CREATING AND IMPLEMENTING COURSE CONTENT CONTEXTUALIZED WITH ANTI-RACISM AND SOCIAL JUSTICE IN CHEMICAL ENGINEERING: HOW FACULTY AND STUDENTS ENGAGED IN THE PROCESS

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INTRODUCTION

The field of chemical engineering interacts strongly with various technical areas that advance energy, medical, and commercial technologies to impact and ideally improve climate change, quality of life, and economic outcomes. Each of these areas intersects with all members of society, but the traditional engineering curriculum engages in depoliticization and decontextualization.[1] Removing this context obscures how these technologies differentially harm, benefit, are developed by, or reach communities with varying identities, where these differences either result from or exacerbate societal inequities.[1-3] Thus, engineering curricula often fail to engage with the principles of anti-racism, diversity, equity, and inclusion (ARDEI) and social justice (defined in Table 1) and how these concepts can be fostered, or hindered, by engineering decisions.[3]

There is a great need to reflect on and engage with this ARDEI and social justice context in our classrooms, particularly reflecting on the intersection of chemical engineering content with marginalized communities. At a minimum, integrating this context into coursework will give students the chance to consider the positive, negative, and/or disparate impacts of engineering decisions on communities, particularly for communities with identities different from that of their own.[3] In the long term, reframing engineering curricula through a social justice lens will not only help students learn to design robust solutions that meet needs equitably, but it will also encourage critical thinking about how to *define* problems [3] and how to take community-engaged approaches that center and include affected communities in engineering efforts.[4]

Some educators have made significant strides in integrating real-world context, current issues, and diverse communities into engineering curriculum, often in tandem with utilizing inclusive teaching pedagogies. Inclusive teaching practices and pedagogy already highlight how integration of diverse contexts, interests, contributors, and experiences increases inclusivity and engages students.[5-6] Hirshfield and Mayes wrote homework questions for reaction engineering courses that capture varied student interests (e.g., kinetics of baking, diamond rings, ethical considerations of commercial products) and current events (e.g., the Flint water crisis).[7] Riley implemented pedagogies of liberation by encouraging students to challenge traditional assumptions, power structures, and terminology often found in engineering curricula when teaching engineering thermodynamics [8] and wrote a textbook that reframes thermodynamics as energy, a more inclusive topic that is framed as a basic human need and that emphasizes student engagement.[9] Faculty have also incorporated social justice in core engineering classes such as mass and energy balances,[10] unit operations,[11] feedback control systems,[3] and numerical methods.[12]

While the above examples highlight the significant work done to integrate ARDEI and social justice contexts into curricula, this integration has not been done in a scalable way such that many or all faculty can teach a contextualized curriculum and students can continue this discourse throughout their degree. This is in part because faculty do not necessarily have the training, background, time, access to resources, or even confidence necessary to contextualize their curriculum. While some training that highlights the importance of

this work and general strategies to begin it has been provided to the larger chemical engineering community,[13-14] there is a need for sustainable, accessible, action-driven solutions that give faculty a starting point using the direct context of their own courses.

One low-cost, low-barrier, scalable option to integrate ARDEI and social justice context into curricula is to embed this context into homework problems. Context can be added either by appending it within existing problems or writing problems from scratch. This approach has several benefits. First, it presents an option that is a manageable time commitment, as writing technical problems at the appropriate level for students in any given course can be time consuming and difficult. Additionally, development of ARDEI-context homework problems would create a lasting and reusable resource that can be shared among faculty. Through this approach, students can consistently engage with this context in many courses if many faculty within a department commit to this work. Finally, this approach lends itself well to collecting feedback and adapting over time.

We created a workshop and lasting resource to provide faculty with a starting point for centering anti-racism and social justice in their engineering curriculum. The workshop, which is freely and publicly available via a website, provides faculty with training on how to incorporate ARDEI and social justice context into homework problems. We subsequently surveyed students on the impact of engaging with these questions and surveyed and interviewed faculty on the process of developing these questions. In this paper, we detail the content and format of the workshop, as well as the positive effects that engaging with these questions had on students to provide resources and motivation for other institutions to implement this approach as a first step to integrating ARDEI and social justice in their engineering curriculum.

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.

RESEARCH DESIGN

The researchers and authors of this paper are or were members of the Northwestern University Department of Chemical and Biological Engineering (ChBE) ARDEI Committee. We focused on committee initiatives related to engineering education, developed the workshop described in this paper, and conducted surveys to carry out this study. The IRB at Northwestern University determined that the study meets the criteria for exemption from further IRB review (STU00216756). Consent was obtained from student and faculty participants, student data were provided anonymously, and faculty interviews were de-identified.

Glossary of Terms Used

First, we define a glossary of common terms used in this text and within the workshops to provide readers with the same definitions and background we provided to participants (Table 1).

