5-1-2023

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MAY 01 2023

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The Physics Teacher 61, 343–350 (2023)
https://doi.org/10.1119/5.0087490

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STEM professionals make decisions that impact society in a wide variety of ways. Making thoughtful decisions often requires them to consider a complex set of real-world implications that can impact multiple stakeholders, and there may not be a single "best" solution to be discovered.[1] These decisions can also be political in nature.[2,3] In contrast, science is often portrayed as being purely objective and apolitical.[2–4] Physics instruction often reinforces this portrayal by focusing exclusively on physics content knowledge and skills.[5] Some physics programs have been expanding to include technical skills that are relevant in the workforce,[5] and this expansion likely benefits students in their careers. But undergraduate physics programs, and STEM courses generally, rarely prepare students to grapple with the types of complex, ethical decision-making that they will encounter in STEM.[6]

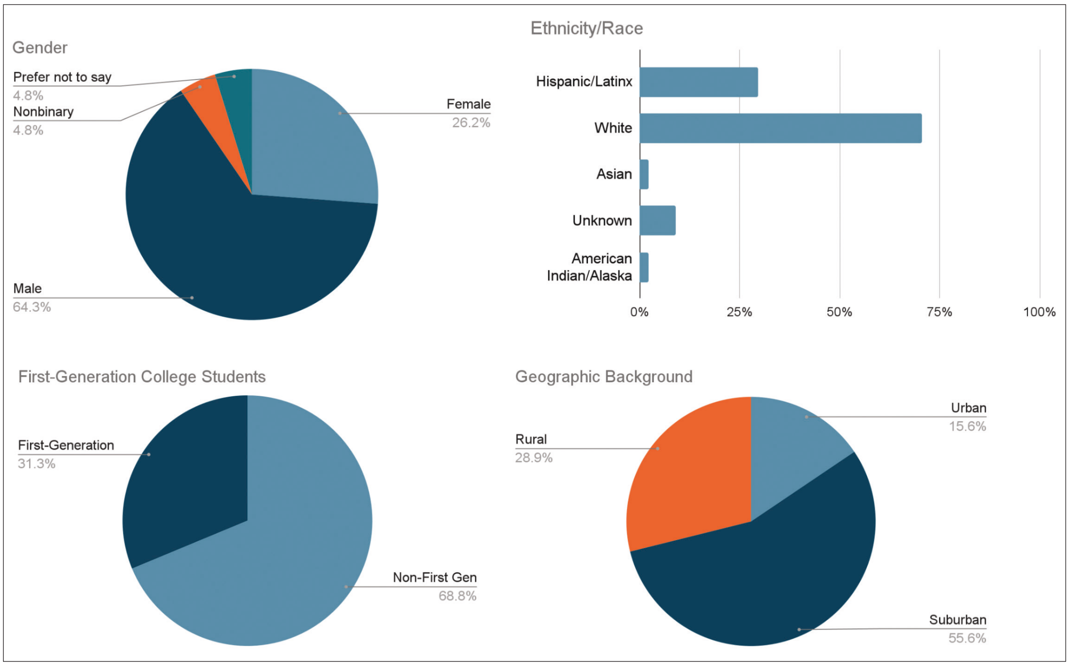

Fig. 1. Self-reported demographic data from two semesters of each course (85% of students completed our demographics survey). For ethnicity/race, students were able to select more than one category, so percentages add up to more than 100%. Geographic background describes the location(s) where students spent most of their childhood. Some students are represented more than once due to multiple enrollments across both courses. Forty-four student enrollments are represented. Demographics across the two courses are similar, with Modern Physics having a slightly higher proportion of multiracial students and Observational Astrophysics having a slightly higher proportion of first-generation college students and students from suburban backgrounds.

Because the typical scope of physics courses is fairly narrow, we are not fully preparing the physics community to face the challenges of a complex society. For example, Cech finds that engineering students experience a declining sense of social responsibility during their undergraduate degrees.[7] She argues that the characterization of science as apolitical and meritocratic contributes to this decline.[2] As such, we expect the same would be true in physics programs and courses.

