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Integrating social responsibility and diversity, equity, and inclusion into the graduate chemistry curriculum†

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Science's broader impacts and the historic social, political, and geographic implications of these impacts are rarely discussed in graduate STEM curricula. A new required "Scientific Responsibility and Citizenship" course for first year chemistry graduate students was developed and taught at UC Berkeley. The course examined a series of case studies in which basic chemistry research led to societal impacts and discussed the diversity and equity of the research process and resulting consequences. The impact of the course was examined through pre- and post-surveys and interviews with participants. The course was found to have raised students' awareness and sense of responsibility for the impacts of their research and the importance of diversity, equity, and inclusion. Students also expressed an increased sense of identity and value alignment with the community as a result of the course. This study shows that even a relatively low-commitment intervention (6 hours in total), can have a large positive impact on students' awareness of the social context of science and their perceptions of department values.

Introduction

The composition of the United States chemistry research community is not representative of the United States population. Various systemic barriers have hindered individuals with historically minoritized identities from entering and thriving in the field.[1–5] The lack of diverse representation in science has also precipitated inequitably distributed benefits and harms resulting from scientific advancements.[6,7] Data provided by the National Science Foundation (NSF) show that despite increasing overall enrollments in chemistry degree programs in the past decade, the representation of historically excluded racial and gender identities has not improved.[8,9] Data show that the composition of entering undergraduate classes often achieves parity with the general population, but attrition rates are higher for minoritized students.[10,11] The largest gap in retention of minoritized students tends to occur between graduate school and postdoctoral studies,[8] highlighting retention in graduate degree programs as a key concern.

Educational studies have shown that minoritized students are more likely than non-minoritized students to state altruistic and community-oriented motivations for pursuing science, technology, engineering, and math (STEM) fields,[7,12–14] and yet, most graduate STEM programs include little curricular discussion of science's inequitable impacts on historically excluded communities and ways to correct them. Feelings of value misalignment in chemistry and better alignment in other fields may contribute to the lack of retention of minoritized students.[2,15] Current efforts toward increasing diversity, equity, and inclusion (DEI) in STEM fields generally focus on increasing the numbers of women and racial minorities in these fields, but less commonly considered is the question of whether the existing ideals of scientific excellence and the current norms of scientific practice best serve a diverse scientific community and broader society.[16] Both are important—the diversity of our community's members must be increased, and these members must be retained by honoring their values and identities. Increasingly, efforts are being made to make classrooms and laboratories more conscious of DEI, through inclusive teaching practices, the reframing of course content and the context in which it is presented, and improved accessibility (an often-underappreciated challenge in lab sciences).[17–20] This project was motivated by a desire to incorporate the consideration of science as a social process into the scientific curriculum, and an examination of how the subjectivities of scientists have influenced research and its impacts.

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A new required course was developed in the UC Berkeley Department of Chemistry for first year graduate students titled "Scientific Responsibility and Citizenship", first offered in the fall of 2022, that addresses these issues of scientific impacts on society and DEI. The course explained the different forms of implicit bias that exist in research, and examined inequities in who has been included in scientific decision-making, which problems and results we value, and how the broader impacts of research have benefited and harmed different communities unequally. The purpose of the Scientific Responsibility and Citizenship course was twofold: (1) to communicate to students, particularly those with historically excluded identities, that the unique perspectives they bring are valuable to science and necessary to shaping a field that will equitably serve global humanity, and (2) to provide students with some strategies through which to consider the inclusivity and equity of the potential broader impacts of their research. Faculty instructors for the graduate scientific courses for first years were also asked to integrate some of these concepts into their coursework, and various faculty in the department were invited to attend the course and join the student discussion groups. The attending faculty were thus also exposed to the course material.

The development and implementation of the course was motivated by two research questions:

- How will a relatively low time-commitment course that discusses the connection between DEI and the broader impacts of chemistry research affect student perceptions of these issues?

- What effect would integration of these topics have on students' self-reported sense of connection with their peers and the community, and their values and objectives as scientists?

The contents and discussion format of the Scientific Responsibility and Citizenship course are not usually a required part of chemistry curricula at the undergraduate or graduate level (though efforts to include these topics in chemistry education do exist).[21,22] Historical and contemporary examples of the inevitable interactions between science and society suggest it may be essential to scientists who wish to achieve a positive impact in their field and beyond. The first iteration of the course reflected an overall successful endeavor by faculty and students to build community and to raise awareness and understanding of DEI issues and broader impacts of science. Should other institutions wish to offer a similar course, the ESI† associated with this manuscript includes all course materials, a teaching guide, and survey instruments.

Theoretical frameworks

Course design and assessment of the impact of the course were informed primarily by the following theoretical frameworks: the tripartite integration model of social influence (TIMSI) theory, critical race theory as it applies to academic settings, feminist science, and a framework for institutional diversity interventions (Fig. 1). TIMSI theory provides a framework for understanding what factors build science career intentions in students. Critical race theory and feminist science examine the structural biases that affect each student's experience based on their background and identity. The institutional diversity

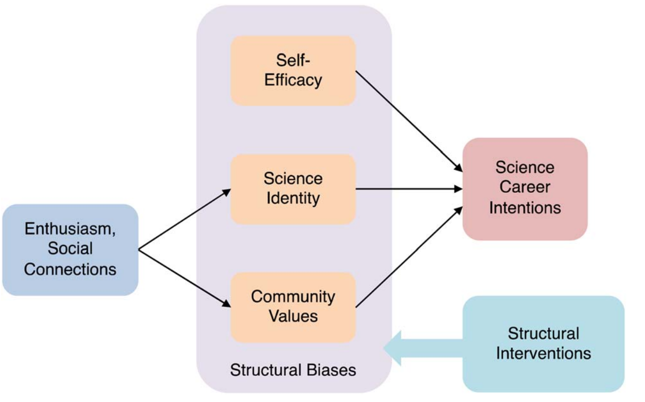


Fig. 1 A scheme depicting the theoretical frameworks used for this study and their relationships to each other. Self-efficacy, science identity, and science community values are three components that build up a student's intentions to pursue a career in science (TIMSI framework). Fostering enthusiasm and social connections contribute to building science identity and value alignment. Structural biases influence a student's ability to achieve self-efficacy, and their perception of science identity and community values, and especially hinder minoritized students' persistence in STEM fields (critical race theory, feminist science). Structural interventions can work toward countering existing structural biases (institutional diversity interventions framework).

interventions framework offers a way to approach structural interventions to counter these structural biases.

TIMSI theory formed a starting point for understanding the relationship between value alignment and retention of minoritized students. Estrada and coworkers have studied the integration of minoritized students into scientific communities and their perseverance in the field through Kelman's TIMSI theory.[23–26] TIMSI describes three factors that contribute to a student's integration into a community: self-efficacy, identity, and values. Self-efficacy, or a "rule orientation", refers to a student's belief in their ability to comply with the requirements or expectations of the community. In science education, self-efficacy includes a student's ability to learn material and conduct research. Psychological and educational studies have shown that self-efficacy is a key predictor of academic perseverance. Building self-efficacy is in turn tied to environmental and social support. Identity, or a "role orientation", refers to a student's sense of belonging and personal identification with the community—in other words, how much a student identifies as a scientist and a member of the scientific community. Lastly, the internalization of community values, or a "value orientation", refers to a student's feeling of congruency with actions or beliefs held by the community—how much a student feels that the priorities and objectives of the scientific community are aligned with their own. While significant efforts are often made toward improving self-efficacy of students to boost retention, research suggests that identity and value orientations are stronger predictors of a student's perseverance in the sciences.[27,28] This project is focused on exploring these two latter aspects of TIMSI theory. Applied at the graduate level, the role and value orientation of PhD students may be described by priorities in research direction or success metrics.[29] We were interested in studying whether this course could be both a way for students to consider and discuss their own value and role orientations, and a way for the department to signal its own values and vision of a scientist.

