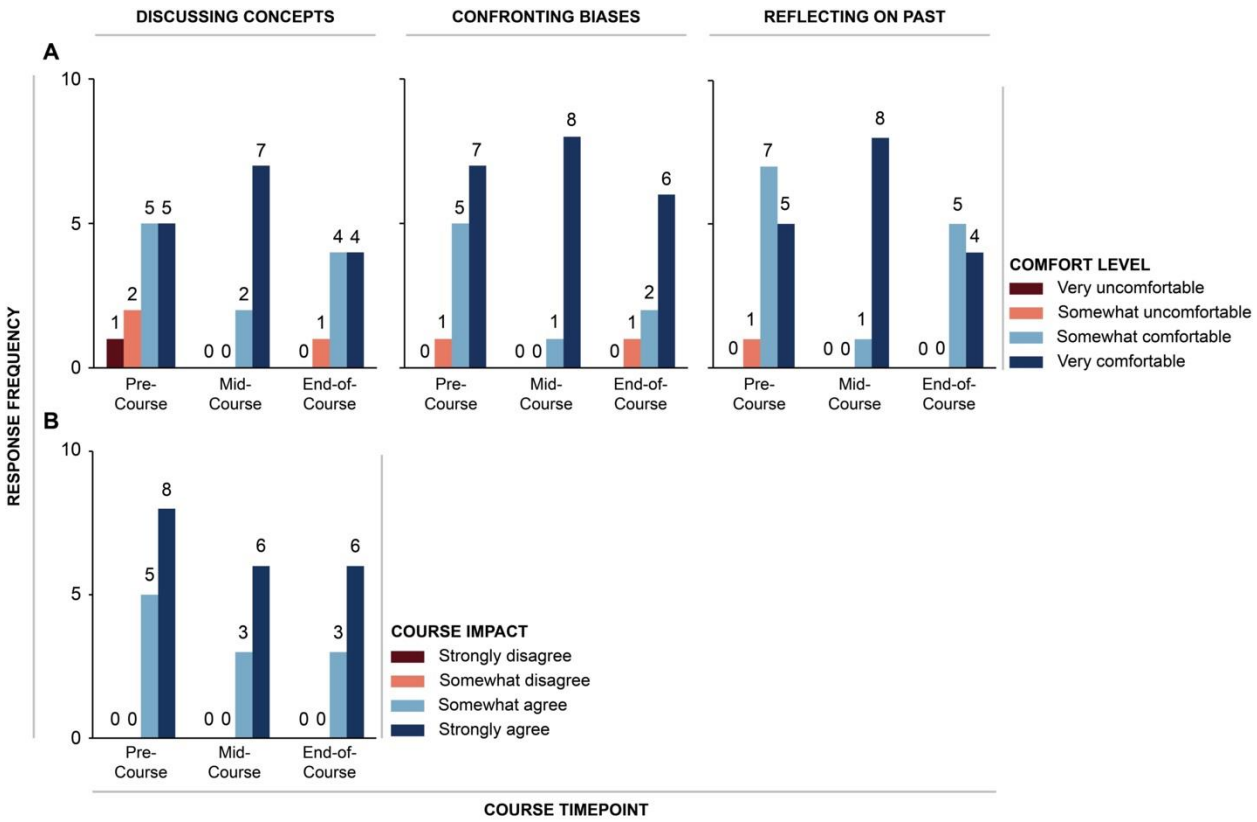

Figure 2. Student assessment of and impact of course on comfort level with engaging with ARDEI-related topics over time. A) Number of students at each time point (pre-course, mid-course, and end-of-course) who rated their level of comfort in "discussing social justice concepts in the context of engineering and science with peers and faculty" (discussing concepts), "confronting my own biases related to race or other forms of identities" (confronting biases), and "reflecting on my own past experiences with incidences of perpetuating or experiencing racism, inequity, or injustice" (reflecting on past). Comfort level survey questions at each time point were conducted using a 4-point Likert scale ranging from "very uncomfortable" to "very comfortable". **B)** Number of students at each time point who indicated the degree to which they agreed "the course will increase (pre-course)/increased (mid-course and end-of-course) my comfort in discussing ARDEI concepts". Course impact survey questions at each time point were conducted using a 4-point Likert scale ranging from "strongly disagree" to "strongly agree".