TABLE 1
Glossary of Terms

Term	Definition
Anti-racism	An active and conscious effort to work against multidimensional aspects of racism.
Diversity	Having people of different backgrounds, ethnicities/races, genders, sexualities, perspectives, and mental and physical ability present; note that the presence of a diverse group does not necessarily mean each member is being treated equitably or being supported as needed.
Equity	Providing support to people on an individual basis to ensure that each member of a group or community can participate equally.
Inclusion	The active, intentional, and ongoing engagement with diversity (in the classroom or broader communities) in ways that increase awareness, knowledge, and understanding of the complex ways individuals interact within systems and institutions. We note that this is a more traditional definition of inclusion, but we want to incorporate the idea that we are trying to create an environment and culture where members who have historically been excluded or marginalized are welcomed and accommodated within an organization or group.
Social Justice	The idea that all people, regardless of identity, deserve equal access, opportunity, rights, and to be treated fairly. Justice often includes the actions that lead to the dismantling of systems and structures that uphold inequality.

Faculty Workshop

The workshop for faculty was hosted in two parts, consisting of an asynchronous pre-work portion and a synchronous virtual workshop portion. Workshop attendance was voluntary, but all core and adjunct faculty were highly encouraged to attend by department leadership. All resources for the asynchronous portion were hosted through Canvas® (learning management system). The workshops and resources are described below and are all freely provided at the website: https://sites.northwestern.edu/ardeiquestionworkshop/. Materials can also be provided by contacting Jennifer Cole at jennifer-cole@northwestern.edu.

Asynchronous Workshop and Pre-work. We created an asynchronous pre-work section of the workshop, hosted through Canvas, to enable faculty to complete the workshop materials at their own pace and schedule. This pre-work took about two to four hours to complete during a two to three-week span in advance of the synchronous workshop. The goal of this pre-work was to provide context on the importance of integrating ARDEI context into courses, a baseline DEI terminology to provide sufficient background for all faculty, example ARDEI-context questions, and corresponding analysis using a harm prevention worksheet created by the ARDEI Committee (details in Table 2). Additionally, after faculty successfully completed and deployed ARDEI-context questions in their classrooms, their completed questions and corresponding solutions were added to Canvas for the continuous updating of resources and sharing of ideas. The Canvas site included separate pages on each of the topics shown in Table 2.

Example questions. We provided faculty with three example ARDEI-context questions written to highlight different types of question development (i.e., written from scratch versus adapting a textbook problem), methods of ARDEI-context integration (i.e., background information, problem solving, resource providing), and question engagement (i.e., resource utilization, brainstorming, reflection, technical problem-solving). Example questions were provided in the topics of fluid dynamics, separations, and kinetics and reactor design, and details about each question's content and method of question development are described in Table 3. Questions can be found on the workshop website, and solutions can be provided by contacting Jennifer Cole at jennifer-cole@northwestern.edu.

Synchronous Workshop. The synchronous workshops were hosted as one-hour virtual sessions, and faculty were expected to have completed the pre-work and brought in a question idea or a fully written question along with the completed harm prevention worksheet. The workshop began with a brief introduction, and then faculty were separated into breakout rooms with at least one other faculty and one workshop facilitator for discussion and feedback on their ARDEI-context question. The goal of this session was primarily to support faculty in question development through sharing resources and ideas, providing suggestions for edits or enhancements, and discussing how to address or prevent potential harm or trauma to students holding marginalized identities brought up by the question. Afterward, faculty were asked to complete a brief survey to assess utility and success of the workshop format and content at helping faculty develop ARDEI-context questions. (Contact the corresponding authors for the faculty survey instrument.) The workshop was given three times (twice in Summer 2021 and once in Winter 2022), and after receiving feedback from students on the ARDEI-context questions used in Fall 2021, we adapted the workshop slightly for Winter 2022 to address the student feedback, specifically encouraging and discussing adding lecture components to problems. We occasionally provided additional feedback if faculty made edits to their question after the synchronous workshop.

Question Deployment and Student Surveys

To assess the impact of ARDEI-context questions, we reached out to faculty teaching each quarter who participated in the workshop(s) to see if they planned to deploy the question in their course. For those who were, we provided faculty with a link to a Qualtrics® survey, where no identifying information was collected, to give to their students in order to assess the success and impact of the ARDEI-context question on student learning and association with chemical engineering and social justice concepts. (Contact Jennifer Cole at jennifer-cole@northwestern.edu. for the student survey instrument.)

Faculty deployed these ARDEI-context questions in a range of core and elective courses, where classes contained undergraduate students only, graduate students only, or a mix of both. Typically, these questions were integrated into homework sets; however, some faculty included lecture components or integrated ARDEI-context into course projects. The list of courses per quarter where data were collected is provided in Table 4.

Faculty Interviews on the Question Development Process

To further explore faculty experiences during the ARDEI-context question writing and/or deployment process, we interviewed faculty after engaging with the workshop and/or deploying questions in their classes. We aimed to assess common challenges and solutions to those challenges, as well as resources used, experience with question deployment, and feedback for future faculty interested in undergoing this question development. Questions that did not apply to a given faculty member were passed, such as if they had not yet used the ARDEI-context question in their class. (Contact Jennifer Cole at jennifer-cole@northwestern.edu for faculty interview questions.)