Critical race theory informed our approach to shaping the presentation of department values. Critical race theory analyzes the systems of racism that are ingrained in the structures of our culture and society.[30,31] Educational settings reinforce the cultural values and superiority of dominant groups by perpetuating systems that privilege these groups.[32,33] The ways that "professionalism", "success", and "merit" are defined contain biases toward the dominant culture and these biases are perceived as "normal".[34,35] In turn, the generation of knowledge is colored by these biases. Critical race theory acknowledges the existence of these endemic biases and aims to dismantle this ideology to move toward a system that more equitably recognizes the cultural wealth and contributions of diverse members of society.[36] Intersectionality is a core tenet of critical race theory, recognizing the interplay of multiple aspects of an individual's identity, including race, gender, class, sexuality, and disability, in shaping a person's experience in society.[37–39] Feminist science similarly examines systemic biases in the processes through which scientific knowledge is generated and received, and challenges assumptions of objectivity in research.[40–45] Modern science has historically been performed, funded, and interpreted mostly by members of dominant groups (for example, Western, cis-male, heterosexual). As a result, the beneficiaries of scientific work have also primarily been dominant groups. Feminist science recognizes that science has occurred in this context and uses it to reframe our understanding of science. Change requires action at the structural and systemic level, rather than the individual. Allyship is grounded in action and recognition of the systemic nature of existing problems.[46] When the values of the system better align with those of its diverse members, minoritized members may in turn better trust the system to represent their interests and priorities. In the Scientific Responsibility and Citizenship course, the history and structure of scientific research was analyzed through a lens of critical race theory, seeking to identify the underlying systemic biases that have influenced the practice and impacts of science. This study seeks to understand whether students are receptive to discussion of these topics in a chemistry curriculum and how this will affect their experience as scientists and their intended practice of science.

Thoman and coworkers propose a framework through which to implement institutional DEI-related changes.[47] The framework outlines a series of five steps along which faculty progress from possible resistance to evidence-based diversity-enhancing interventions toward a decision to implement them. The steps are: (1) noticing that a diversity problem exists, (2) interpreting the problem as urgent and needing immediate intervention, (3) assuming personal responsibility for tackling the problem, (4) knowing how to help and feeling competent in implementing intervention strategies, (5) taking action to intervene. Although graduate students do not have as much independence as faculty, they still possess some degree of agency in deciding how to engage in their teaching, research, and interpersonal interactions. The structure of the course followed this framework to first raise graduate students' awareness and sense of responsibility, and then to discuss strategies for action. The steps in this framework were also used to evaluate students' convictions to implement DEI-enhancing actions in their various roles in the program.

Methods

The study was approved by the UC Berkeley institutional review board, protocol ID# 2022-04-15263.

Course implementation and participants

A new required Scientific Responsibility and Citizenship course was developed for first year graduate students to take in their first semester. Participation in the course was mandatory for first year graduate students, but participation in this research study was voluntary and consent was obtained from students to allow their course materials to be used or this study. The first-year cohort consisted of 44% non-male students. 15% of the cohort identified as Native Hawaiian/Pacific Islander, American Indian/Alaska Native, Latinx/Hispanic, or African American/Black (minoritized groups in STEM in the US). The remainder of the cohort identified as non-Hispanic White or Asian. 32% of students were not US-citizens.

The authors of this manuscript were involved in the design, teaching, and evaluation of the course. K. T. X. designed the course, and co-taught the first iteration of the course with M. B. F. and A. M. B. K. T. X. also conducted the interviews and data analysis for the evaluation of the course. A. M. B. supervised the course design, research design, and data analysis. F. D. T. and A. M. B. taught subsequent iterations of the course. All authors were involved in discussions throughout the conception, design, and implementation of the project. As the researchers conducting the evaluation of the course were also involved in the course design and implementation, we acknowledge the possible existence of biases in the interpretation of the data.

Pre- and post-survey design and analysis

The pre-and post-survey both contained ten statements for which students rated their level of agreement. Five of these statements were drawn from "Responses to 10 common criticisms of anti-racist action in STEMM" (rows 1–5 of Table 3).[48,49] The other five statements were related to scientific responsibility and broader impacts of research, based on concepts from the feminist science literature (rows 6–10 of Table 3).[44,50] The post-survey contained an additional set of questions to understand the impact of the course on their actions and their perception of the department, and to gather feedback on the course. Both surveys were piloted with 3 respondents prior to implementation in the class, leading to minor phrasing changes to clarify questions. Students filled out the pre-survey in the first class, and the post-survey in the last class. The pre- and post-response distributions to the 10 statements were compared using the Mann–Whitney U test to analyze for

Table 1 Free response questions asked in the post-survey

1	Did you talk about this course with anyone outside of class? If yes, which parts of this course did you talk about?
2	What is the most important thing you learned from this course? Why?
3	How might you change your approach to research as a result of this course?
4	How did this course affect your sense of connection to the community in our department?
5	How did this course impact your values as a professional chemist?
6	Do you think the department's values are well-aligned with yours?
7	The instructors for your other classes also tried to relate their teaching to the content in this course. Did you think this was effective?
8	Do you have feedback on how we can better incorporate social responsibility content into our curriculum?
9	Do you have any feedback for improving this course?

statistically significant differences in responses before and after taking the course. The free response questions that were asked in the post-survey are included in Table 1.

The post-survey free response questions were analyzed through deductive coding. Codes were created based on TIMSI theory and the framework for institutional diversity interventions (Table 6). Inter-coder reliability was evaluated for 36% of the responses with 93% agreement between two coders and Cohen's kappa of 0.74. Consent to participate in this study was collected during administration of the post-survey in the final class. 60% of the class ($n = 45$) consented to their pre- and post-survey responses being used in this study. The full surveys are included in the ESI.†

Interviews

Interviews were conducted with 5 students and 5 faculty attendees of the course. 5 of the interviewees identified as men and 5 identified as women or nonbinary. 7 of the interviewees identified as White and 3 identified as non-White or multiracial. The pre- and post-survey questions were validated with the students, and more detailed feedback was received. Interviews with faculty were conducted to gain insight into faculty perceptions of the course and its value in the curriculum. Consent was obtained separately for the interviews, and responses are de-identified. Interviews were recorded and transcribed, and analyzed through thematic analysis/inductive coding.[51] The questions asked in the interviews are summarized in Table 2. Common themes from the interviews are summarized in Table 8, with examples of quotes that contributed to the theme. The full interview protocols are included in the ESI.†

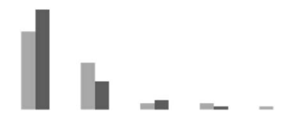
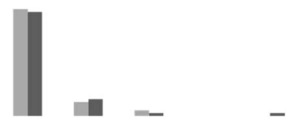
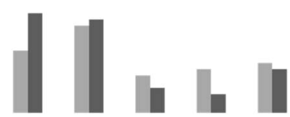
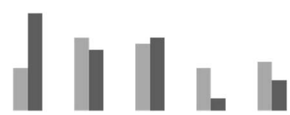
Designing a graduate scientific citizenship course