The course increased student confidence in connecting social justice topics to their research and daily lives but confidence level plateaus at the mid-course point

Increasing student confidence in connecting social justice topics to their research and daily lives, from the lab to implementation, will facilitate willingness and ability to engineer considering social justice. This increased confidence and facilitation of engagement was one of the goals of the course; we found that confidence level increased from the start of the course but plateaued at the midpoint (Fig. 3). We believe the plateau represents both a recognition of the complexity of these topics, and the inherent idea that some people, particularly those holding majority identities, may never be fully comfortable with these topics due to lack of lived experiences or fear of causing harm.

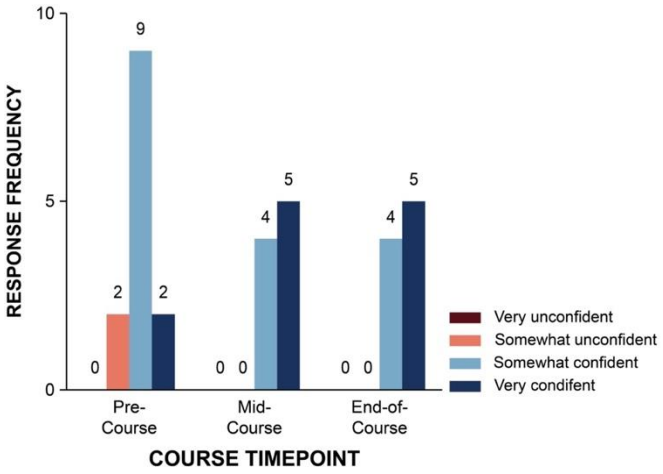

Figure 3. Student assessment of confidence in connecting ARDEI concepts to activities beyond the course over time. Number of students at each time point who rated their level of confidence in "connecting concepts learned in this course with your own research and daily life, on the research-scale all the way to potential implementation". Confidence level survey questions at each time point (pre-course, mid-course, and end-of-course) were conducted using a 4-point Likert scale ranging from "very unconfident" to "very confident".

The course increased student motivation and ability to tangibly incorporate ARDEI concepts into their lives

Independent of where student motivation and ability to tangibly incorporate ARDEI concepts into their research and daily lives began, we hypothesized that the course would have a positive impact on these factors. To quantify these characteristics, we asked students about both their self-assessed motivation and ability to do incorporate these concepts at all time points, as well as whether they felt the course had an impact on these factors. While students largely started off and remained motivated, the two students who started off indicating they were not motivated became and remained motivated by the mid-course timepoint (Fig. 4A). To confirm the course is the result of this impact, we asked students directly if they believed the course would and did have an impact on this motivation directly (Fig. 4B). Students initially reported being hopeful about the course's impact, and this assumed impact was later reported as confirmed at the mid-course and end-of-course time points. Notably, the only person who did not think the course would have an impact on their motivation later noted the course had a strong impact on them—indicating the ability of the course to reach even those who are not initially engaged or interested in thinking about ARDEI.

Meanwhile, students reported a mixed, but overall positive, ability to tangibly incorporate ARDEI concepts into their research and daily lives (Fig. 4A). While the number of positive results did not appreciably change throughout the course, as many of the objectives that help students with this more tangible incorporation are the focus of the second quarter of the course, only one initial "disagree" respondent was unaccounted for over time due to lack of continued response, while the other two moved to a positive response by the mid-point. Notably, even some of the respondents who initially strongly agreed came to somewhat agree with the statement at

later time points. While this might seem as if the course is having a negative impact on some students' reported ability to tangibly incorporate ARDEI concepts into their lives, when asked directly if they believed the course would or did have an impact, the overwhelming response was positive, even for students whose assessment of their tangible ability decreased (Fig. 4B). The two students who initially did not think the course would be helpful in supporting this type of engagement in their lives later reported that the course did have this impact. This speaks further to the course's ability to reach even students who are not initially engaged, as tangible incorporation is steps beyond simply having the motivation to make change.