Moreover, students who aspire to contribute positively to society through their careers often do not pursue physics or other STEM degrees because they believe that physical scientists do not center those values in their work.[6] This perceived value misalignment is especially salient for women and people of color,[6,8–11] and many of these students do leave STEM because of it.[9,11,12] Despite this perception, there are many large-scale challenges that STEM needs to address in the coming years, such as global climate change, and these challenges often disproportionately impact communities of color. Diverse coalitions of physical scientists with relevant lived experiences are best positioned to collectively generate innovative, equitable solutions for societal challenges. Therefore, it is critical to enable students with altruistic and collectivist values,[8] particularly students of color from impacted communities, to find opportunities to enact their values through STEM.

To build and retain a more conscientious future coalition of physicists and other STEM professionals, it is important that the physics teacher community confront the myth of scientific objectivity and apoliticism in the classroom. We should help students explore the real relationships between physics and society and support them in practicing ethical reasoning about complex social problems in physics contexts. We recognize that this is a difficult task: most of us did not experience this type of instruction as students; there are few resources and examples of ethics-focused curricula; and the resulting conversations among students have the potential to be complicated and difficult to facilitate. Within engineering education, there are some instructional resources for teaching about ethics,[13–15] but they often focus on microethics as opposed to macroethics.[15,16] Microethics encompass intracommunity professional practices such as data integrity and plagiarism, while macroethics encompass decisions that could have larger-scale societal impacts. While microethics are important, many STEM professionals who specialize in ethics have articulated the additional need to teach about macroethics.[14,15,17–19]

In this paper, we present seven curricular and pedagogical features that we have found useful when designing units about ethics, physics, and society. We also describe several instructional examples from our local work that draw on these features. We hope that by sharing our struggles and successes, we can help other introductory physics teachers in their own efforts to support their students.

Overview of our work

We have been designing, testing, and refining curricular materials and pedagogical approaches to support students' reasoning about ethics, physics/STEM, and society locally since fall 2018. Our primary instructional goals are to support students in building empathy for various stakeholders who may be differently impacted by scientists' work[20–22] and in developing a sense of agency for improving how scientists and society interact.[23] We consider these goals and our overall focus to be consistent with the goals of culturally relevant and culturally responsive instruction,[24,25] and thus with our mission as a Hispanic-Serving Institution.[26]

All of the authors of this article are or have been affiliated with the Physics Department at Texas State University, a large, diverse, public Hispanic-Serving Institution in San Marcos, TX. Our author group includes people at a variety of academic career stages, with institutional positions that range from undergraduate students to faculty, as well as multiple gender identities, racial identities, and socioeconomic backgrounds. A detailed description of the authors' positionalities is provided at the end of this article. Collectively, we have the perspectives of curriculum developers, education researchers, lead instructors, undergraduate Learning Assistants, and students in the courses we focus on here.

In this paper, we aim to provide a framework that can be adapted for a variety of physics topics and instructional contexts. We provide examples of how we used this framework to help introductory physics instructors better envision what this might look like in their courses. Based on lessons we have distilled from existing literature and our own experiences, we posit that the following curricular and pedagogical features are important to the success of ethics, physics/STEM, and society instruction. In this list of features, parentheticals indicate which of our goals are particularly likely to be supported by each feature based on our review of existing literature.

1. First-hand stakeholder accounts (*empathy*)[21,27]
2. Historical context (*empathy*)[28]
3. Scaffolded perspective taking/eliciting students' personal stances (*empathy, agency, and cultural relevance*)[1,20,24]
4. Facilitated small-group discussions; norm setting (*agency*)[29]
5. Formal ethical approaches (*agency*)[19]
6. Connections to local issues and/or current events (*cultural relevance*)[30]
7. Showcasing science activism/activists, particularly activists from minoritized groups (*agency*)[31,32]

In the following sections, we describe the ethics-focused curricular units we developed for two undergraduate physics courses at Texas State University and the student outcomes we have observed in each. One unit focuses on nuclear physics, and the other focuses on Maunakea and the Thirty Meter Telescope (TMT). The nuclear physics unit is part of a Modern Physics course that is required for undergraduate physics majors and minors. This unit was taught in person and then synchronously online due to the COVID-19 pandemic. The TMT unit is part of an Observational Astrophysics course that is an upper-division physics elective. This unit was taught synchronously online during the time period considered. When online, both courses used Zoom's breakout rooms and various collaborative editing tools to encourage student interaction. Both courses tend to enroll between 15 and 25 students. Slightly less than half of the Observational Astrophysics students considered here (44%, $N = 15$) had taken Modern Physics with an ethics unit previously. Aggregated, self-report demographic data from two semesters of each course are included in Fig. 1.

