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PAPER

The "Who" in Engineering: Sociotechnical Engineering as Memorable and Relevant

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ABSTRACT

Does emphasizing the role of people in engineering influence the memorability of engineering content? This study is part of a larger project through which our team developed a new undergraduate energy course to better reflect students' cultures and lived experiences through asset-based pedagogies to help students develop a sociotechnical mindset in engineering problem solving. In this study, students in the class were invited to participate in semi-structured interviews (n=5) to explore our effectiveness in helping them develop a sociotechnical mindset around energy issues and conceptualize engineering as a sociotechnical endeavor. This study focuses on an activity during the interview where the participants were asked to sort a variety of images associated with class learning experiences along a spectrum of least to most memorable. Emergent themes from students' responses revolved around learning experiences that included global perspectives and emphasized a "who" (i.e., whose problems, who is impacted by engineering, and what type of engineers the students will choose to become) as the most memorable. Our results indicate that students found the sociotechnical aspects of the course more memorable than the traditional canonical engineering content. These findings suggest that framing engineering content as sociotechnical can be one strategy to increase student engagement, increase memorability of lessons, and help students to think more deeply about their own goals as future engineers.

KEYWORDS

sociotechnical thinking, qualitative methods, card sort, student perception, memorable, culturally inclusive pedagogies

1 INTRODUCTION

Engineering codes of ethics often discuss the safety and welfare of humans and society, yet the way we teach engineering rarely includes either people or the impact of engineering technologies on society [1]. Students know that they should care about humans and that ethics are important, but what does the equation they are learning to solve have to do with human life or social justice? Cech argued that, despite many students entering engineering with a commitment to public welfare, engineering's

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“culture of disengagement” leads students to be disenfranchised and care less about their impact as engineers and social consciousness when they graduate than when they matriculated [2]. One reason for this decline in student concern for public welfare may be the lack of exposure and practice students receive in their engineering curriculum that includes, let alone highlights, how human life and decision-making are involved in engineering [3]. The attitudes held by engineering faculty regarding the public and humanities may also perpetuate these values in students [4]. The engineering sciences, considered foundational knowledge and usually offered during the second year, are perhaps the most guilty of presenting engineering content as devoid of human or societal context [5]. Common in the engineering sciences is the use of the “engineering problem-solving method” (EPS) or “engineering as problem definition and solution” (PDS), which trains students to methodologically dissect and solve a technical problem with mathematical solutions [6]. While an important engineering tool, the emphasis of PDS above all else in these foundational courses has perpetuated the dominance of mathematical problem solving as the highest value in engineering. This unintentionally reinforces the worldview that technical rigor is more important than the context in which engineering is practiced [7], [8].

This paper describes a research project where we drew from features of culturally inclusive pedagogies to integrate people into engineering content [9] throughout the duration of an entire course focused on energy [10]. The interventions we used included using examples of engineering found in non-Western cultures, featuring racially diverse experiences of people who practice and are impacted by engineering, and building people into discussions and calculations of how energy is sourced, generated, and used. While elements of the project have been published elsewhere [9]–[21], this study in particular analyzes how students engaged with and remembered different types of course content to examine whether our inclusive pedagogy had an impact in shifting students toward valuing sociotechnical issues.

1.1 Project context

This paper focuses on students’ experiences within a single course within the Integrated Engineering curriculum at the University of San Diego. Integrated Engineering, founded in 2017, has an overarching mission to provide an engineering education around skills and habits of mind [22], rather than disciplinary content, to help develop engineers who acknowledge engineering as a sociotechnical endeavor and apply their knowledge to complex sociotechnical issues [23]. One of our program’s goals is to present an alternative discourse to begin to normalize engineering as sociotechnical, rather than continuing to uphold the social/technical dualism commonly seen in engineering classes [24]. A simple first step in this direction is presenting engineering content in a way that is not devoid of people.

This study is part of a National Science Foundation–funded project to investigate how culturally sustaining pedagogies (CSPs) can be integrated into undergraduate engineering curricula [16]. Our team sought to modernize engineering energy education to better reflect students’ cultures and lived experiences [25] by developing a new undergraduate energy course that implements features of CSPs throughout [26]. Another goal of the project was to integrate energy as a concept that continues to evolve in engineering and highlight the interconnectedness between society and engineering—what we refer to as a “sociotechnical approach” to teaching engineering. As instructors, we hope our course can serve as a model for demonstrating how engineering courses can help students develop a sociotechnical mindset for engineering problem solving.