TABLE 2
Asynchronous Pre-work Content

Term	Definition	Resources
Definitions and Establishing Community Guidelines	Definitions of ARDEI-related terms; Explanation of community guidelines as a way to host discussions in a safe and inclusive way, leaving space for discomfort and reflection; Reflection on creating community guidelines in class	• Video explaining page contents • Definitions of common terms in the context of ARDEI discussions • Sample community guidelines
Reading: Incorporating ARDEI into Class Homework and Examples	Literature from *Chemical Engineering Education* about importance of integrating diverse topics into questions	• Video explaining page contents • During and post-reading reflection questions • Selected reading [7]
Example Problems	Example ARDEI-context questions written by ARDEI Committee members (fluids, kinetics, and separations) and a worksheet to help faculty reflect on whose voice is being uplifted by the added context in the question, and how the way the question is posed may prevent further harm to marginalized students	• Example fluids, kinetics, and separations questions • ARDEI Harm Prevention Worksheet • Video explaining example separations questions • Video explaining ARDEI Harm Prevention Worksheet • ARDEI Harm Prevention Worksheet filled out for separations question
Understanding and Preventing Harm	Explanation of why it is important to consider positionality and unconscious bias when discussing ARDEI topics, resources (Social Identity Wheel) for reflection on positionality and bias, and explanation of types of harm and the importance of understanding and preventing harm.	• Video explaining the importance and examples of inclusive teaching practices • Selected readings [7, 16-19] • Links to inclusive teaching resources provided by the teaching center on campus
Inclusive Teaching	Resources on inclusive teaching practices and a reading activity with reflection questions for a subset of the selected readings [7, 16, 17]	• Video explaining the importance and examples of inclusive teaching practices • Selected readings [7, 16-19] • Links to inclusive teaching resources provided by the teaching center on campus
Additional Resources	Links to external resources at and beyond the university aimed at supporting students and further providing information on integrating ARDEI context into STEM curriculum and classrooms	• ChBE Department and University resources ▪ Use of visual art in teaching engineering (document compiled by A. Abegunde) ▪ The NU ChBE Department's ARDEI Committee Website [20] ▪ Handout compiled by teaching center on campus about campus resources for supporting students • General and STEM Education Resources [21-23]
Completed and Draft ARDEI-Context Question Bank	Contains all faculty-written ARDEI-context questions and solutions to enable faculty to share resources and ideas; this page is continually updated as more questions are completed	• ARDEI-context questions and question solutions written and used by faculty who participated in the workshop and study (kept internal to institution's department)

TABLE 3
Example ARDEI-context Questions Provided with Asynchronous Workshop Content

Course	Question Description	Question Development Process
Fluid Dynamics	This problem focuses on how simple fluid dynamics concepts can be used to estimate the speed of a river current. The question is modified to incorporate ARDEI concepts by asking students to estimate the speed of the current of a contaminated river, specifically in Navajo rivers facilitated by uranium mining on Navajo Nation and Lakota Nation lands. Students are asked to think about the negative effects of uranium mining on the Navajo community as well as what safeguards could have been implemented to prevent such impact on communities. This should help students think beyond the financial benefit of chemical engineering projects and consider the societal impact of their decisions.	Adapted from a textbook problem by adding additional context, resources, and subparts
Separations	This problem focuses on the separation of hydrogen sulfide (H_2S) from a feed gas. The existing textbook question provides technical information about the problem and asks students to do calculations to determine what the separation output and number of equilibrium stages are. The question is modified to incorporate ARDEI concepts by adding both background and additional question subparts. The background included a preface describing what H_2S is, where it is found in drilling processes, and its dangers to human health to emphasize why the separation is necessary. Additional subparts added to the problem ask students to answer questions related to (i) H_2S regulation, (ii) a current event related to H_2S exposure, (iii) utilize the tool Social Explorer,[24] which gives students free (through a university sponsored account) access to past census data, to interpret the relationship between chemical plant locations and marginalized community locations by focusing on the area in the previously mentioned current event as a case study, and (iv) to make actionable recommendations to chemical systems producing H_2S above threshold levels.	Adapted from a textbook problem by adding additional context, resources, and subparts
Kinetics and Reactor Design	This problem focuses on how susceptible-infected-removed (SIR) ordinary differential equation models are used to understand the spread of disease. The problem walks through the kinetic equations describing the basic SIR model, and subsequently asks students to interrogate how population dynamics change as a function of changing transmission and recovery rates. Finally, to incorporate the ARDEI component, students are asked to think about how the ideal SIR model would need to change in the context of something like the COVID-19 pandemic, where disease spread and treatment were not equitably distributed among populations, and factors such as socioeconomic status, race, environmental conditions, access to health care, and underlying health conditions caused differences in disease dynamics, often most negatively impacting marginalized groups.	Written from scratch

TABLE 4
Course Information and Survey Response Rate for Courses Where Faculty Deployed ARDEI-context Questions