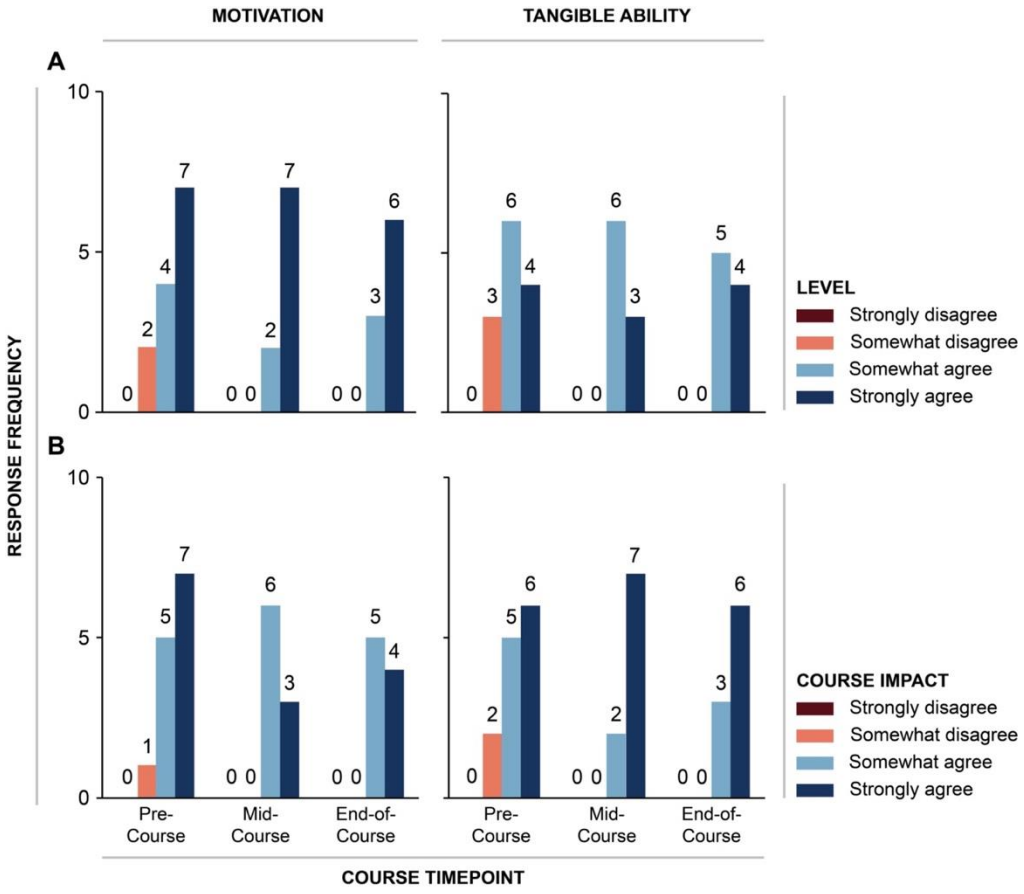

Figure 4. Student assessment of level of and course impact on level of motivation and tangible ability to incorporate ARDEI concepts into their lives over time. A) Number of students at each time point (pre-course, mid-course, and end-of-course) who rated how strongly they agreed with the statement that they are "motivated to incorporate ARDEI concepts into my research and daily life" (motivation) and "able to tangibly incorporate ARDEI concepts into my research and daily life" (tangible ability). **B)** Number of students at each time point who indicated the degree to which they agreed that "the course will increase (pre-course)/increased (mid-course and end-of-course) my motivation to incorporate ARDEI concepts into my research and daily life" and "the course will increase (pre-course)/increased (mid-course and end-of-course) my ability to tangibly incorporate ARDEI concepts into my research and daily life". All survey questions at each time point were conducted using a 4-point Likert scale ranging from "strongly disagree" to "strongly agree".