The Integrated Approach to Energy course, offered for the first time in Spring 2020, is the first major-specific class that students in the program take. We designed this course to teach energy concepts relevant to engineering students of the 21st century, emphasizing the sociotechnical nature of the energy challenges facing today's professional engineers. Importantly, this new energy course is not meant to "remake" Thermodynamics; in fact, we recommend that students who are interested in energy-related issues still take Thermodynamics to develop an in-depth understanding of heat engines for fossil-fuel applications. Instead, this class is a modern sociotechnical energy course developed from scratch that focuses on energy concepts as broadly relevant to both the profession of engineering and the future of our planet.

Not only has our research shown that sociotechnical contexts can enhance students' learning of technical content [27]–[33], but sociotechnical thinking is critical for tackling the complex problems we face today globally [34]. After all, engineering alone cannot solve complex sociotechnical issues [35]. Additionally, by drawing upon culturally inclusive pedagogical literature [9], we believe featuring people in engineering problems can also help students better connect to course material and remember it later. We hope that helping students connect human experiences with engineering will help them develop positive attitudes towards engineering for people and encourage them to continue learning and thinking purposefully about their societal impacts and whose voices are in the foreground and whose are missing.

1.2 Memorability

In education research, the concepts of memory and learning are often intertwined [36], [37], though the meanings of each vary based on the disciplinary context in which they are used. *Memorable* is defined by the Oxford English Dictionary as "worthy of remembrance or note; … not to be forgotten." Marmur, in mathematics education, suggests memorable events to be "not merely as events that can be recalled from memory upon request, but as events that additionally hold significance and meaning for a person who experienced them"; this research suggests connections between memory, emotions, and learning [38]. As such, the memorability of a classroom event can shed light on the cognitive and affective dimensions of learning. Bloom's Taxonomy, most well known for the cognitive domain frequently used to structure educational assessment, describes three hierarchical models used to classify learning objectives into levels of complexity. Of the three domains (cognitive, affective, and psychomotor), our work in this paper explores learning in the affective domain, which includes "changes in interest, attitudes, and values" [39].

The study described in this paper measures the memorability of various class topics and activities through a retrospective protocol that uses images to elicit students' memories about those topics and activities. While measuring memorability may not be a perfect assessment of learning (e.g., surprising events can be memorable), it does provide insight into what students found notable and what types of topics and activities held meaning to them. This is pertinent as one of our goals is to influence the shaping of their figured world as they are discerning what engineering means to them [40].

2 METHODS

This study describes the findings from the second offering of the course in Spring 2021, which had nine students enrolled. The course met twice a week, for 80 minutes each session, for 28 sessions throughout the semester. Given the COVID-19 pandemic, all course meetings were held on Zoom.

We conducted student interviews at the end of the course to explore students' perceptions and reactions to our approach in helping them develop a sociotechnical mindset around energy issues and internalize engineering as a sociotechnical endeavor. We aimed to analyze how students' authentic responses to course material revealed the degree to which they valued the sociotechnical aspects of engineering, particularly compared to the technical aspects presented in the course.

2.1 Data collection

We recruited an external researcher, a postdoctoral researcher hired in the School of Engineering, to conduct interviews with students to ensure that students would feel more comfortable responding and not fear that their responses would affect their grades. This researcher was not associated with the development of or observations in the class. Because this individual was previously unknown to the students, she was invited to the class by the instructor to introduce herself as the researcher who would be conducting interviews on the students' experiences in the class. Students were informed of the opportunity to participate in the interviews during class by the instructor and were sent email solicitations directly from the postdoctoral researcher. Students were incentivized to participate in the study with $50 gift cards as compensation for their time.

Five students (four women, one man) out of a total of nine students in the class opted to participate in semi-structured interviews (n=5), which were conducted shortly after the close of the semester. All students were second-year engineering students majoring in Integrated Engineering. Due to the small size of our program, other identifying information is not provided in this paper. All interviews were conducted remotely via Zoom, as the university had not yet resumed in-person classes after the transition to emergency remote instruction due to COVID-19 [13]. Interviews ranged from 27 to 55 minutes long, recorded by the interviewer on Zoom and transcribed through the GoTranscript online service. After the interviews were completed, the postdoc de-identified the data to ensure that students' responses would stay confidential from the other authors, who were professors in the same department and would have these students in their classes in the future. Only the transcriptions, using pseudonyms, were provided to the research team by the interviewer.