Core/Elective	Quarter	Undergraduate/Graduate/Mix	Number of Total Responses	Response Rate (% of Class)
Core	Fall 2021	Undergraduate	36	85.7%
Core	Fall 2021	Undergraduate	13	48.1%
Elective	Fall 2021	Mix	6	33.3%
Core	Fall 2021	Graduate	12	36.4%
Elective	Winter 2022	Mix	12	48.0%
Core	Winter 2022	Undergraduate	4	44.4%
Core	Spring 2022	Mix (Primarily Undergraduates)	15	39.5%
All Courses	2021-2022	Mix	98	51.0% of enrolled students

RESULTS

ARDEI-Context Question Writing Workshop Built Faculty Confidence and Supported Question Development

Quantitative responses to the post-workshop survey highlighted the impact of the workshop on supporting faculty in engaging with and writing ARDEI-focused content. Out of the 16 total faculty who attended, representing adjuncts as well as greater than 80% of core faculty, 14 faculty responded to the survey. After completing the workshop's asynchronous pre-work and synchronous sessions, faculty reported increased confidence in incorporating ARDEI and social justice topics into course and homework questions compared to before the workshop (Figure 1A). Additionally, nearly all faculty reported that they intended to use the ARDEI-context question that they wrote or brainstormed during the workshop and write additional questions for their future courses, highlighting the success of the workshop in helping faculty with both current and future question development (Figure 1B). Those who responded "maybe" to using and writing ARDEI-questions primarily indicated they wanted to do additional work to refine their questions rather than use them in their current form. Together, these findings speak to the success of the workshop in encouraging and preparing faculty to include ARDEI and social justice context into their course problem sets.

Qualitative responses to the survey revealed the key aspects of the workshop that faculty found most beneficial. Faculty attributed the workshop's success primarily to both the compiled resources, which gave them ideas and a shared vocabulary and starting point, as well as the discussion, which helped provide feedback, ideas, and specific resource procurement regardless of question stage. Additionally, during the faculty interviews, one faculty member commented on "*just how useful the workshop for faculty was to kind of break down some of the barriers. Just from faculty perspective of doing this, even though you want to do it…you don't know where to start or...you just ran out of time. But this kind of forced you to think about it ahead of time…just thinking through how to do more of this stuff…that's a really solid resource and…I think a major point of success.*" Given the resources provided in this paper, this workshop format could be recreated and deployed at other university settings, further expanding this work and enabling other faculty to undergo this training. For example, we have already adapted this workshop for other formats and settings, such as the American Society for Engineering Education (ASEE)/ American Institute of Chemical Engineers (AIChE) Chemical Engineering Summer School in 2022 where we presented a version of the workshop in a 90-minute format (without pre-work) to a larger audience including faculty from across the nation.

Faculty-Developed ARDEI-Context Questions Spanning a Variety of Topics

We interviewed 11 faculty members after the workshop and after many had deployed their questions to gain a better understanding of both the question-development process and the questions themselves. Of the 16 faculty members who attended the workshop, five wrote a question at the workshop and later used that same question in class (for one of which there is no student data as that class was taught after the student data collection period ended), two wrote a question in the workshop but later used a different question in class due to changing course assignments or change in class topic focus, and nine participated in the workshop but did not deploy a question in any class. Of these nine faculty members, four remained in the brainstorming and question writing phase throughout the data collection period, three

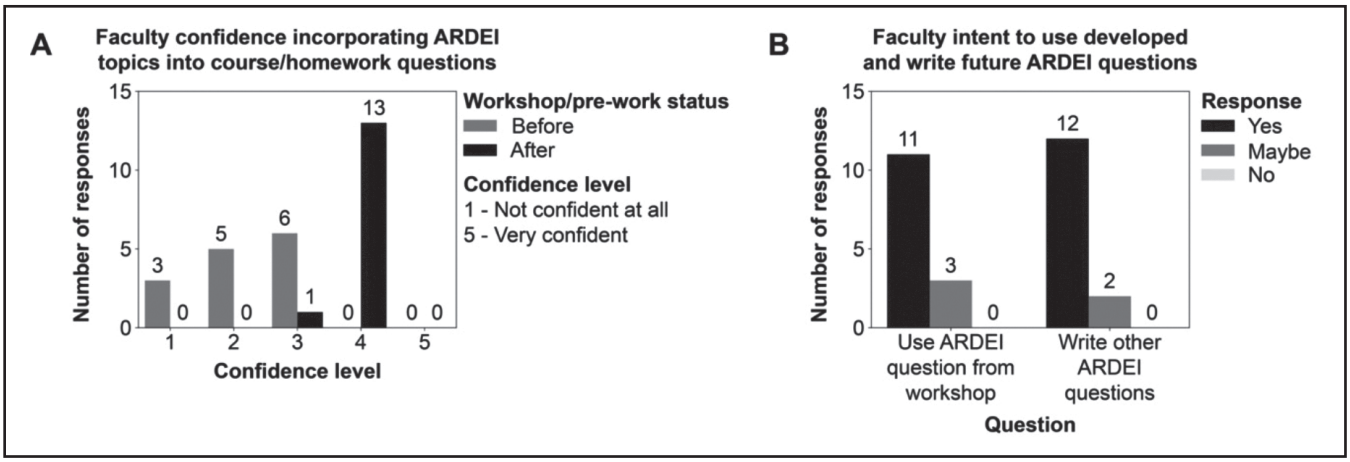

Figure 1*: Faculty engagement with the workshop increased confidence in and intent to incorporate ARDEI and social justice topics into course questions and content.*

started or created problems for courses that they are no longer assigned to teach (as the workshop occurred before course assignments), and two created problems for courses they teach but did not deploy them during the data collection period.