In addition to asking students to self-assess their ability to tangibly take actions, we analyzed their journal entries associated with case study lessons to quantify the number of suggestions they proposed when asked to explain their role in addressing inequity (Table 4). Overall, most students were able to propose more than one concrete suggestion related to their role in combating inequity in both a case study that is more removed from student work and experience directly (case study in AI) and a case study that is directly related to current student environment and experience (case study in academia). This analysis provides further evidence of student ability to suggest tangible actions, which is in alignment with our assessment that the course is positively impacting this skill. Additionally, this speaks to how Course Objective 6, which entails recommending tangible actions, was not a specific focus of the lectures but was implicitly learned and demonstrated by example in case studies and reflections in journal entries.

Table 4. Number of student proposed suggestions to combat inequity related to case study topics based on journal entries.

Number of ARDEI-Related Suggestions	Week 5: Case Study – Bias in AI (Number and % of Students)	Week 7: Case Study – Inequities in Academia (Number and % of Students)
0	0 (0.0%)	1 (6.7%)
1	4 (26.7%)	5 (33.3%)
2	8 (53.3%)	6 (40%)
3	1 (6.7%)	2 (13.3%)
4	2 (13.3%)	1 (6.7%)

The course structure supported students in meeting the course objectives

In order to determine if the course structure—including assignments, organization, materials, and interactions with peers, faculty, and TAs—was well received by the students and fostering the benefit we hoped to achieve, we analyzed the longitudinal survey in addition to the university course evaluations. While the course was low commitment, requiring 3 or fewer hours a week from students, students reported significant learning gains and overall satisfaction with the course (Table 5). Much of the course is designed around discussion during class time, and hinges on positive and fruitful interactions with peers, faculty, and TAs. Students reported initial and continued belief that these interactions and discussions increased their ability to engage with ARDEI concepts (Table 5, Fig. 5)—including those who initially did not think interaction with the faculty and TA would be impactful. The importance of these discussions was also highlighted in qualitative responses, such as "*the class open discussions were really great to allow to hear a wide variety of perspectives on individual topics and hear about people's personal experiences with ARDEI related issues in both negative and positive contexts*".

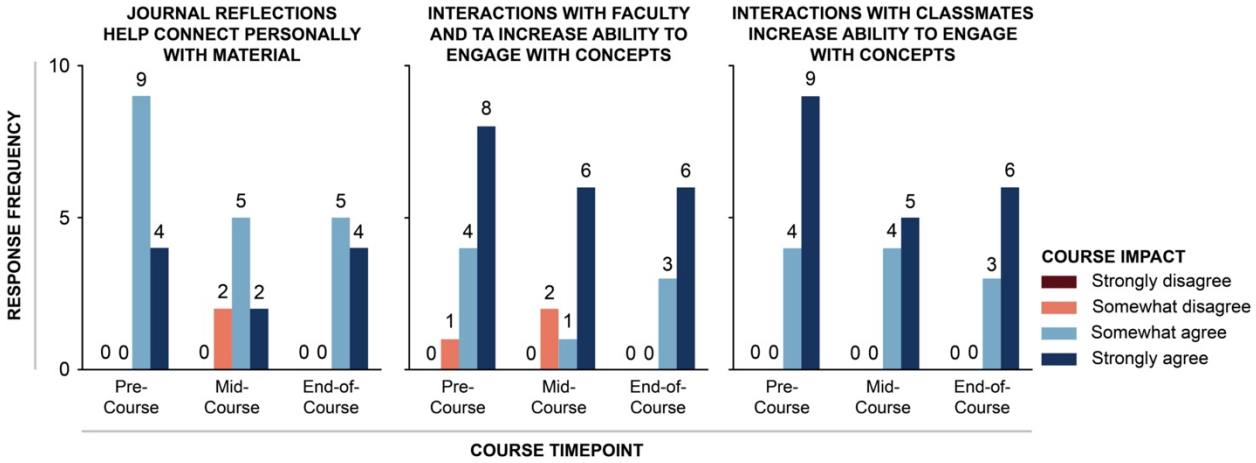

Figure 5. Impact of course structural features on various aspects of student learning. Number of students at each time point (pre-course, mid-course, and end-of-course) who rated how strongly they agreed with the statements that "the journal reflections will help (pre-course)/helped (mid-course and end-of-course) me connect personally with the material", "interactions with the faculty and TA will increase (pre-course)/increased (mid-course and end-of-course) my ability to engage with ARDEI concepts", and "interactions with my fellow classmates will increase (pre-course)/increased (mid-course and end-of-course) my ability to engage with ARDEI concepts". All survey questions at each time point were conducted using a 4-point Likert scale ranging from "strongly disagree" to "strongly agree".