The Scientific Responsibility and Citizenship course was designed with a few intentions: (1) to integrate with scientific content students are learning in their other graduate chemistry courses, (2) to feel relevant and practical to their experience as PhD chemists, (3) to accommodate an expected wide range of previous experience with and receptiveness to DEI topics. The course aimed to explain the importance of DEI to professional chemistry and scientific research, and to help students gain an appreciation for the utility of consulting experts in neighboring fields. The topics covered are summarized in Table 5. Detailed

Table 2 Questions asked in interviews

Graduate student interview questions		Faculty interview questions	
1	Validation of pre- and post-survey questions	1	Last fall we invited you to attend a class for the new Chem299 Scientific Responsibility and Citizenship Course. What are some things you remember about either the course content or the experience of attending?
2	What are some concepts from the course that were new to you or that were particularly thought-provoking?	2	What are some concepts from the Chem299 class you attended that were new to you or that were particularly thought-provoking?
3	Do you have any specific ideas for things you plan to do as a graduate student or in the future to improve the inclusivity of your work as a scientist?	3	Do you think this course is a good addition to the graduate curriculum? Why or why not?
4	How did the course affect your connection with others in the cohort? What about your connection with the faculty who were involved?	4	How do you think this course could be improved?
5	What are some things that you value in chemistry research? What impacts do you hope your research will have, either on the scientific community or beyond?	5	Do you think scientific responsibility and DEI should be integrated more into our curriculum? What are other ways we can integrate concepts about scientific responsibility into our graduate curriculum?
6	How do you feel about the alignment of your personal values with those of the department or the chemistry community? What does value alignment mean to you?	6	Are there occasions when you engage in conversations about broader impacts and social responsibility with students?
		7	Do you have any other comments on your experience attending the class or on the course in general?

Table 3 Pre- and post-survey levels of agreement with a set of statements related to anti-racism and scientific responsibility

	Statement	Mean agreement[a] before class 1	Mean agreement[a] after class 6	*P* Value (Mann–Whitney *U* test)	Graph of responses[a,b]
1	There is no evidence of systemic bias in STEM and academia	1.64	1.36	**0.044**	
2	Don't politicize science! Stick to the science, not social issues	2.13	1.89	0.363	
3	Hiring, awards, and citations should be based on merit; the identity of the scientist does not need to be considered	3.22	2.80	0.154	
4	I'm not racist or sexist, so I don't need to do anything more	1.64	1.40	0.146	
5	Improving equity and inclusion does not benefit STEM as a whole	1.20	1.27	0.784	
6	My research is fundamental so I can't control what other people use it for eventually	3.02	2.51	**0.025**	
7	As an academic chemist, the eventual impacts and applications of my work are not my responsibility	3.02	2.84	**<0.001**	
8	Scientific research is objective; the identity of the scientist is irrelevant	2.76	2.33	0.130	
9	There's no such thing as racist or sexist science, only scientists	2.04	1.82	0.525	
10	Scientific progress and discovery inherently benefit everyone	2.93	2.33	**0.031**	

[a] Responses were coded with the following values: strongly disagree (1), slightly disagree (2), neither agree nor disagree (3), slightly agree (4), strongly agree (5). [b] Lighter grey bars represent pre-survey responses, darker grey bars represent post-survey responses.

course materials are included in the ESI,† including the course information and syllabus, handouts and slides for each class, and a teaching guide.

Because this course was intended as an integration with the scientific curriculum and not simply an unrelated addition, the department faculty were included in the development and implementation of the course in various ways.[52] Discussions were conducted with all the faculty teaching first-year graduate courses in chemistry to determine what course content could be relevant, and to strategize for inclusion of scientific content in the course and inclusion of DEI and scientific responsibility-related content in the chemistry courses. These discussions also confirmed that sufficient support for the development of such a course existed among faculty. The faculty teaching other first-year graduate courses were asked to include related content in their teaching to aid the sense of connectivity between this course and the students' scientific coursework. For each session of the course in which a case study was discussed (classes 2–5),

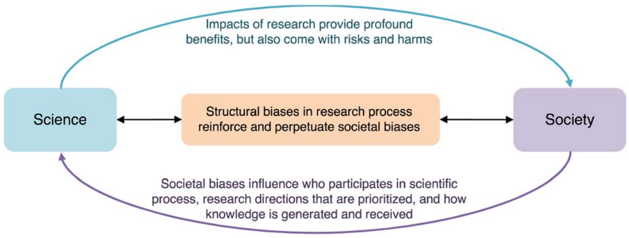


Fig. 2 Diagram showing influences between science and society. Though science is often considered to operate separate from social influences, it is conducted by scientists who live in society. An active feedback loop between the practice of science and the existence of social biases affects what science is funded, conducted, and recognized, and its downstream impacts.

2–4 members of the faculty who conducted research in areas related to the case study were invited to attend and participate in the discussion with the students.

The course was heavily discussion-based, an unusual format in STEM curricula. The case-study-based course format was partially inspired by Transforming Scientific Knowledge: Science and Feminism taught by Heather Shattuck-Heidorn at Harvard University in Spring 2018.[53] As the first semester of the first year tends to be one of the busiest periods in the program, the course was also designed to have a minimal workload burden on the students while still conveying the desired material. The course met six times, approximately every other week, for an hour each time. The department chair (white, male), the associate dean of DEI (white, female), and a graduate student instructor (Asian American, female and nonbinary) co-taught each class. Attendance was the only requirement to receive a passing grade, and no work was assigned outside of class. The instructors provided snacks for the students in each class.

Students were asked to consider the connections between scientific research and social influences and how the two inform each other (Fig. 2) and were introduced to theoretical frameworks through which to consider this relationship. The course emphasized science as a social process, the limitations of objectivity, and the complexity of the ethical decisions and broader impacts of science. In each case study, the problems were often structural and systemic. Possible structural solutions were discussed, and students were asked to consider the roles that scientists can play in different careers and career stages. As the students consisted of 68% US citizens and 32% international students, the course was designed to include case studies primarily related to American scientists, but with a global perspective on the impacts and implications of scientific research. The goal was to equip students with some knowledge and basic abilities to thoughtfully consider social and scientific responsibility throughout their ensuing graduate studies and future careers.

Classroom agreements and exit tickets

Due to the potentially sensitive and controversial topics discussed in this course, a few measures were taken to maintain a comfortable and safe setting in the classroom. A set of classroom agreements‡ was employed to set the tone of discussions and to maintain a collegial atmosphere. The classroom agreements (summarized in Table 4, and included in the course slides in the ESI†) were explained in detail in the first class, during which we also explained the purpose of having each agreement, and were shown again briefly at the beginning of each subsequent class as a reminder. Students were also provided with an anonymous feedback form, which employed a link to a Google form monitored by the instructors. Anonymous exit tickets were collected at the end of each class, in which students were asked to list one thing they learned, a question they still had, and any feedback on the course.

Class 1: introduction to scientific responsibility and DEI

The first class was intended to bring all students to a shared foundational level of knowledge. The incoming first year cohort consists of students from various backgrounds, with varying degrees of exposure to topics related to DEI. In particular, a number of international students noted that they were unfamiliar with the context and history of DEI, particularly race, in the United States of America. A set of statistics from the NSF was shown, along with some studies illustrating implicit bias in citations, hiring, and funding. Students filled out a pre-survey in which they rated their level of agreement with a series of statements. These data were to be compared with their responses to a post-survey at the end of the semester.