In terms of questions, the 11 interviewed faculty developed 15 questions to varying degrees of completeness, where 40.0% of them were developed from scratch, while 46.7% were developed from previously existing resources including textbooks, previously used questions, colleagues, workshop examples, and other resources. Both the ARDEI-component and technical component of each of the questions developed or in-development are summarized in Table 5. Inequities exist across many facets of life; from unequal access to healthcare, education, clean air and water, to undue burdens of pollution, climate change impacts, and higher exposure to risk factors that have resulted from historic exclusion and injustices built into the systems and structures around us. The ARDEI contexts highlighting those inequities that were added to problems span a similarly wide variety of topics, making the strategy of adding context to engineering problems versatile to different courses and topics of interest. We provide these faculty-made examples to help facilitate question ideation for others who may be interested in incorporating ARDEI-context in their own classrooms but do not know where to start.

Given the diverse contexts, it is unsurprising that when asked what the easiest part of coming up with the question was, 46.2% of responses indicated that it was identifying the ARDEI context. However, when asked what the hardest part of developing the questions was, the most common challenges were finding data or resources to support the ARDEI context (23.8% of responses) and connecting the ARDEI-context to the technical component related to class material (19.0% of responses). Thus, we asked faculty what resources they were able to find, and we compiled a list of these resources in the hopes of helping others in this process:

- Reports or other resources from government entities such as EPA, NIH, National Academies, United Nations, European Commission, state health departments, and local or federal policies
- Reports or other resources from non-government organizations such as Natural Resources Defense Council, National Society of Professional Engineers, University Corporation for Atmospheric Research, The Nature Conservancy, the Innocence Project, or other university or university library resources
- Articles from non-academic sources such as the *New York Times* and *Chemical & Engineering News*
- Other resources such as academic journals, textbooks, legal briefings, tap water databases, or personal knowledge of events

Interestingly, when attempting to connect the ARDEI-context to the technical component related to class material, many faculty opted to create the ARDEI-component as a qualitative part of the problem. While we did not provide specific materials during the workshop on how to grade these parts as the focus was on problem development, during workshop discussions we recommended that qualitative problems either be graded for completion based on thoughtful effort or be designed to ask students to explore or find specific resources. However, given the frequency with which faculty are creating these qualitative problems, additional guidance on assessing student responses could be useful.

Engaging with ARDEI-Context Questions Supports Student Understanding of How ARDEI and Social Justice Intersect with the Chemical Engineering Field.

We surveyed students who engaged with ARDEI-context questions written by faculty who took the workshop and taught in 2021-2022 academic year to determine (1) the impact of engaging with the question on student learning and awareness of chemical engineering's (CHE) societal impact and (2) to assess students' perspectives as to whether incorporating ARDEI-context into homework questions is a good way to engage with these important topics. We collected data on a total of 98 students across five core classes (3 undergraduate, 1 mix with mostly undergraduates, 1 graduate) and 2 electives (open to both undergraduate and graduate) using the student survey. Given the small sample size within any one class, we analyzed this data collectively to get a sense of generalizable success of this method.

We first assessed how engaging with the ARDEI-context question impacted students' ability to connect ARDEI principles to chemical engineering concepts (Figure 2A). Nearly all students (n = 84/98, 85.7%) somewhat or strongly agreed that engaging with the questions increased their awareness of and ability to recognize how ARDEI and social justice relate to chemical engineering. A similarly high fraction (n=82/98, 83.7%) somewhat or strongly agreed that engaging with the question increased their ability to critically evaluate how current engineering practices or theories have been used to promote or fight inequity. Most students (n = 81/98, 82.7%) also reported an increased awareness of how marginalized communities are impacted by engineering decisions. Finally, in assessing the longer-term impact of engaging with ARDEI-questions, most students (n = 80/98, 81.6%) reported that engaging with the question increased their desire to make a change in chemical engineering or whatever field they are pursuing. Notably, this question had the highest fraction of students who strongly agreed with the statement, further indicating the potential to foster positive long-term impacts on students' goals and roles in the field.