Notably, several students also commented on the discussion environment in both the university administered end of term surveys and the journal entries. In the last journal entry, students noted that "*this class has been incredibly useful for me to have conversations with my peers about topics on diversity, inclusion and safety in the context of engineering and beyond. I am very grateful for the opportunity to have had these meaningful conversations, and I am excited to take this with me as a researcher in my future career*". Another student noted that "*it provided us a weekly space to share our thoughts as a group on what is currently going on in our lives. I also think it provided an opportunity for all of us to come together as a class to talk about issues that are typically glossed over in higher education, and learn more about each other as a cohort*". In the end of term surveys, students wrote "*this course was discussion–centric and maintained a safe environment while doing so, which made it very easy to learn about some challenging ARDEI topics*" and "*I appreciated how we discussed very heavy ARDEI topics in a safe environment*." This highlights how the measures we used to create a safe environment for these discussions—such as setting up community guidelines—were key to the success of this course.

The assignments used were overall of strong benefit and connection to the course. While journal reflection assignments were met with mixed reviews in terms of benefit throughout the quarter, we attribute this largely to different styles in and preferences for learning and engagement with material. (Fig. 5) Students reported that the course challenged them intellectually, effectively integrated theory and practice, and included assignments that stayed consistent with the course (Table 5). Additionally, students reported the course organization and texts proved beneficial. Thus, overall, we believe that the course structure is a strong asset to the course in helping students meet the objectives.

Table 5. Summary of university course evaluation questions and results.

Question	Number of Responses	Average	Standard Deviation	Interpretation
Hours spent on course per week	10	3 or fewer	0	Course has minimal external requirements on student time but is still able to provide significant benefit.
Overall course rating	11	5.27/6.00	1.42	Course is well-rated despite potentially sensitive nature of the material.
How much you learned in the course	10	5.10/6.00	1.73	Students gained significant learning from the course.
Effectiveness of challenging intellectually	9	4.78/6.00	1.92	Students were challenged intellectually, as concepts may have been new to many students.
How well assignments stayed consistent with course	10	5.30/6.00	1.06	Assignments support and are directly connected to the course objectives (Figure 1).
How well course effectively integrated theory and practice	10	5.50/6.00	0.97	Course content was clearly tied to goals and students' research/lives; the content was action-driven.
How well organization of the course facilitated learning	10	5.40/6.00	1.07	The lesson plan outline provides a well thought-out course that supports students through the course objectives.
Rate the texts used in this course	8	5.88/6.00	0.35	While there was not a textbook, the provided (developed or sourced) resources before, during, and after class were deemed useful.
Rate how well this course helped you improve your ability to solve real problems in the field	10	5.10/6.00	1.66	Content was actionable and related to students' research areas and the field of chemical engineering.
Rate how well the lab/discussion section made an important contribution to the course	8	5.75/6.00	0.46	Discussion during class, which was the majority of the class, was helpful and productive.

DISCUSSION

Students displayed changing locations in stages of competence with course content

One of the most interesting observations we found was how student responses changed with time regarding questions of confidence. As discussed, students who begin the course with a lack of confidence in the material and their ability to apply it progressed through the course with an increasing sense of confidence. Conversely, many students who began the course with a high level of confidence wavered as the course continued. We find these observations analogous to the stages of competence [27], [46], though competence can be redefined as confidence here. Students who began with a lack of confidence started with conscious incompetence, or awareness of what they did not know. As they gained knowledge with time, they moved to a place of conscious competence, or learning. Students who began in a place of confidence started with unconscious incompetence, or ignorance of the scope of what they did not know. To be clear, this is not a negative place to start; rather, it emphasizes the ability of the course to show students – even those who are aware of ARDEI to some extent – the wide expanse of ARDEI concepts, particularly when intersected with STEM. With time, confident students either became slightly less confident or moved to a place of some lack of confidence. We attribute this to moving to a place of conscious incompetence, or awareness. We believe that the second quarter of this course will allow all students to have a mixture of conscious incompetence (awareness of what they do not know), conscious competence (recognition of what they are actively learning), and unconscious competence (mastery of some material).