Class 2: case study—Berkeley and nuclear chemistry

The second class introduced the first case study. UC Berkeley's history in nuclear chemistry was chosen to illustrate the connection between basic science and real-world impacts, and the complexity of scientific ethics. The subject of nuclear weapons and the decision to deploy them remains sensitive. This class and discussion aimed to maintain emphasis on the

Table 4 Classroom agreements

1	Take space/make space
2	Speak honestly and personally. Use "I" statements. Listen actively
3	Use evidence to support your claims. De-escalate; criticize ideas, not individuals
4	Assume best intentions, but own your impact
5	We must make sure everyone feels safe. But safe is not the same as comfortable. Take risks, make mistakes
6	You don't have to play, but you are not allowed to damage the game. Active listening is also participation
7	Anonymity. What is said (and by who) stays, what is learned can leave
8	We are all in this together. Take care of yourself and each other!
9	You are not responsible for having all the answers, but you are responsible for seeking and learning. Ally is an action word

Table 5 Scientific responsibility and citizenship course content

Class	Topic	Discussion questions	Theoretical frameworks and key resources
1	Introduction to scientific responsibility and DEI	As scientists, do we have a responsibility to improve DEI? Why or why not? In what ways?	Intersectionality[37–39] Critical race theory[31,34,36] Allyship Implicit bias[54–56]
2	Case study—Berkeley and nuclear chemistry	From the development of the atomic bomb to CRISPR, Berkeley scientists have been involved in the research behind paradigm-shifting technologies. To what extent are scientists responsible for the impacts and applications of basic research?	Atomic heritage foundation[57] Nuclear Princeton[58] History of the development of the atomic bomb[59] Ethics of chemical weapons research[60]
3	Case study—hormonal birth control	What structural inequities exist in drug development? Whose knowledge is valued? Whose diseases and treatments are prioritized?	Neglected tropical diseases[61] Barbasqueros[62] Contraceptive clinical trials in Puerto Rico[63] Contraceptive inequality[64,65] Feminist science[42,66]
4	Case study—rare earth elements	To what extent are we responsible for considering the sourcing of our chemicals and the disposal of chemical waste?	Rare Earth elements[67] Environmental justice[68] Flint, Michigan water crisis[69]
5	Case study—legacy chemicals	When the risks of a chemical are discovered after it is already in widespread use, how can we respond to mitigate harm?	Polyvinylchlorides (PVCs)[70] Chlorofluorocarbons (CFCs) and ozone destruction[71] Bisphenol-A (BPAs)[72] Climate engineering[73] Polyfluoroalkyl substances (PFAS)[74]
6	Building an inclusive community	How should we treat each other to be respectful and supportive of the diversity of ideas, identities, and experiences that are part of our community?	Self-determination theory[15] Optimal distinctiveness theory[75] Social influence theory[23,24]

impacts of the research process, rather than the deployment of nuclear weapons in World War II. We discussed the detriment of nuclear research to indigenous peoples and lands, and highlighted some Manhattan Project scientists with minoritized identities. Students were given a detailed timeline of events prior to the development and deployment of the atomic bombs in Japan, and were asked to indicate at what stage they believed clear ethical wrongdoing first occurred, and at what stage a scientists should have intervened. Even for a topic for which most students agreed there was an ethical breach, there was a range of disagreement on when this wrongdoing occurred and how it could have been avoided. This exercise demonstrated the challenge of scientific ethics and decision-making.

Class 3: case study—hormonal birth control

The second case study was the development of hormonal birth control, which served to illustrate biases in research problem selection and project design. Hormonal contraception is widely recognized as a positive medical advance, and many argue it was a key factor in women's empowerment and ability to enter the workforce. Yet, the process of its development is fraught with inequities in terms of race, gender, and socioeconomic class. This class covered a brief history of the discovery of norethisterone, the first progestin used in hormonal contraception, by organic chemists in Mexico, followed by the economic impact of harvesting its synthetic precursor by Mexican barbasqueros, the health risks placed on Hispanic women during clinical trials conducted in Puerto Rico, unequal access to the resulting contraceptive pill in the early decades of its use, and continued inequities in contraceptive access and burden of responsibility. The field of feminist science was introduced in this class, along with a model of scientific inquiry proposed by feminist scientists that removes the assumption of objectivity implicit in the scientific method.

Class 4: case study—rare earth elements

The third case study looked at the mining of rare earth elements (REEs) to illustrate the need to consider the life cycle of our chemicals, from sourcing to waste disposal. REEs are essential in numerous industrial chemical processes, including many that are related to clean energy and energy efficiency. The mining of REEs is fraught with environmental, economic, and political harms and inequities. The areas in which REEs are mined suffer enormous environmental destruction, and the high value of REEs has instigated severe economic, political, and military conflicts over resource control. The possible actions by individuals, corporations, and governments to tackle these issues were discussed, as well as the sourcing and waste disposal of chemicals and other research-related consumable items (gloves, pipette tips, vials, *etc.*) used by Berkeley researchers.

Class 5: case study—polyvinylchlorides

The fourth and final case study used polyvinylchlorides (PVCs) as an example of a legacy chemical—a chemical whose negative environmental or health impacts are discovered only after it is in widespread use, generating a complex problem in managing its persistence and propagation. The supply chain of PVCs from the manufacture of the vinyl chloride monomer to the molding of PVC plastic components involves specialized methods and machinery and industries that are already in place, making PVCs cheap and efficient to manufacture. The process of synthesizing the monomer is toxic and hazardous, and single-use PVCs are a persistent pollutant. A replacement for PVCs is challenging, however, as it would need to either integrate easily into the PVC supply chain or undergo the expensive process of developing a separate supply chain to compete with PVCs. This class also introduced several other examples of legacy chemicals, including chlorofluorocarbons and their ban under the Montreal Protocol as a positive example of swift and effective scientific and regulatory response.

Class 6: building an inclusive community

The final class introduced a few theoretical frameworks to understand the importance of value alignment and sense of belonging to retention. Data from the climate survey that motivated the development of the course were shown. Students discussed their own personal values and motivations for pursuing research. Information was provided to students so that they may access relevant on-campus resources and organizations related to DEI, student leadership, and other academic departments with pertinent coursework. Students were also given two assignments they were to complete during the course of their graduate career. The first assignment was to find a case study, similar to the ones covered in this course, that examined the interactions between scientific research and society, which they could optionally share with the teaching team for use in future iterations of this course. The second assignment was to "affirm a peer's research idea"—students were instructed to find a research topic that they felt personally interested in and was related to their personal value system in some way. Then, they were to share this idea with a friend and listen to their friend's idea. The students were instructed to respond with support and encouragement, and perhaps find some relevant literature together or discuss ways to conduct the research. The purpose of this assigned exercise was to build scientific community through the affirmation of each other's values and the research topics tied to them.

A post-survey was administered in this class, where students rated their level of agreement with the ten statements in the pre-survey from class 1 again, and then answered a series of additional questions to gather their feedback on the course in general. Data from the two surveys were used to assess the effectiveness of the course.

Results and discussion

General enthusiasm for the course

Pre- and post-surveys provided an initial general understanding of the impact of the course. In the first class, students were asked to fill out a short pre-survey in which they rated their level of agreement with each of ten statements (Table 3). In the last class, students rated their level of agreement with the same ten statements again and were also asked a set of free response questions. Nearly all students (93%) thought that the course should be offered again, and 87% of respondents reported discussing the course with someone outside of class, indicating that they found the content important enough to share with others or interesting enough to continue discussing amongst each other.