TABLE 5
Faculty-developed ARDEI-context Questions and Their Content

Overall Questions Context	ARDEI-Component		Technical Component	
	Content	Problem Type	Content	Problem Type
A chemical harmful to human health found in water systems	Inequities in exposure to chemical; inequities in medical treatments impact; environmental impact	Short answer	Henry's Law, gas laws, dissolution	Calculations
(Alaskan oil) pipeline	Environmental impact; land use/misuse/access/rights	Short answer	Pressure drop; pump sizing	Calculations
HeLa cells and resulting technology	Injustice in acquisition of HeLa cells	Discussion and reflection and open-ended questions	HeLa cells and resulting technology	Reading/research on topic (pre-discussion assignment)
Urban heat stress	Inequities in effect of urban heat stress on certain populations	Conceptually set up a model for a city block, determine model variables	Energy balances	Use energy balance equations in the model
Refrigerants	Fluorocarbon impact on environment and disproportionate impact on marginalized populations	Research; short answer	Thermodynamic properties (of refrigerants)	Calculations
Climate change, sea level rise globally, particularly affecting developing nations	Impact of sea level rise on communities (general) and specifically industry, economy, displacement; Analysis on a national level, not individual or societal group level.	Essay	Sea level change (related to sustainability challenges)	Analysis of numerical data/trends
Polymer recycling research/technology	Access to recycling technology, impact on community	Essay	Polymer recycling plant/ process design	Design a process for polymer recycling (and subsequent analysis for economic and environmental impact)
Fluid mechanics, hydroelectric power generation	Impact of hydroelectric power generation on indigenous communities; Code of Ethics	Research (lit search); reflection	Power from fluid momentum	Calculations
Transportation emissions; combustion reactions, formation of NOx, Ozone	Impacts of this chemical reaction on marginalized communities, technologies aimed at reducing emissions, and benefit and accessibility of the technologies	Short answer/essay; discussion in class	Sticking probabilities	Calculations
Chlorofluorocarbons (CFCs)	Impact of CFCs; Climate change; Environmental justice	Short answer/essay; discussion in class	Chemical reaction rate expressions	Set up rate equations, calculations
Use of DNA fragments in criminal identification	Racial breakdowns overturned convictions; connections to use of DNA fragments	*Problem not fully developed*	DNA fragments and analysis	*Problem not fully developed*
Metals mining and processing	Impact of processing chemicals on Indigenous populations	Short answer	Separations related to extracting metals; material and energy balance	Calculations
SIR model for disease spread in the context of COVID-19	Inequities experienced by Black & Brown communities and frontline workers	Modifying rate equations; discussion	Multiple reactions A $\rightarrow$ B $\rightarrow$ C; model fitting and parameters	Generating equations; discussion
Social construct of race and its impact on bioinformatics research	Influence of social construct of race on how data sets are collected and interpreted	*Problem not fully developed*	Analysis of data sets	*Problem not fully developed*
Chemical leak and how plants respond	Unequal impacts vs proximity to leak and time elapsed (and who is in proximity)	*Problem not fully developed*	Process controls around response to leak, exposure vs proximity and time; quantifying risk	*Problem not fully developed*

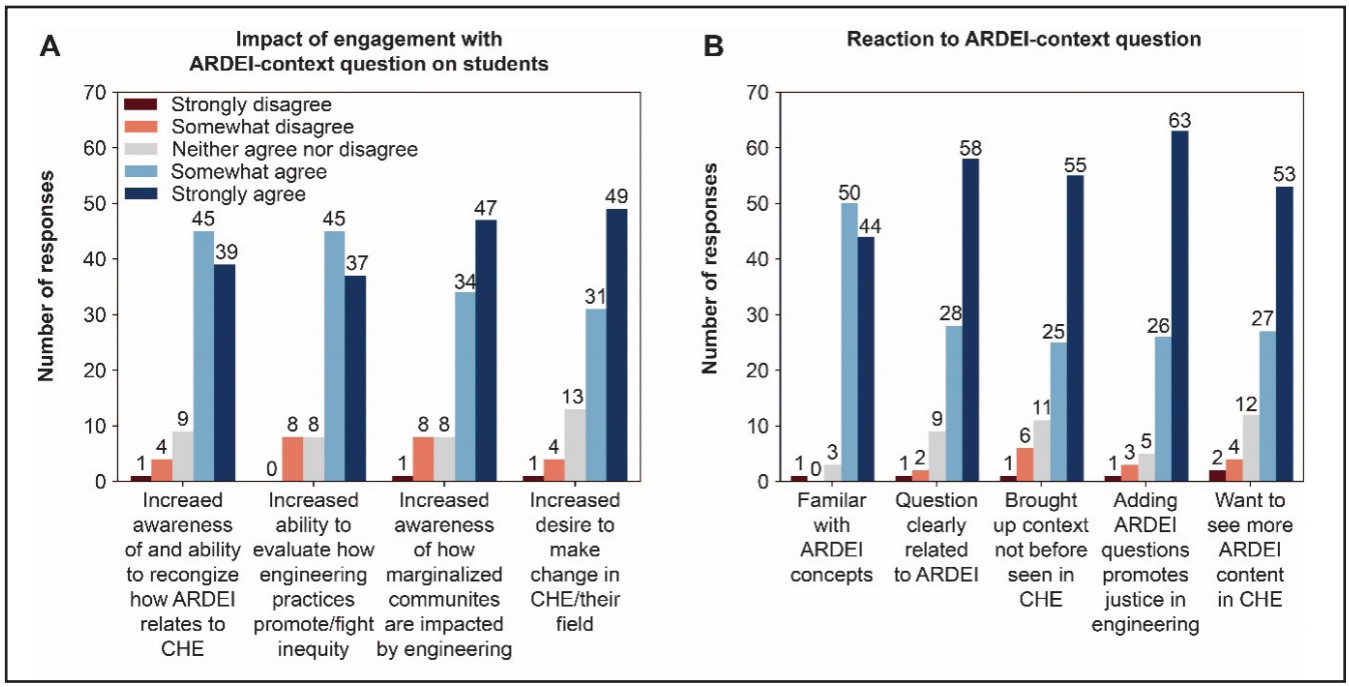

***Figure 2**: Student quantitative responses indicate the positive impact of engaging with ARDEI-context questions and the desire to see more of these types of questions in their courses.*