Students learned in course, but recognized more learning is needed for application

Another similar observation is related to questions about the course's impact versus students' ability to apply concepts to their research and general life. The course was largely viewed as more or equally helpful at the end of the course when compared to the beginning, demonstrating the success in teaching students about ARDEI and advancing abilities to discuss such concepts. However, when asked about applying these skills to their lives, students felt either the same level of confidence or less confident. We attribute this again to their realization of what applying such complex and nuanced concepts means; with a greater appreciation for the content and its scope, students perhaps recognized the care one must take to properly apply these lessons to the real world.

Implicit and explicit learning allowed multiple objectives to be touched

As discussed earlier, objectives that were originally intended for the second quarter of the course were sometimes marked as met by students later in the first quarter of the course. This was unintentional in the design of the course but is a welcome side effect of the material. We believe that this early exposure will make the second quarter of the course even more effective, as students have already begun unconsciously considering them. Furthermore, we believe that students will once again realize what more they have to learn about these objectives as they begin explicitly learning about them. In this case, we might expect another dip in confidence towards course content while hopefully maintaining perceived course value.

Students found this course to be unique, and they wanted continued engagement with social justice concepts

Several students indicated finding this course to be unique and both personally and professionally beneficial. For example, when asked on the university course evaluations to summarize their reactions to the course, one student noted that "*learning about ARDEI concepts in the context of STEM in a formalized way was new to me, and I found it very helpful*". On the same survey, when if the course helped them learn, another student said "*Absolutely! This course helped me contextualize my identity in grad school and research in such a helpful way. I deeply appreciate all of the information about resources for grants, TAing, safety, and mental health. I also really enjoyed the opportunity to learn how equity plays a role in research and science*." These examples, in addition to the quantitative data above, highlight the impact that this type of course can have on students. Further, when asked for suggestions for improvement, while most students did not list anything or explicitly wrote "*N/A*", one student noted that *"the course could include discussions of ARDEI, diversity/identity focused initiatives graduate students could get involved in".* This indicates student desire to take concrete action in their communities following engagement with this course, highlighting the ability of the course to spark an interest in making a change themselves.

Students benefitted from the first quarter of the course, and the second quarter will continue these gains

The codification of ARDEI concepts into the course and first year graduate students' curriculum, careful design of the course, and subsequent implementation resulted in overwhelmingly positive reviews from students. The goal of the course to make ARDEI concepts an integral part of graduate student training has thus far been successful. Future studies will include an analysis of the same cohort of students participating in the second quarter of the course. This will allow for a complete review of the course. Another cohort of students will also be studied, following any changes to the course which are deemed necessary from student, instructor, and TA feedback. We are hopeful that the second quarter of the course will allow students to move into the implementation stage of the course, in which concepts they learn can readily be applied to their graduate school research, career beyond graduate school, and everyday life. Based on some comments in the final journal reflection—students share the belief that the second part of the course will be similarly enriching. For example, one student noted: "*truthfully, I think I got more out of this class than I initially expected to coming in.... I thoroughly enjoyed this class and I am excited to take the next installation of it*". With this ultimate achievement, more holistically trained researchers and engineers will be able to enter the workforce.

AUTHOR CONTRIBUTIONS

KC conceived of the idea for the course. KC, ANP, CMA, AED, BD, RL, JJR, LCS, and JLC designed and proposed the course for approval by the department and university and developed course objectives and content. JLC served as the course instructor and KC served as the course teaching assistant and managed the data collection. KC, ANP, and JLC designed and conducted the study, applied for IRB approval, analyzed and interpreted results, and drafted the manuscript. CMA, AED, BD, RL, JJR, and LCS provided feedback on the manuscript.

KC is the first author of this paper. ANP is the second author. CMA, AED, BD, RL, JJR, and LCS are co-third authors. JLC is the corresponding author.

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