Shifts in statement agreement

The content of the course was intended to shift students toward disagreeing more with each of the statements. The Mann–Whitney U test was used to evaluate the statistical significance of differences in the responses. The data for these responses are included in the ESI.† After taking the course, students were more likely to disagree with four of the statements (rows 1, 6, 7, and 10 of Table 3):

- "There is no evidence of systemic bias in STEM and academia" ($p < 0.05$).
- "My research is fundamental, so I can't control what other people use it for eventually" ($p < 0.03$).
- "As an academic chemist, the eventual impacts and applications of my work are not my responsibility" ($p < 0.001$).
- "Scientific progress and discovery inherently benefits everyone" ($p < 0.04$).

The main themes of the course were related to evidence of bias and the responsibility of academic researchers and basic science to consider the impacts of their work, so these shifts in opinion reflect that the course content was effective on these topics. Students already disagreed with four other statements and continued to disagree after taking the course, showing no statistically significant shifts in opinion (rows 2, 4, 5, and 9 of Table 3).

Two statements reflected ambiguous agreement before and after the course (rows 3 and 8 of Table 3). For the statement "Hiring, awards, and citations should be based on merit; the identity of the scientist does not need to be considered", a student may have thought that a process free of bias should not judge a scientist based on their identity. However, due to existing inherent biases in publishing, funding, and citations (which inform hiring and award decisions), by not considering a scientist's identity, these biases are perpetuated. Biases against minoritized chemists must be actively combatted rather than taking a "race-blind" or "gender-blind" approach. These concepts were addressed in class 1 but was not explicitly reiterated later in the course, so emphasizing them more may improve student understanding in future offerings of this course. The statement "Scientific research is objective; the identity of the scientist is irrelevant" may have been worded poorly. Students may have agreed with the statement considering that a good scientific experiment should be reproducible by any scientist. The course did emphasize that scientific research contains subjectivity and bias in problem selection, and the problem with considering research and merit to be purely objective, and student responses to the free response questions and interview questions seem to show understanding of these concepts. However, future iterations of the course may emphasize these points more.

Success in raising awareness and responsibility

Free response questions were coded according to five codes: two drawn from TIMSI theory and three drawn from the framework for institutional diversity interventions (Table 6). Identity and value codes correspond respectively to the role orientation and value orientation described in TIMSI theory. Awareness, responsibility, and action codes correspond to progressive stages of the framework for institutional diversity interventions.

The free response question results (Fig. 3) indicate that the course succeeded in raising 96% of students' awareness of the relationship between DEI and the broader impacts of their research and 93% of students' sense of responsibility for scientists to consider these topics. 51% of students expressed more knowledge and motivation to take action on these issues. Many

Table 6 Coding for analysis of free responses in the post-survey

Code	Description	Did the course have a positive or negative impact on…	What a positive impact might look like
I	Identity	…How well the student identifies with the community and their sense of belonging?	Talking about the course to others, or mentioning that it increased their sense of connection or comfort with the other students, or with the instructors
V	Value	…The student's perception of agreement between their own values and the department/community's values?	Mentioning changes in their own values or their perception of the department's values
N	Awareness	…The student's awareness that underrepresentation or consideration of broader scientific impacts is an important problem?	Mentioning that they learned something new about the impacts of research or of diversifying science; realizing that diversity and broader impacts are important
R	Responsibility	…The student's sense of personal responsibility for solving the problem?	Mentioning that they feel responsible to bringing about change in the field or a desire to change their approach or desire to learn more
A	Action	…The student's knowledge and motivation to take action to help solve the problem?	Actions beyond being generally more mindful/thoughtful on these issues; *e.g.* mentioning that they will look closer at funding sources or continue to have discussions, or try to build a more inclusive environment; or suggestions for actions to take by themselves or by the department

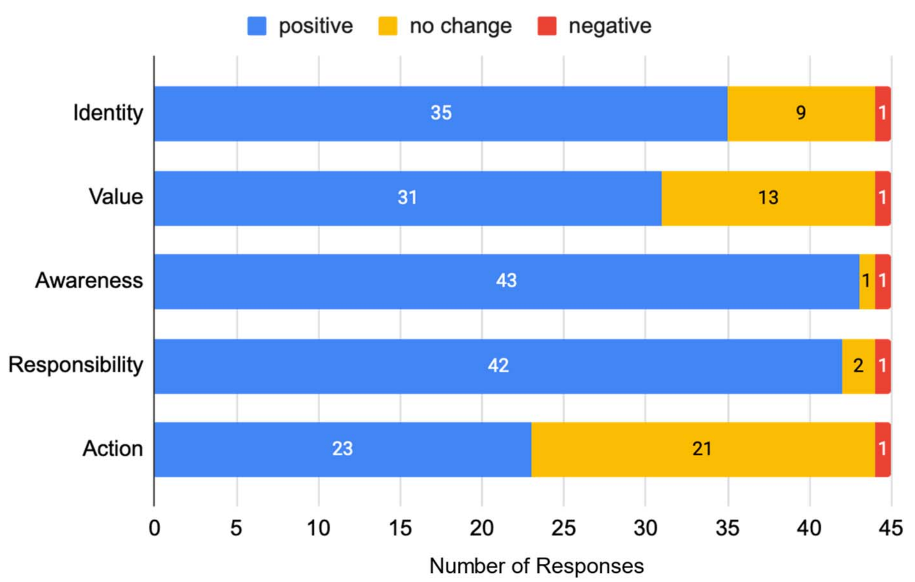


Fig. 3 Coding results for free response questions. Responses were analyzed using 5 codes defined in Table 3. Student responses to all survey questions were considered together to determine whether students experienced a positive, negative, or no change for each coding category.

Table 7 Trends in responses to free response questions

Description	Examples
Understanding the connection between DEI/social responsibility and scientific research	"Because humans are involved in the research process, there must always be discussion about the impact that our work has on ourselves and the people around us. Although the findings of the hard sciences are mostly objective, being involved in science must create room for debate on gray areas" "[I learned] that social issues are also relevant to science and scientists. What we do/follow reflects our values and sets examples for others. I found this important as this was a facet of science that I had ignored for a long time. But now I realize that it does exist and one needs to acknowledge the same" "We do have the power to control the downstream impact of our work, even if our research is fundamental. I found this important because I previously thought I couldn't do much to control it, but I learned that it is our responsibility to do so" "I learned to be more considerate in my research and think about how ethics plays a role in science beyond conducting experiments accurately and ethically. I used to think chemistry and other physical sciences were fairly insulated from any social issues, but I was very much proven wrong through the various case studies"
Ideas for taking action	"As a budding chemist, I was not aware of the tiny things that I could do on a personal level that could have far reaching environmental and social impacts. For example, being aware of the chemicals that I order keeping in mind its waste management and sustainability. Therefore, I believe that the coursework has now groomed me to be a "responsible" professional chemist" "I think I will consider the implications of my chemistry at scale more. Would I want to my chemistry to be done at industrial scale—or would that be very bad for one reason or another. It may also be helpful to talk to members of other disciplines (like chemical engineers or environmental scientists) to gain a more well-rounded picture of the impacts of my research" "I think the department can start by streamlining vendors […] by maybe giving discounts or promotional things for buying from sustainable vendors. […] I think it'd be interesting if the course would get together to write proposals that support various changes. Like for instance we could write and sign petitions for sustainable material resourcing, or protections on locals that are being affected. The concern here being that everyone is busy, and it's hard to get uniform contributions and effort on the part of everyone. You could localize it instead by encouraging members of the same lab to see in what ways can ideas from the class be implemented in their own lab group environments" "The course did a good job with showing statistics on percentage of people from diverse categories of caste, creed, gender, colour, nationality, *etc.* in academics or any other field *per se*. But I suggest conducting a panel discussion with the faculty/graduate student recruitment team of UCB so that one can actually get insights about how these social factors are considered in reality. For example, if they are in situation to choose between two people with similar profiles, what would they weigh their decisions on? Such real-life examples would actually motivate students to be morally and socially responsible"
Improved sense of connection with the department	"[The course] made me feel more connected to the department – very nice to see the chair so often in such a nice, comfortable environment too! And cool to see that a fellow grad student could make such a difference in the department" "It helped me feel more connected, especially since the department chair was part of it which made it feel like this was something the department as a whole valued and supported which was really nice because I personally value and support these topics too" "I think having guest faculty at the classes was interesting. I enjoyed listening and speaking with them on the topics of the course"