We use our local examples to illustrate what it can look like to implement these proposed key instructional features in a physics course (summarized in Table I toward the end of this article) and the potential benefits of doing so. We encourage readers who would like to learn more about the specific instructional materials used to contact us directly.

Modern physics: Nuclear physics

In the following paragraphs, we describe the implementation of two versions of a nuclear physics ethics unit, as well as our rationale for the changes we made for version 2. We then showcase some positive student outcomes based on students' written reflections.

Unit implementation: Version 1

We first designed, implemented, and studied a unit that focuses on the Manhattan Project. We embedded the unit in a larger unit on nuclear physics in an upper-division Modern Physics course.[23,35] We modeled the unit structure after an engineering ethics instructional approach called *Scaffolded, Interactive, and Reflective Analysis* (SIRA).[36] In alignment with our key features, the SIRA approach engages students in perspective taking, centers on a controversial topic, draws on

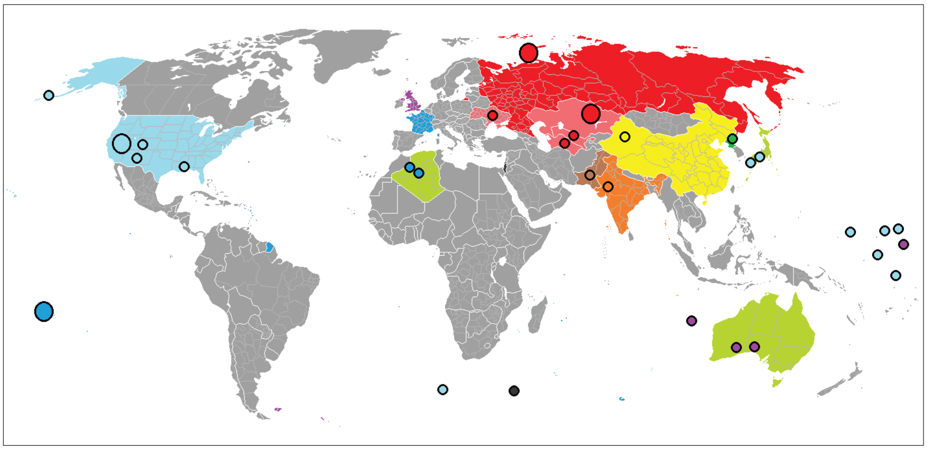

Fig. 2. A map of all nuclear detonations from 1945 to 2012. Over 2000 nuclear explosions have been conducted, in over a dozen different sites around the world. In version 2 of our nuclear unit, we share an interactive map of these detonations[33] with students.

Fig. 3. First atomic bombing of Hiroshima, Japan, by B-29 Superfortresses on August 6, 1945.[34]

first-hand accounts and other artifacts, and uses an ethical approach.

This unit begins with a brief introduction about why we are creating space for ethical conversations and an activity where students generate discussion norms that the class will aim to follow[29] (see Ref. 37). After a few class sessions focused on "standard" nuclear physics content, students begin to engage with our five-part series of worksheets on nuclear ethics (approximately one 50-min class period per part).

The first two parts provide a general introduction to the topic. In part 1, students research key people and events related to the development and use of the first atomic bomb. We also ask them to identify key stakeholders and consider how each might have been impacted by such developments. In part 2, students are introduced to Beauchamp's "Four Principles" ethical approach[38] and discuss how these principles can be applied in their day-to-day lives.[39]

In the last three parts, we guide students to try to understand others' perspectives while also forming their own opinions. For these three parts—*Beginning the Manhattan Project, Dropping the Bomb*, and *Living with the Bomb*—students read first-hand accounts from politicians and physicists from different moments in history. The accounts, excerpted from Ref. 40, include Einstein's letter to FDR, the Franck Report (advocating against military use of the atomic bomb), the Science Panel report (recommending military use of the bomb), Bohr's open letter to the United Nations, and the Russell–Einstein Manifesto. We ask students how the arguments in these excerpts align with Beauchamp's four principles and in what ways they agree or disagree. At the end of the unit, we ask students if/how their position on the ethics of the atomic bomb development has changed and why. The prompts are not intended to sway students to adopt a particular stance; rather, they are intended to provide entry points to considering U.S. physicists' roles in this complex and in many ways tragic history.