The interview began with asking the participants the following general questions: Why did you choose to major in engineering?; How do you define engineering?; Please describe an engineer; What kind of problems do you think engineers might solve?; and What differentiates engineers versus non-engineers? [11], [12]. The interview moved into investigating why the students chose Integrated Engineering as their major and continued with questions about the energy course, such as the most and least interesting things about or from the class, and how the class compared to other engineering courses at the university. In addition, the interview included two activity questions. The first was a question asking students what information they would gather to inform their design if instructed to design a power plant from scratch. Specifically, this question sought students' authentic articulation of any of the pillars within the PESTLE (political, economic, social, technical, legal, and environmental) framework [41], which was used throughout the class.

The second activity question included an online hands-on card-sorting activity, during which participants were asked to sort images from the class on a spectrum from least to most memorable. This paper focuses on the results from this card-sorting activity, whereas results from the rest of the interviews are published separately [10], [11].

2.2 Card-sorting activity

We utilized a card-sorting approach, which elicits the framework that a participant uses to understand an idea. During a card sort, the participant physically manipulates the placement of cards to illustrate their thinking, while explaining their answers to open-ended questions aloud to the interviewer. Card sorting is an approach often used in user-experience design of web interfaces, where users are asked to sort cards into categories to provide usability feedback on, for example, how to organize context menus [42], [43]. Within academic research settings, cognitive psychologists have used it to measure expertise in a variety of disciplines [44], and anthropologists refer to it as "pile sorting" and use it in cultural domain analysis [45]. In higher education STEM fields, card sorting has been used by education researchers to measure conceptual expertise in physics [44], biology [46], [47], chemistry [48], [49], and engineering [50], [51]. These studies showed card sorting to be a useful tool tracking the progress of students towards more expert-like thinking. Chen and colleagues digitized the method by creating a platform, named Collection and Analysis of Research Data for Sorting (CARDS), and applied this technique to engineering education to explore how faculty and engineering students from a variety of engineering disciplines conceptually organized engineering knowledge (i.e., by cross-disciplinary skills or by disciplinary focus) [50].

In addition to mimicking the CARDS platform, which allows for a flexible and modular workflow for participants to think while they sort, our activity also draws inspiration from online techniques learned during emergency remote teaching due to the COVID-19 pandemic [13], [52]. Given that these semi-structured interviews were conducted remotely, we capitalized on the opportunity to incorporate a tool that students had already used in the class: Miro boards, an online collaborative platform. Our study adds a qualitative element to digitized card sorting by pairing it with interviewing to explore the open-ended question "What elements of the energy curricula and activities created a memorable impression on the students?"

The activity begins with seven cards stacked on top of each other on the left side of the screen in no particular order. Student participants were asked to drag and drop the cards from least to most memorable, at any point along the spectrum, in any way that made sense to them. Participants were explicitly told that they did not have to rank-order them and that it was fine to stack several cards in the same spot. The interviewer encouraged the participants to think aloud during the sort and explain their thought process at the end of the sort. Figure 1 shows the Miro board at the start of the card-sorting activity.