responses captured the concept of scientific responsibility and the importance of DEI clearly and concisely (Table 7). Out of the 45 total responses we analyzed, eight students included an explanation of how the human subjectivity of scientists can influence the way research is conducted and its resulting impacts, and why it was important for scientists to consider the connection between social factors and fundamental research. Twelve students also mentioned that these concepts were new to them and that the course changed their thinking.

Fewer responses indicated clear ideas for action-based solutions. Nine respondents indicated that they would be more thoughtful about waste generation and management (Table 7). While these sentiments are certainly positive, they are also still generally vague. Further research would need to be conducted to determine whether students' actions, in terms of waste disposal habits or chemical ordering, for example, actually change significantly. Six students had specific suggestions for the department to implement, such as systematic ways to change chemical ordering habits in the department, ways for students to organize larger actions together, or department events to further educate the community on social issues. Three students expressed a limited scope of influence as graduate students. Graduate students do have limited power to enact structural changes, but it seems promising that the sentiment appears to be seeded in many students, which they may act on at points in their careers when they do have more opportunities and ability to make these changes. From these data, a key area for improvement in this course would be to provide more specific and practical guidance on actions students can personally take to tackle the problems introduced in this course.

The responses also indicated that the course had a social benefit for students. 78% of students reported that the course also improved their sense of community with each other and with faculty who were involved throughout the course, including the department chair, and 69% of students reported that the course improved their feeling of value alignment with the department. Three students specifically expressed appreciation that the department chair and associate dean were involved in teaching the course, and for the faculty guests, as these aspects allowed students to get to know the department leadership and demonstrated that this course was important to the department and its faculty (Table 7). The course also gave them opportunities to socialize with each other and the faculty. The work of Estrada *et al.* suggests that role and value orientation are strong predictors of student perseverance in the sciences.[23–25] A course that can help build these aspects of a student's sense of belonging may be beneficial to their experience in graduate school.

While the post-survey responses were overwhelmingly positive, a small number of respondents ($n = 2$) expressed general ambivalence toward the course material (*e.g.* "I did not gain anything I did not know or needed to know from this course"), and one respondent expressed ire that this course was required of them (*e.g.* "Any attempt to force your ideas of social responsibility onto scientists is socially irresponsible").

The free response questions and anonymous exit tickets collected at the end of each class indicate that students entered the class from a wide range of previous experience with topics covered in this course. Several students were already deeply familiar with concepts related to DEI and science and technology studies and were able to provide suggestions for further reading. These students mostly appreciated the course content as it was already well aligned with their own values:

e.g. "I think it helped re-centre the dangers of reckless research and made me understand how decisions at the basic science level could snowball into so much more without oversight. I have always valued equitable research from the start, but this really deepened my understanding of how research can be inequitable at every level. Additionally, it gave me a new drive to better understand how my field of research fails disadvantaged communities".

Many students, particularly a few who self-identified as international students, noted that they had no exposure to this subject matter before, and expressed appreciation in having a chance to discuss these topics with their peers (*e.g.* "I am an international student and I was surprised to see how diverse the academic field in the USA is, but I started to think there is still room to be improved from today's lecture"). One challenge in course design was to accommodate this expected range of backgrounds in a relatively short amount of time. Some exit tickets revealed that the theoretical frameworks were confusing to some students, and some exit tickets expressed a desire for deeper nuance in the discussion. Since there is no unified curriculum for these science and technology studies in most chemistry undergraduate programs, future cohorts are likely to contain the same range of experience, and the course material should continue to be tailored to accommodate this variance.

Value of discussion and discourse

Interviews conducted with students and faculty guest attendees of the course provided some further insight on the impact of the course. Faculty and students who agreed to be interviewed all felt that the Scientific Responsibility and Citizenship course was a positive addition to our curriculum. We were not able to interview students who had a negative reaction to the course, but the experiences and responses described in the interviews still provide some understanding of which aspects of the course were effective and which could be improved.

A common takeaway described in the interviews is the entanglement and inseparability of science and the scientist. As such, the scientific process and the social environment in which it occurs must be considered together. This relationship between science and society was the key learning goal of the course. Three of the five interviewed students expressed that as a result of the course, they identified the sourcing of their chemicals, supplies, and other research materials, and the handling of waste from their research as areas in which they could consider the environmental impact of their work during their graduate degree. The nuclear chemistry case study was mentioned by two students as the example that illustrated most clearly how very fundamental research can rapidly and unpredictably develop into massive societal impacts. Faculty agreed that this felt like an important topic to cover: "we have just too many past examples of research that has gone different ways, unexpected ways, where there haven't been any safeguards installed upfront. And so that I think it's important for anyone who grows as a scientist to think about the larger picture". Students also expressed that the course illustrated the complexity of the interactions between science and society, and the lack of clear and easy answers. However, they were not usually discouraged by this complexity. As one faculty attendee observed: "I didn't think people were thinking like, chemistry is intrinsically evil. […] My general feeling was that people were thinking that there were opportunities to solve some of those problems and to prospectively think about those things". Students expressed that the complexity of these issues indicated the importance of active and ongoing discussions among scientists about the broader implications of our work.

Students and faculty alike expressed that the course provided what felt like a safe and respectful space for debate and disagreement (Table 8). Students noted that they did not agree