Rationale for changes

When observing student engagement and outcomes, we discovered some limitations in our initial approach. In Ref. 23, we found that Latinx, multiracial, and/or female students may have a harder time developing a sense of agency when instruction is centered on historical examples because of the historical exclusion of women and physicists of color from those spaces. In Ref. 35, we noticed that while Beauchamp's approach can provide meaningful support, it doesn't always provide enough flexibility and ease of use for students to fully express their ideas.

With these prior limitations in mind, we designed and implemented a revised version of this unit that includes an exploration of current nuclear ethics issues and pathways for students to get involved in discussions about nuclear policy. Version 2 also orients differently to formal ethical approaches by introducing a few approaches to consider as options rather than requiring students to all use the same approach.

Unit implementation: Version 2

Our revised nuclear physics unit includes four parts, again with norm setting and standard physics content at the start. In part 1, we ask students to consider what it means to act ethically and compare their ideas with short summaries of ethical approaches (utilitarian, duty-based, virtue-based, and others). Part 2 focuses on the early history of nuclear weapons and physicist advocacy. We ask students to consider three of the first-hand accounts used in the previous unit—Einstein's letter, the Franck Report, and the Science Panel report. Again, we prompt students to articulate the possible ethical reasoning behind each and share what they think. These two parts fall into one 50-min class period.

Parts 3 and 4 diverge more strongly from the previous version of the unit. Both center ongoing issues and advocacy, and both take up about one class period. Part 3 focuses on nuclear weapons. We ask students to listen to the podcast episode "At the Brink: Modernizing Doomsday"[41] and discuss its contents, including information about the creation of the Bulletin of Atomic Scientists. During class, we watch a video representing nuclear weapon deployments throughout history[42] and review plots from the Doomsday Clock website.[43] Students also read about the American Physical Society-sponsored "Physicists Coalition for Nuclear Threat Reduction,"[44,45] and we elicit their ideas about what, if any, roles physicists should play in advocating around nuclear weapons policy.

Lastly, part 4 focuses on nuclear power. We assign two videos about nuclear power.[46,47] Students are asked to draw from these videos to articulate nuclear power's potential risks and benefits. We highlight the stance taken by a physicist in one of the videos, who states that "people like her" view nuclear energy as a necessary piece of combating global climate change. We encourage students to articulate their own opinions about whether they would support funding for this type of research and what questions or concerns they might have.

Student outcomes

Despite some drawbacks in earlier iterations of this unit, all iterations resulted in positive outcomes for many students. Students reflected positively on the nature of class discussions and the unit's importance, for example,

> *During the discussions [about the Manhattan Project], we managed to have serious, fun, and conflicting conversations without feeling the pressure of getting a question wrong because there is no right or wrong.*

and

> *I think talking about why we would or wouldn't change things that happened with the development and use of the atomic bomb was very important in providing a greater sense of how to judge actions you should or shouldn't take as a scientist.*

We also see evidence that this unit was noteworthy to students within the context of the whole course. For example, one student wrote,

> *The ethics part of the course was my favorite. It was interesting to see how the STEM world interacted with government. I now understand the importance of public speaking as an engineer. I also realize how ideas in science can greatly shape history and how we must be careful with what we decide to create.*

Our shift to include both current and historical advocacy by physicists also seems to contribute to an increased sense of agency among students who are motivated to do more. One student mentioned subscribing to the nuclear policy podcast series we highlighted, while another wrote,

Fig. 4. An artist's rendering of the Thirty Meter Telescope on Maunakea.[48] Courtesy TMT International Observatory.