Overall, the students surveyed, who comprise a mix of undergraduate and graduate students, had an overwhelmingly positive response to engaging with these ARDEI-context questions. These findings highlight the short- and longer-term positive impacts of these questions on students and support the overall goal of implementing ARDEI-contextualized curriculum to create socially conscious and anti-racist engineers.

To gauge students' perspectives on this method of engaging with ARDEI-content, we asked questions about their existing familiarity with ARDEI and social justice concepts and if they had already engaged with these topics or would like to see more questions like these in other courses (Figure 2B). While nearly all students (n = 94/98, 95.9%) reported being familiar with ARDEI concepts, students (n = 80/98, 81.6%) confirmed that there is a lack of integrating this context into courses. Most students (n = 86/98, 87.7%) also reported that the question they engaged was clearly related to ARDEI, indicating the success of the faculty in writing questions that directly address these topics. Given the success of connecting the ARDEI context to the engineering content and the positive impacts of engaging with the questions, students agreed that adding ARDEI and social justice concepts into chemical engineering course questions is a good way to promote social and/or environmental justice in engineering practice (n = 89/98, 90.8%). They would also like to see more ARDEI and social justice focused content integrated into CHE course questions (n = 80/98, 81.6%). These results highlight students' desire to engage with ARDEI-contextualized chemical engineering curricula and support this method as a low-barrier, low-cost, successful method of facilitating this engagement.

When given the chance to leave additional, qualitative feedback, students reported both appreciating the effort being made to incorporate ARDEI into curriculum and a desire to see more than just integration of this content in homework problems. While some faculty integrated lectures related to their ARDEI-context problems, those who did not received feedback from students wishing for discussion of the topic rather than just encountering it on homework problems. For example, one student said, "*I think it would be more beneficial to use questions like these as a starting point for a larger class discussion rather than it simply being a homework problem*." Another student in a course that used both a discussion and homework reported that "*the discussion of the question in class was a bit more useful than answering the question individually for homework, where we weren't discussing and learning collaboratively*." Meanwhile, other students in that same course asked for the discussion to be deeper, but still acknowledged that this was a great step. These findings speak to student desire to engage with this material frequently and critically. One student highlighted this point, saying, "*The ARDEI questions allowed me to have more of a connection with the impacts of research and engineering. This not only brings social justice topics forward but also helps me learn the material in a more memorable way*." Another student said, "*I really liked how this was incorporated into our homework problem set!*"

Collectively, these responses highlight the benefit of integrating this content and how this is a good first step of integrating social justice throughout engineering curriculum. Following this feedback, some of which was collected after Fall 2021, we recommended to all faculty deploying questions in Winter and Spring 2022 to integrate lecture components and updated the workshop's synchronous session to encourage and further support this recommendation.

While most faculty who deployed a question did hold a class discussion (n = 5/7, 71.4%), one faculty member noted during the interviews that it "*felt like there was certainly apprehension*" during the discussion and they were surprised that "*at least for those [students] who responded to the survey, they just wanted more.*" This further shows that despite possible discomfort during a discussion, students still appreciate its inclusion in class. This faculty member also noted that "*what will also help is having this from multiple directions… it'll just feel less like non-sequitur… as this just becomes sort of a routine part of discussion…I welcome the growing comfort and maybe even just maturity or practice around these topics…*" and "*support from the department and from other faculty and courses may have an actual tangible, palpable impact on these questions in my courses if it's not the first time they're seeing it.*" We hope all faculty approach this work similarly ready to embrace the initial discomfort and agree that as more faculty engage in incorporating ARDEI-context into course questions and discussions, the process will become more comfortable for students and faculty alike.

While we created the workshop with the main goal being to help facilitate question creation and did not provide detailed training on holding these class discussions, more could be done to help faculty learn to facilitate these discussions in class. In an effort to provide some guidance on this, we used the workshop itself to model how to discuss these topics in class by presenting definitions of ARDEI-related terms to ensure everybody is on the same page and having community guidelines, each included in the pre-work. We also recommended that faculty wishing to hold discussions in class should do similarly. However, as part of the data analysis, we recognized that there was still a need to learn more about having discussions, so we worked with our teaching and learning center to develop a series of trainings on engaging with ARDEI topics in class that was open to all department faculty. For others hoping to adopt these ARDEI-context questions and hold discussions in class, we recommended working with the university's teaching and learning center for further guidance and support.