Table 8 Quotes from interviews

Description	Examples
Opportunity for discussion and discourse	"I think this is the class that most explicitly is about everyone coming in all level playing fields, and then figuring something out together, which I don't think you'd get in most of the grad classes" – student "I think that this might be a controversial thing, but [I think] that it is actually okay for me to not have the same opinion or values as other people in the department. Because this is a diversity question. I think that seeing those other values and knowing them is important, because we need to know how to handle those values at the same time. Especially when you take it out of the context of the greater university, because there will also be people outside of the greater university with the values that we don't agree with, as well as the values we agree with. Knowing how to handle those on a smaller scale will allow us to handle those on a larger scale" – student "Having those discussions and being able to talk freely about those things, and actually hearing other people's opinions who you don't agree with, I actually think that's really good. And how to deal with that as a scientist, right? If someone does criticize your idea, or maybe they're not even criticizing your idea, they just have a different hypothesis, right? How do you normalize that interaction? Maybe it starts with a class like this" – faculty "I feel like the faculty also learn [...] how the students are viewing these things. [...] In listening to the students, you get a sense of what the students think is important, and it should help faculty–student communication" – faculty "For social justice issues in research, there has, to my knowledge, never been a formal curriculum. So either it comes with informal discussions, or sometimes it comes from outreach activities or the news. But a structured introduction to what the problems are, and how we approach them, that's one really good part about this course. And I think the second part is just providing a vehicle for discussion. Because, you know, many of these, to be honest, can be contentious topics. That's not saying we shouldn't talk about them. But of course, there's a resistance for someone to say, I'm gonna bring this up and at the risk of running into a big fight with my lab mates, right? But this course is a way for first year students to sit together and say, right now we have to talk about it. And that's how I feel, that's when I think it's valuable as a vehicle to remove the barrier" – faculty
Active continued discussions	"I think that part of that means talking about the implication of creating a technology. We recently had a group meeting where we were remarking on this really cool physics development, I think it was a nuclear laser or something, [and it uses] enough energy to shut down the town adjacent to it. And talking about that implication, as well as talking about the science, I think, allows us to stay grounded in the real-world impact of what we do" – student "I think one tangible way of doing this is when I'm giving group meetings and [other presentations], making sure I include a slide about who are the communities that are affected by this work. It takes like, one minute to talk about, but can really help direct research motivation. [...] I think there's a lot of opportunities to be talking about [impacted communities], to be included in connection. [...] In science, we're kind of conditioned that these things can be separated and like they should be when you're talking to people who are more interested in hard science" – student
Building community and solidarity to take action	"I think one of the biggest things for me was just seeing these issues brought back to our attention. [...] I think that the course may have helped my cohort get more involved. [...] When you move to a new place, [...] I think it's easy to get swept up in class and whatever new [things are] happening. And so I think for me, it was helpful to reprioritize" – student "I really do think [the course] helped build substantial community in the cohort that I would have felt really lacking if it weren't there. Even though I had disagreements with folks in the context of the class, [...] that doesn't mean that it made me think less of anyone. [...] I felt really, genuinely appreciative that folks were willing to come in and take these questions seriously. It felt like a place that we could go and engage with things that otherwise wouldn't have been made available, which I really love" – student
Seeing chair and faculty prioritize scientific responsibility and DEI	"I think it felt really important that the chair was there facilitating. Regardless of any disagreements I might have with [the chairs], or the way they approach these questions, the fact that they're there and engaging and taking time out of an extremely busy schedule to be like, this is worth six hours of my instructional time on an evening on a Monday over the course of the semester, for us to talk about this as scientific peers made me feel like the department actually genuinely cares about this" – student "I think even just seeing the department chair caring is a big thing. And the department chair being accessible to students is another thing that is pretty unusual, but good. I think the department does value what we talked about: diversity, equity, inclusion, belonging" – student "When I first got here, it was like, wow, I wouldn't expect in the chemistry department for a chair to be really caring about diversity. But there was something kind of nice about that. Like, oh, maybe the department does care about these things" – student "There is a definite tone of like, this is something that is serious and valued in this space, which was really lovely to see" – student

with all of their peers in the discussion groups during the course, but that they were able to have respectful and productive conversations both inside and outside of the classroom on social and political topics. Students and faculty expressed that the discussion guidelines delineated at the beginning of each class provided guidance for their approach to conversations about such topics in the class and beyond. Students appreciated the opportunity to engage with their peers on these topics and to learn that their peers may come from very different backgrounds and hold different ideas and opinions from their own. Faculty do not often discuss such topics with their students, though they often do consider the broader impacts of their research in grant writing and in consulting with industry, and feel that it is an important part of the scientific process. The course provided a formalized venue for discussions of difficult topics that students and faculty otherwise can feel nervous broaching, as they can feel "contentious" or could lead to arguments. Students and faculty alike appreciated hearing each other's perspectives and were hopeful that such settings for discussion may improve faculty-student communication. Being able to give and receive criticism and disagreement respectfully and tactfully is important to scientific discourse and this course provided a moderated setting in which to practice this skill. Faculty mentioned that questioning research methodology and experiment design is key to critically assessing scientific work. The typical structure of STEM courses is not often conducive to debate over problems in which the answer is ambiguous. Yet, novel scientific advances often contain ambiguities and room for interpretation in their early stages, which require scientists to engage in such professional debate. Being able to do so in a respectful manner is therefore essential to the scientific knowledge generation process.

The values that students and faculty identified as important were remarkably similar. Students and faculty both expressed a desire to make a positive impact in the world, but they are also driven by an intrinsic curiosity and desire to seek new knowledge. For faculty, training students is a main priority. For students, interpersonal relationships in the department community are meaningful as well. Students see opportunities to mentor and develop friendships as important aspects of their experience.

Four of the five students who were interviewed had prior experience with the topics covered in the course, but still appreciated the reminder and re-prioritization of these issues and felt that it motivated them to take action together (Table 5). In their first semester, students are busy with coursework, beginning research, and adjusting to the new environment. Often, DEI, outreach, and consideration of broader implications of their work can feel less immediately important and difficult to find time for. Students appreciated the department's emphasis through this course on the importance to consider societal contexts and their interpersonal relationships. Two students expressed that the course helped build closer personal connections and build solidarity to join community and outreach-related activities and organizations.

The students who were interviewed all mentioned the importance of the presence of the department chair in teaching the course (Table 8). The chair's presence and time commitment demonstrated through definite action that the department and its leadership valued these topics. This encouraged students to take the course more seriously, and also conveyed to students that DEI and scientific citizenship in this department go beyond verbal commitments. Students expressed their feeling that the makeup of the department, particularly its faculty, is still lacking in diversity, but they felt that actionable and meaningful changes can happen and has occurred to improve the climate and diversity of the department.

A common request from students and faculty was to offer a separate course that is not mandatory, which would explore scientific responsibility issues in more depth and include more readings and assignments. Offering a mandatory course allowed people who may not have elected to take such a course to be included and exposed to the material, but the workload of the course was kept light to avoid overburdening students. In the interviews, a number of students and faculty expressed that they felt "hungry for more" discussions on these topics. The short format of the course was effective for starting discussions but did not allow for deeper discussions or explorations of the topics. The desire of students and faculty for more discussion and education on these topics can be seen as a success of the course in piquing interest and facilitating productive and intellectually enjoyable discourse. The short course can bring students up to a similar base level of knowledge, while a more intensive iteration of the course would allow interested students to engage with the material in more complex ways. A longer course could also include invitations of guest experts from adjacent fields who could provide further insight. As the topics do not necessarily require advanced scientific knowledge to be able to engage in thoughtful discussions, the course material may be similarly effective for undergraduates. A workshop for postdoctoral researchers may also be beneficial both intellectually and for building community.

Limitations

This study was conducted at UC Berkeley, and the results may contain features unique to this department. Berkeley is considered a politically liberal and progressive city and so its chemistry program may attract students whose political views have a similar skew. Students were told the goals of the course in the first lecture, and knowledge of the intentions of this project may have biased their responses or their decision on whether to consent to participate in this study. The post-survey respondents who consented to participate in this research study may contain some bias toward students with stronger opinions on the course (either strongly positive or negative). The wording of the post-survey open-response questions may encourage respondents to emphasize changes resulting from the course more. The participants who agreed to conduct an interview all had strongly positive reactions to the course. Participants with negative reactions did not volunteer for interviews. The overall sample size of this study is small. Continued study over subsequent years and in other departments or institutions can provide a more accurate view of the impact of such a course.