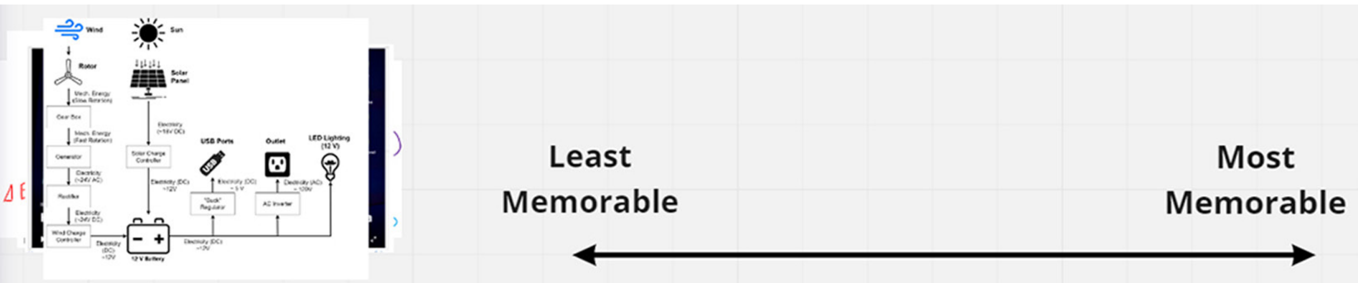

Fig. 1. Miro board at the start of the sort

Each card was a screenshot of a PowerPoint slide that students saw in class at some point during the semester. The seven cards were selected by the researchers based on the types of activities they spanned, from snapshots of videos, to activity introductions, to slides with the instructor's handwriting working through equations to solve a technical problem. In some cases, slide titles were first removed from the card to prevent cuing the participant towards recalling the class content just from the title rather than from the content. We deliberately chose images that represent a spectrum of active vs. passive learning; topics from early in the semester to more recent; and canonical engineering examples vs. examples that included more diverse faces, reflected students' own experiences, and represented a variety of cultures as sources of engineering knowledge. Table 1 summarizes the content of each card and the context of when the slide was shown in class from the instructor's perspective.

Table 1. Summary of lecture slide "cards" used in the interview card-sorting activity

Card Name	Summary of Card	Class Context
[7 Generations Principle]	A quote from Oren Lyons, faithkeeper of the Onondaga and Seneca nations of the Haudenosaunee (Iroquois) Confederacy, describing the 7 generations principle, a guiding concept prevalent in many Native American tribes. This quote was used alongside the Brundtland Report's definition to introduce the concept of sustainability to students.	Class 3: 5 min explanation by the instructor
[Efficiency]	A mathematical definition of efficiency in an energy context relating useful energy delivered to the energy input. This slide is the first time efficiency was defined in the class. This definition was then used multiple times throughout the semester to calculate different efficiencies.	Class 4: 5 min explanation by the instructor
[Units]	Diagrams showing the relationship between body measurements and units in 4 different historical contexts. The takeaway for this slide was that units are a social construction derived originally from body measurements and can vary from culture to culture.	Class 5: 5 min explanation by the instructor
[EnergiPlant]	A block diagram of the Primo EnergiPlant—a standalone, renewable energy generation station that combines solar, wind, and a battery to provide power and lighting. The EnergiPlant is a physical structure placed in the plaza directly outside the engineering building on our campus [53].	Class 11: A recurring graphic over several weeks showing the EnergiPlant, a major focus of analysis in the course
[Wind Turbine]	A conservation of energy analysis of wind energy to calculate the work that can be extracted by a turbine. This analysis was done in the larger context of the EnergiPlant and formed the basis for equations used in homework to analyze wind turbines.	Class 11: Part of a 45-min module on energy analysis for wind turbines
[Environmental Justice]	This was the introduction slide to a breakout activity where students watched a short video and read an article and then discussed several guiding questions in their small groups. The video is a short clip of a tribal leader explaining the history of nuclear waste and the taking of land from the Western Shoshone tribe [54]. The article was written by Dr. Ayana Elizabeth Johnson, a Black climate scientist, explaining the ways in which racism impacted her ability to do her climate science work [55].	Class 24: 30-min activity, including debrief in a larger lesson on environmental justice
[Energy Poverty]	This TED talk [56] shown in class was presented by Dr. Rose Mutiso, a Kenyan native, who described energy poverty affecting nearly two-thirds of Sub-Saharan Africa and the need to build a new energy system to grow with it. The debriefing with the instructor focused on the ways in which energy solutions must be contextually dependent; that the US solution is not a one-size-fits-all solution.	Class 24: 15-min-long TED talk with 5-min debrief by the instructor