One important note is student criticism of this work, which was minimal but highlighted important points. One student reported that they "*do value factoring ARDEI curriculum in chemical engineering courses, but I wish that other issues were more addressed… I wonder what more work ARDEI can do to address these issues and create a more diverse space*." Similarly, another student noted that "*I feel that even though the sentiment is the right one and the question was good, for those of us who are already familiar with these issues (personal background, international students, etc.) the question felt a bit disconnected… I think that it would be much more valuable to hold conversations/lectures/presentations on these issues where people can really ask questions and get enough information, because an out of context homework problem every other day does not feel very effective in this context*." These students brought up the previously mentioned desire for lectures but also for other issues related to ARDEI beyond the curriculum to further foster equitable spaces. Additionally, their full comments highlighted the need to ensure ARDEI-questions do not reinforce stereotypes for marginalized communities, oversimplify, or characterize these topics without depth. Further, those writing the questions should invest sufficient time learning about the topics discussed to avoid these pitfalls. Analyzing these questions to ensure they do not cause further harm, such as by using the harm prevention worksheet, is a first step at addressing these comments. Ensuring these needs are met will take time, effort, and critical thought, but the impacts and benefits to students are clear if this is done well.

Integration of social justice principles into curriculum is important for increasing student sense of belonging, improving understanding of inequity, and supporting marginalized communities, but this integration needs to be handled with care.

While ARDEI-Question Implementation Had Successes, There is Room for Further Improvement in Deployment

While we had 15 questions developed by the 11 faculty members who were interviewed, and six unique questions deployed in seven classes (one class repeated within the academic year), we wanted to gain a better understanding of the efforts to prevent harm and create an inclusive environment during class time. Despite covering community guidelines, content warnings, and harm prevention in the workshop, faculty interviews revealed that these were not universally applied. For example, only 60.0% (n = 3/5) of those who held a class discussion surrounding their questions used community guidelines. Similarly, only 42.8% (n = 3/7) of classes led by 18.2% (n = 2/11) of the faculty interviewed used content warnings. Additionally, including all questions

at all stages of development and deployment, only 36.4% (n = 4/11) analyzed the question for potential harm, though to varying degrees. Though a harm prevention worksheet was provided during the workshop, only one faculty member used it retroactively but did not fully complete the worksheet, and two used it informally to think about the questions but did not formally fill it out. Notably, one faculty member both completed the worksheet and used it proactively during the development of their question as a guideline. We recommend that those who wish to create questions use this strategy during question development to make harm prevention part of the process, rather than an editing tool afterward.

Those who did not analyze the question for potential harm noted reasons such as not being concerned about harm (33.3% of responses, the most commonly found reason), being new to the concept, assuming it was done by a colleague the problem came from, challenges with timing, or being uncertain how to do so. However, we note that lack of concern about harm comes from a position of privilege, and students, like those quoted above, may have lived experiences that go deeper than the question and recognize that there is potential to reinforce negative stereotypes. We hope that the student testimonials above will provide further evidence as to the importance of harm prevention and that more faculty will make it part of the question development process in the future.

DISCUSSION

This paper outlines a low-cost, low-barrier method for integrating ARDEI and social justice context into chemical engineering curricula. Specifically, we analyzed the impact and benefit of writing and engaging with ARDEI-context homework questions on faculty and students, respectively. After the workshop, faculty reported an increased confidence in and intention to write homework or course questions contextualized with ARDEI and social justice. This finding speaks to the effectiveness of the workshop at training faculty in this endeavor. Students also reported the benefits of engaging with these questions, including increased ability to connect engineering decisions to societal inequities and motivation to make positive change in their field. The students' desire to see more of these questions in the classroom provides strong support for the need to incorporate ARDEI-context into chemical engineering curriculum, and the collective faculty and student responses indicate this workshop as a successful method to facilitate this work.

We provide these resources in full in the hopes of sharing this work beyond the original institution. We acknowledge that development of and participation in this workshop and study were facilitated by being members of a private research intuition with the support of a learning and teaching center, in a state that does not prohibit DEI work, and members of a department with a strong commitment to ARDEI. Unfortunately, not all members of academic institutions have this privilege, which may make implementation of this workshop more challenging. We hope that by sharing the overwhelming positive outcomes of this work, members of the chemical engineering education community will feel encouraged to begin integrating ARDEI and social justice principles into their courses.

Integration of social justice principles into curriculum is important for increasing student sense of belonging, improving understanding of inequity, and supporting marginalized communities, but this integration needs to be handled with care. Faculty need to put concerted effort into the questions they write to ensure further harm is not being caused to students holding marginalized identities. This effort will entail engagement with more than just DEI training, but also a deep, critical thought on selected question topics, awareness of and reflection on positionality, and empathy for marginalized communities affected by inequities in engineering.

This workshop is only the first step in empowering widespread faculty to address the harm of allowing oppressive systems, biases, and inequities to remain uninterrogated. Since ABET requirements now mandate minimal inclusion of this work,[25] this workshop can help engineering departments meet this immediate need. Moving forward, we hope that future changes centered on redesigning whole engineering courses and curricula from a social justice lens will become the norm rather than the work of select few faculty.

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