> *I am excited about the Physicist Coalition for Nuclear Threat Reduction. This has given me some hope and a place to engage with the nuclear risk reduction efforts. I have joined it and look forward to receiving more information about this topic. I was curious about how to write to Congress about the modernization of nuclear weapons and I think that this coalition will be helpful in doing so. I understand that physicists have been a key voice in reducing the threat of nuclear war historically.*

Observational Astrophysics: Maunakea and the Thirty Meter Telescope

In the following sections, we summarize the implementation of an ethics unit about Maunakea and the Thirty Meter Telescope that we developed for an Observational Astrophysics course. The unit development was informed by our initial experiences implementing and studying version 1 of the nuclear ethics unit. We again highlight promising student outcomes based on analysis of their written reflections.

Unit implementation

Our TMT unit includes four parts, each corresponding to one 80-min class day. Part 1 consists of class norm setting, as in the Nuclear Physics unit, and an introduction to some of the differing perspectives about the construction of the TMT on Maunakea. Because students may not initially be familiar with the TMT and the controversy surrounding it, we ask them to read a short article and three open letters that have circulated within the scientific community to prepare for this discussion.[49–52]

Part 2 encourages students to draw an analogy to gentrification by universities. Here, students discuss similarities between the consequences of the TMT construction and the consequences of gentrification occurring in San Marcos (where Texas State University is located) and neighboring cities.[53–55] The purpose is to help students relate to the situation in Hawai'i on a more personal level by considering a local

Fig. 5. Maunakea on the Island of Hawai'i. Photo by Alex Eckermann on Unsplash.

issue. Although this is not a perfect analogy, we hoped that students' first-hand experiences with gentrification would resonate with them and help them to empathize more easily.

Part 3 focuses on the histories of Hawai'i and Maunakea. Prior to class, students watch videos that give a brief introduction to colonialism.[56,57] During class, we ask students to construct a timeline of Hawai'ian history and a timeline specifically pertaining to events related to observatories on Maunakea. This task is done by splitting the class into four small groups. One group constructs a timeline of the history of Hawai'i from its kingdomhood to its annexation by the United States, and another makes a timeline from annexation through Hawai'i's statehood. The other two groups are asked to create timelines of Maunakea, one since the beginning of its use as a site for astronomical research in the 1960s to the beginning of the TMT site ideation, and one from the beginning of the TMT site ideation to the present. Students are provided with resources to use as a starting point for constructing timelines of significant events, and are encouraged to identify additional resources to inform their work.

In part 4, we give the students first-hand accounts of various perspectives about the TMT and Maunakea, as well as a handout summarizing formal ethical approaches. The first-hand accounts include the Report of the Hui Ho'olohe,[58] the Science article "No safe haven for the Thirty Meter Telescope,"[59] and a public statement made by Hawai'i governor David Ige in support of the telescope's construction.[60] We ask students to discuss how these stances align with the formal ethical approaches presented.

Student outcomes

Three themes emerged from our analysis of students' written work. First, students had a strong affinity for all parties involved reaching a compromise. For example, at the end of the unit, one student wrote,

> *Now I am not sure how they could go about the construction of the telescope in a way that satisfies the general public, but I do believe that the group behind TMT could work with the people of Hawaii to find a better compromise for both sides.*

Students also realized throughout the unit how complex the TMT controversy truly is, and that context is needed to understand a problem fully. In their reflections, students acknowledged the complexity and attributed their evolving perspectives in part to having additional context, for example,

> *I was strictly on the side of construction. My thought process being along the lines of "What is more important than scientific discovery?" After more thought and consideration, I think I have switched my position. While I would absolutely love if the TMT was constructed, I don't think the cost is worth it at this moment.*

and

> *Once we started looking at how the controversy compares to gentrification in San Marcos, colonialism/imperialism, the history of Hawaii, and read what some of the people of Hawaii think, my standpoint for which side I am on is much more in the grey area.*

The third theme we discovered is that students expressed empathy, informed by the first-hand stakeholders' accounts, and were better able to understand all sides of the argument. For example, one student wrote,

> *My initial reaction was to side with the astronomical community in support of the TMT. As our class discussions progressed, something that helped me empathize with the spiritual aspect of the anti-TMT argument was the "Report of the Hui Ho'olohe."*

Conclusions

In this paper, we summarized our experiences teaching about ethics, physics, and society at Texas State University. We articulated seven key curricular and pedagogical features that guide our instructional design and demonstrated what these look like in two course contexts. We find that students enthusiastically engage with these units and think carefully about the issues at hand. Even though our initial design had some shortcomings, every time we taught one of these units, students gained valuable experience discussing large-scale ethical issues in physics and benefited overall. We hope that other physics educators will find our key features and instructional examples helpful as they design their own units to support future physicists in grappling with their ethical responsibilities in society.