2.3 Data analysis

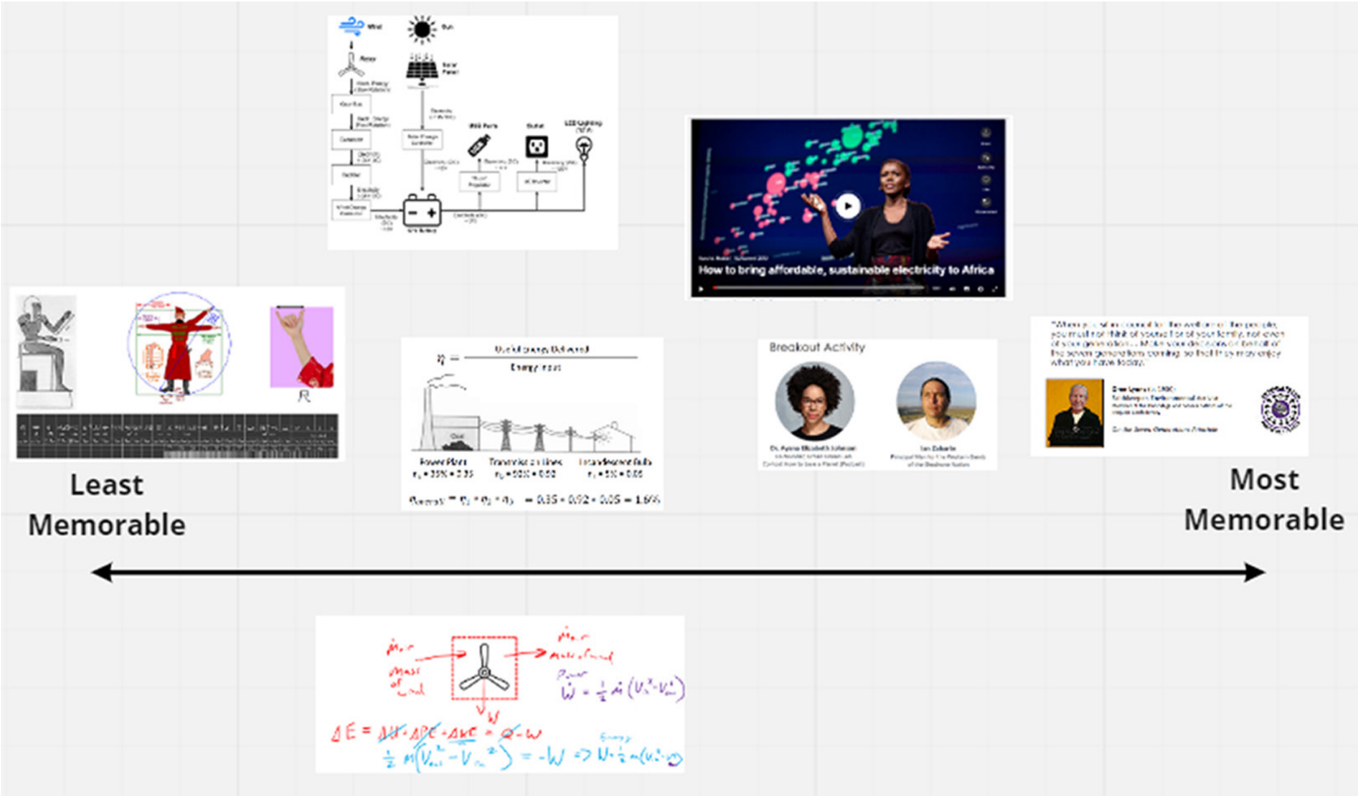

Fig. 2. Example of finalized sort showing ranked groupings from least (left) to most (right) memorable: [Units], [EnergiPlant (top), Efficiency (middle) & Wind Turbine (bottom)], [Energy Poverty (top) & Environmental Justice (bottom)], [7 Generations Principle]

The data were analyzed by interpreting the participants' final card sorts while corroborating their sorts with the transcripts of their interviews during the card-sorting activity. We rank-scored the final card positions by visually grouping each participant's sorts and checking the interview transcripts to ensure the groupings were interpreted correctly based on what the participant was describing during the sort. In general, if the center of a card was placed more than a quarter-card-width away from the next card, they were considered separately ranked. For example, the sort in Figure 2 was interpreted to illustrate four different groupings, with [7 Generations Principle] at Rank 7 (most memorable), [Environmental Justice] and [Energy Poverty] tied at Rank 6, [EnergiPlant] and [Efficiency] and [Wind Turbine] tied at Rank 4, and [Units] at Rank 1 (least memorable). We reached a 91% interrater reliability among three raters (the first three authors on this paper) after only one iteration, and we reached 100% consensus after discussing only 3 cards that varied by one rank by one rater in each case.