The implementation of a course of this nature can have potential negative impacts. Though we did not receive any specific feedback of this nature from students, we acknowledge that discussion of structural bias and inequity can result in disproportionate emotional labor or mental load to minoritized students.[76] Additionally, the positions of power some members of the teaching team hold (Department Chair, Associate Dean) may create an environment in which students are hesitant to voice dissenting opinions. We observed instances where students disagreed with the teaching team during discussions, but we are mindful of the power dynamic in the classroom and how it may affect the openness of discussions.

Conclusions

Development of a course that connects DEI and the broader impacts of chemistry research into the graduate chemistry curriculum

The first iteration of the Scientific Responsibility and Citizenship course at Berkeley was overall well-received by students and faculty. Though Berkeley's chemistry program is highly research-oriented and competitive, students and faculty still value consideration of the social contexts of their work alongside the scientific implications. Despite the short format of the course (meeting for only 6 hours in total), it had a significant impact on students' perceptions of the department and their awareness and sense of responsibility for considering research's interactions with society. This experiment demonstrates that even relatively low time-commitment interventions can be instrumental in shaping the student experience and potentially department culture as a whole. This course was offered for a second time in the fall of 2023 with a different graduate student instructor and department chair, and was once again well-received (92% of students in the second iteration thought the course should be offered again).

Assessment of impact on students' self-reported sense of connection with their peers and the community, and their values and objectives as scientists

The results of our investigation suggest that the development of this course did effectively integrate diversity, equity, inclusion, and the broader impacts of chemistry research into the graduate chemistry curriculum. The integration of these topics and the discussion-based format of the course were welcomed by students and appear to have improved students' reported sense of connection with their peers and faculty who attended the course. After taking the course, students' values as scientists appear to have shifted, and students reported that they would prioritize consideration of the impacts of their research and affected communities more.

Drawing on critical race theory and feminist science frameworks, we aimed to direct students to consider inherent biases in concepts and structures that are considered to be "objective".[34,35] Scientists often strongly believe in the objectivity of scientific research,[50] obscuring the societal factors at play in funding allocation, the design of projects, and interpretation of results into applications. By placing priority on discussions of structural biases and the identity of scientists we aimed to counter insidious existing biases that are accepted as "normal". Elevation of these discussions into a required part of the curriculum also challenges traditional notions of cultural capital[34] in science, and assigns value to the perspectives and contributions of scientists with historically excluded identities. The discussion format of the course and the centering of the subjectivity of researchers is also in line with these critical theory frameworks. The results showed that awareness of these considerations were successfully integrated into most students' views of research, though students may still struggle with translating them into actions. Drawing from TIMSI theory, a goal of the course was also to improve students' sense of science identity and value alignment.[23–26] The results from this study show that this course provided a moderated venue for discussion and discourse, which appeared to help build these aspects of students' experiences. As TIMSI theory studies have shown that improvement of science identity and value alignment are related to retention,[27,28] we hope to see improved retention among minoritized students over time as a result of this course.

Recommendations

We hope that other departments, both in chemistry and other STEM fields, may consider adopting a similar course. The profound interactions between science and society are a highly relevant topic in the education of any scientist or engineer but tend to be under-emphasized if mentioned at all in typical STEM curricula. This course demonstrates that students are receptive to these topics and that the format of learning through discussion may also be beneficial to students' social and scientific development. For those who wish to teach this Scientific Responsibility and Citizenship course, we offer a few recommendations based on our observations from this study, and related work on incorporating social justice frameworks into STEM education and theories on structural change in academic institutions.

The content of this course was designed for a cohort made up primarily of American students. Most of the case studies chosen were related to the US and its history and examined from the perspective of American scientists. Should institutions in other nations wish to adapt this course to their curriculum, it may be appropriate to choose case studies that are more closely related to the historical and cultural context familiar to the respective students. As an important component of this course is to consider the subjectivity that scientists (often subconsciously) bring to their work, students should be encouraged to consider how their national and cultural context may color the values they prioritize, and what privileges or limitations their perspectives contain.

The participation of department leadership in the instruction of the course is crucial. Studies have shown that effective institutional change must involve academic leadership. The presence of the chair and associate dean in the offering of the course at Berkeley was noticed by students and demonstrated the dedication of the department to equity and inclusion through action. The presence of the chair provides authority and access: the authority of the department chair may have encouraged students to take the course seriously, and the discussion format also enabled students to interact with the chair and form an approachable relationship.

The course material should be based on evidence in the academic literature. Citations and quantitative evidence where possible lend gravitas and credibility to the topics discussed. Students should be encouraged to engage critically with the literature and consider where it may not be free from bias, which is a common tenet of social justice education, grounded in critical theory.[77] The material should also be kept closely relevant to the students' field of study and where possible, practical actions that students can take should be presented, though the latter is often a challenging part of designing social justice course material.[78,79] Discussions of scientific ethics can easily veer into philosophical territory, which, while intellectually stimulating, can make the problems discussed feel abstract. Theoretical frameworks should be used to demonstrate how scholars have analyzed similar issues, and theories should always be tied back to actionable solutions by scientists. Clear answers often do not exist, and this should be acknowledged, but suggested approaches should also be discussed.

In discussions of social issues, disagreements will likely occur. If the discourse is respectful and productive, disagreement can be educational. The introduction of "classroom agreements" at the beginning of each class were mostly effective in building a respectful environment, and is a recommended practice for discussion-based teaching of potentially contentious topics.[80] Instruction staff should be prepared, however, to redirect unproductive discussion back to the intended topics and discussion questions. Some training or learning of discussion-based teaching and moderation techniques may be useful for the instructional team prior to teaching this course.[81] Through debate and discussion on these complex and often sensitive topics, a culture of trust can and must be developed over the duration of the course. Trust-building between community members and different constituencies is often identified as a key step in creating an inclusive institutional environment. We hope that this trust extends into interactions beyond the classroom as well.

In summary

The Chemistry Department at UC Berkeley undertook an experiment in redefining what constitutes essential knowledge in a graduate chemistry program. The consideration of science as a social process at every stage, from basic research to application, was included in a required course for first year graduate students. The content and the discussion-based format of the course were both unusual for a graduate STEM program but were both well-received by nearly all students and faculty who participated. In addition to a shift in perceptions of diversity, equity, inclusion, and the broader impacts of chemistry research, students also reported improvements in their sense of connection with their cohort and with the department community and leadership. The course succeeded most in raising students' awareness and sense of responsibility for the impacts of their scientific work, as reflected by shifts in agreement with a set of statements and coding of short free response survey questions. The course also provided a venue for moderated discussion and disagreement, which was appreciated by students and faculty. Students and faculty were able to engage in productive and thoughtful conversations on complex historical and contemporary topics, and built relationships with each other in the process. Future iterations of the course will reveal its impact on the graduate program over time.

Data availability

The data supporting this article have been included in the main text or as part of the ESI.† Data collected from free response questions and interviews are available upon request from the authors for confidentiality reasons.

Author contributions

K. T. X. conceived the project, conducted the course design, research, and data analysis, and prepared the initial manuscript. A. M. B. co-taught the course and supervised the course design, research, data analysis and writing. M. B. F. and F. D. T. co-taught the course and provided advice on the research process. All authors were involved in the revision and writing of the manuscript and approve the final version.

Conflicts of interest

There are no conflicts to declare.

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Notes and references

‡ Classroom agreements were adapted from Caroline Saouma's "Brave Space Norms" for her course at the University of Utah, UC Berkeley's Chemistry Departmental Information and Brainstorming Session (cDIBS) discussion guidelines, and UC Berkeley's Respect is a Part of Research discussion guidelines.

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