Table I. Summary of the seven key curricular and pedagogical features we identified as important for ethics units, and examples of how each feature was enacted in a Modern Physics course and an Observational Astrophysics course. Initial and revised versions of the nuclear ethics unit are included for illustrative purposes.

Key Feature	Modern Physics: Nuclear Physics–Version 1	Modern Physics: Nuclear Physics–Version 2	Observational Astrophysics: Maunakea and the TMT
First-hand stakeholder accounts	Excerpts from Ref. 40 including Einstein's letter to FDR, the Franck Report, the Science Panel report, the Russell-Einstein Manifesto, and others	Historical accounts: Einstein's letter to FDR, the Franck Report, and the Science Panel report. Current accounts: podcast episode on nuclear policy by a political expert, YouTube video featuring nuclear physicists sharing their perspectives	Open letters for and against the TMT and in support of the protestors[50–52]
Historical context	Students create timelines of key events before, during, and after the Manhattan Project (1930–1970), in addition to reading historical accounts (above)	Students read historical accounts from before/during the Manhattan Project. Students watch a video of nuclear weapon deployments through time	Students research general Hawaiian history prior to annexation (1800–1898) and between Hawai'i's annexation and becoming a state (1898–1959). Students also research the early history of Maunakea and the recent events involving the TMT
Scaffolded perspective taking/eliciting students' personal stances	Prompts guide students to articulate others' stances and their own, e.g., "What was the main argument made by Einstein and his colleagues?" and "What do you think about the decision Einstein made to advocate for the development of the atomic bomb? Would you have made the same decision? Why or why not?"	Prompts guide students to articulate others' stances and their own, e.g., "What do you think about physicists taking up these roles to advocate for nuclear weapons policies today and in the recent past? What roles should they play?"	Prompts guide students to articulate stances for and against the construction of the TMT on Maunakea, e.g., "Consider the arguments you've read about from various stakeholders … what ethical approaches do they use when making their arguments?" and "Have your thoughts changed since the beginning of this unit? If so, why and in what ways?
Facilitated small group discussions; norm setting	Unit begins with a discussion about class norms. Students spend most of the class time discussing prompts in small groups, with the lead instructor and undergraduate Learning Assistants facilitating	Same as Modern Physics Version 1	Same as Modern Physics units
Formal ethical approaches	Students consider and apply Beauchamp's "Four Principles" ethical approach[38] throughout the unit	Students are presented with a variety of ethical approaches and draw on the ones that are most useful to them during the unit	Students are presented with a variety of ethical approaches and consider which are being used to advocate for or against the construction of the TMT on Maunakea
Connections to local issues and/or current events	Not an explicit focus	Students learn about and discuss current issues related to nuclear weapons and nuclear power, including current debates around nuclear power	Students are prompted to relate the potential construction of the TMT to the gentrification of the city of San Marcos (where Texas State University is)
Showcasing science activism/activists, particularly activists from minoritized groups	Some historical examples of activism by physicists, e.g., the Franck Report, are included	Historical and current examples of activism/advocacy by physicists are included. Additions include the Bulletin of the Atomic Scientists and the Physicists Coalition for Nuclear Threat Reduction. Physicists' roles and responsibilities are explicitly discussed	The stance of protestors, the report of the Hui Ho'olohe ("listening group" report that provides perspectives of Native Hawaiians), and an open letter from SACNAS are included and discussed

Acknowledgments

We thank the Texas State Department of Physics and the Texas State Honors College for enabling us to teach these courses. We also thank the Texas State University College of Science and Engineering Dean's Office and Provost's Office for partially funding this work.

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