It is important to note that the numerical rank is the researchers' interpretation of the participants' sorts, which uses the placement of a card on the spectrum as a proxy for memorability, rather than directly measuring memorability. Providing the participants a variety of cards to sort through, instead of simply asking students "what was most memorable from the class?" enabled us to utilize the sorted images as a visualization tool to guide the qualitative analysis. The images helped elicit students' memories and accompanying reflections. However, the numbers presented in Table 2 may not necessarily represent how students may have ranked the cards themselves, particularly since they are portrayed in this analysis as each having equal weight. The ranked-scoring method used in the pseudo-quantitative analysis attempts to account for the participants' overlapping placements of cards by assigning ties and using the full range of scores from 1 to 7.

In addition to using the transcript data to corroborate the ranking, we also analyzed the transcripts using inductive coding to identify themes in the students' interviews during the sorting activity. First, the interview transcripts were coded by the card that the participant was talking about at each moment. These quotes were all grouped by their cards to find similarities in what the participants had to say about each topic, which led to several emergent themes around duration spent on the activity, type of activity, and how recently the topic was discussed in class. These themes were set aside as not significant data for the research question being investigated, which pertains to the significance of each card's topical content to the student. The remaining quotes were re-sorted based on the perspective-taking the participant demonstrated in their description of the card; namely, whether or not the student considered the topic important or relevant, and if so, why.

3 RESULTS

Table 2 shows the ranking of each participant and the resulting final memorability score for each card. While the card [Energy Poverty] was awarded the highest score for memorable and the [Units] card unanimously scored least memorable by all participants, it is also interesting to note that the more memorable cards are all grouped closely together with a sharp drop off in score for the less memorable cards.

Table 2. Interpretation of ranking for each interviewee and final memorability score (where *more memorable* is represented by a higher numerical value)

Card name	Lucy	Sonia	Meg	Aliana	Bryan	Memorability score (out of 35)
[Energy Poverty]	7	6	7	3	7	30
[Environmental Justice]	7	6	7	2	7	29
[EnergiPlant]	5	4	7	5	5	26
[7 Generations Principle]	4	7	4	7	3	25
[Efficiency]	2	4	3	6	5	20
[Wind Turbine]	3	4	2	4	2	15
[Units]	1	1	1	1	1	5

Reviewing the transcripts, students' perception of certain cards in terms of the type of activity, timing in the semester, and duration spent on the activity were as expected. In general, students rated a card as more memorable when it was an active-learning type of activity, when the activity was recent (i.e., at the end of the semester), and when a significant amount of class time had been spent on it. Two themes—*relevance* and *"who" in engineering*—revealed more interesting data about what made the content appealing to students.

3.1 Relevance of the topic

In describing their sorts to the interviewer, one criterion that students indicated influenced the memorability of the topic was how relevant or useful they thought the topic would be to their future selves as engineers. Particularly, students found the topic of some cards irrelevant to the modern era and not important to store in their memories. For instance, one student said,

> "I think [the [Units] card] is about measurements and how they differ from culture to culture, but I don't remember much more than that. **It just doesn't seem that important, especially because I know we have standardized units now.**" (emphasis added) (Sonia)

Some students demonstrated a sociotechnical mindset in their indication of what was or wasn't useful to them. In these sorts, students described a clear delineation between cards that represented purely technical content and those that highlighted the sociotechnical nature of engineering, with sociotechnical content being more relevant to their future selves. For example, Sonia shared,

> "*[While pointing to the cards [EnergiPlant], [Wind Turbine], and [Efficiency]]* These are just the specific energy things that maybe I'll need in the future, but maybe not. **I'm not really sure if I'll have a need for these.** ... *[While pointing to the cards [Energy Poverty] and [Environmental Justice]]* Because these are like the environmental justice parts, which, as I talked about, I think those are important. **I could use them no matter what my career is.**" (emphasis added) (Sonia)

Similarly, Aliana suggested the relevance of a specific topic when she referred to "real-world applications." In the following quote, she compares more abstract concepts—such as "reducing the temperature of the earth" with "fundamental changes"—that are needed in our engineering decision-making that impacts equity.

> "I really liked whenever we talked about, not exactly how to calculate energy and stuff like that, but watching videos, like this one [Environmental Justice]. I don't know, it was just so much more of a real-world application. ... Her article on how all of these coal plants and stuff are always near the minority communities and stuff. ... I just think, like, at the end of the day, those are the things that are super important, that we need to change besides just reducing the temperature of the earth and, like, switching to more renewable energy. Those are big things that we need to actually fundamentally change about the way that we deal with energy." (Aliana)

3.2 Who in engineering?

Comments about the "who" in engineering emerged more frequently, more passionately, and from more students than those about the relevance of the topic. Notably, the cards [Energy Poverty], [Environmental Justice], and [7 Generations Principle] clearly highlighted communities, while the other cards did not. When discussing these three cards, all the participants credited some aspect of the memorability to the people described in the topic. One student thoughtfully described this person-centric aspect as the main criterion for when content in class really “clicked” or resonated with them:

> “I think when I can somehow relate to … [what] we’re talking about in class. It really clicked. … I think it’s really interesting to learn about different people and their stories and what they’re going through and what they’re doing to make a change.” (Meg)

Students’ descriptions about their most memorable cards often included commentary about whose problems they were solving, who is impacted by the engineering, or who they would be as future engineers. The perspective of people, in contrast to abstract engineering problems that did not feature people, seemed to provide an additional layer of relevance to students.

Whose problems, and whose solutions? The original video related to the [Energy Poverty] card discusses energy accessibility as a problem for the African continent and how West-imposed solutions not only will not work in a drastically different context but also perpetuate unjust power relations. When discussing this card specifically, several students indicated that (1) they recognize injustices and (2) injustices can occur differently in every country. However, the students remained in a semi-transitive state [57], [58], as their quotes suggest an interest in Africans’ suffering and poverty rather than a personal connection to Africans’ empowerment or how to advocate for change. The idea that African countries can have different problems than European or North American countries is novel; students have a surface-level focus on this novelty rather than digging deeper into a comparison. We consider three student responses and explore the range of their awareness.

Aliana used the term “impoverished,” which indicates a power dynamic where one community is made poor at the expense of another. Her quote below is the least critically aware of the three: she has identified that injustice is at work; there are problems in the world, and these problems matter. While the point seems trivial, many engineering classes do not even get this far in having students critically think about the impacts of engineering problem solving.

> “I love talks like this, where we talk about energy in impoverished communities or places like Africa. I thought this was one of the most impactful things we did that I would probably apply to—I think this is one of my biggest takeaways from the class.” (Aliana)

Lucy points out in the quote below not only that she understands there are problems, but that they can look different in every country. She is interested in the idea that the energy problems that African countries face are not the same problems the United States faces.

> “I really liked that because it was. … We were talking about the United States’ approach to energy, and how we have all these different problems here that’s preventing us from having a sustainable future. All those problems were different from the problems in Africa. I thought it was really interesting to see how our problems vary. We are two very different countries that both want the same thing, yet we have different problems based on different things, like money, urbanization, industrialization, all types of stuff like that.” (Lucy)

Sonia's quote below represents a deeper reflection than those of the other two participants. Not only does she recognize that solutions are not one-size-fits-all, but she captures the key message that it is important to let the local community be integral in the solution of the problem.

> "Like, every country is different; they have different access and options. … We need to listen to Africa and countries, like, what they say that they need and not just, like, what the West thinks that they need. I think that's really important." (Sonia)

While the students present a surface-level consciousness and understanding of the power dynamics at play discussed within the video, there are also indicators that the students are shifting away from this type of thinking and towards something deeper. We can consider even this basic recognition of injustice to be a success, as the initial course in a sociotechnical engineering program.

Who is impacted by engineering interventions? Students described some cards as more memorable, based on the demonstrated impact of engineering interventions on communities, in both positive and negative ways. For example, communities most negatively impacted by climate change would be the most positively affected by engineering interventions, while some engineering interventions may negatively impact some communities more than others. One participant summarized the [Environmental Justice] card in one sentence, remembering the takeaway being how minoritized groups need to be included in the creation and decision making of climate-change solutions because they are disproportionately affected by it. High memorability was captured in topics that emphasized the size of the impact on people. For instance, Lucy said, while referring to [Energy Poverty] and [Environmental Justice],

> "It also had to do with the more global perspective, rather than just these math problems that we had to do here in this unit. The same for this one: we had to talk more about who gets affected by the things that engineers do and what we have to [consider] when we are developing something. I really liked those two the most, which is why I think it will be the most memorable for me." (Lucy)

In describing the [Environmental Justice] card, Aliana stated,

> **"It was just so much more of a real-world application and how this is actually affecting people. I think those were the times where I was super interested,** … how all of these coal plants and stuff are always near the minority communities and stuff, and how they need to be a part of the solution. That really stuck." (emphasis added) (Aliana)

These examples represent a common theme demonstrating sociotechnical perspectives, particularly the impact of engineering on people, as memorable and important to students.

Who will I be as an engineer? Some students showed further development in their self-reflection than others. Specifically, some students demonstrated transitivity and self-agency in their descriptions of why certain cards were more memorable to them. The theme of "who will I be?" draws upon critical discourse analysis (CDA) developed by Fairclough [59]–[61]. Fairclough argued that CDA provides a method to identify the hidden messages that may be present in different social structures. Two particular contrasting concepts that emerge from CDA are nominalization and transitivity, where nominalization describes when actors are not clearly involved in processes—there is a blurred line between an action and who performs it [59], [62], [63], while transitivity describes a clear connection between subjects and objects by providing a clear indication of who is involved in the action [59], [62], [63]. The concepts of nominalization and transitivity can be used to describe how individuals make sense of presence and abstraction and the social actors (including their own agency) involved in engineering activities [64]. The following quotes demonstrate evidence of first-person perspective-taking that clearly indicated the impact Sonia hopes to enact as a future engineer, showing a clear connection between herself and her actions.

> “If you want to be environmentally conscious and fight against climate change, you also have to be actively anti-racist. I thought that was very important especially for me to remember.”
>
> “You have to think about how what you’re doing today will impact the future. I think this is especially important because what has been done in the generations before mine has really impacted my generation, and now we’re the ones who have to fix all the problems. We need to do our best to not make problems for future generations.”
>
> “Because these are, like, the environmental justice parts, which, as I talked about, I think those are important. I could use them no matter what my career is.” (Sonia)

The theme of “who will I be?” emerged organically throughout the interview transcripts due to their noticeable difference in participants’ language around the use of “I/me/my” when describing how some cards were memorable because of how it reflected what type of future engineer the participant wanted to be.

Overall, students described learning experiences as more memorable when they included global perspectives and emphasized a “who” (e.g., who is affected by engineering interventions, problems that were linked to communities). Other students described a card as more memorable when they were able to relate it back to their own lives and lived experiences. That is, memorability seemed to be more tangible when participants could see themselves or others reflected in the cards and actions presented through the sorting exercise. Thus, it is important to consider how lived realities are important in engineering sense- and meaning-making.

4 DISCUSSION

Through the results and description of the participants’ card sorts, we found that students thought topics that revealed a “who” behind the engineering were the most memorable. Notably, the participants spent much of the interview time describing the cards that had sociotechnical content to the interviewer, who was not familiar with the course topics. Participants often went out of their way to explain the takeaways from the activities to the interviewer, focusing on the sociotechnical aspects of the cards.

These card sort and interview results suggest that the research team was successful in infusing sociotechnical thinking into an engineering course and that we were able to make progress in shifting the dominant discourse. For example, when students described certain cards as relevant or useful, one metric they used to determine the relevance of the topic was whether it was purely technical (less useful) or sociotechnical (relevant no matter what their career ended up being). The outcome that even a few students saw sociotechnical engineering as more valuable than canonical engineering is an encouraging step in the right direction since typically engineering students prioritize the technical [28]–[30].

Another success that our work highlights is the agency that students began to develop in who they wanted to be as engineers and what they would value as practitioners. In Bloom's Taxonomy, the affective domain categorizes the manner in which people deal with emotional issues, including values, motivations, and attitudes [65]. The five major categories in the affective domain, ranging from simplest to most complex behavior, are *receiving phenomena*, *responding to phenomena*, *valuing*, *organization*, and *internalizing values*. Students typically begin at the *receiving phenomena* end, where they may demonstrate an awareness or willingness to hear a new perspective. The participants in this study who described how certain course topics were more important to their futures demonstrated levels of *valuing* (attaching worth to an object or behavior), *organization* (organizing values into priorities by contrasting different values), and *internalizing values* (demonstrating a pervasive, consistent, predictable value system that controls their behavior). Particularly, engineering issues that involved or impacted people (especially themselves or their future selves) seemed to resonate more with students, leading them to make a higher value judgment on the card in discussion. As noted in the discourse analysis, some students showed further development in their self-reflection than others, demonstrating *organization* and *internalizing values*. For instance, some students directly contrasted sociotechnical and technical issues in their value judgments, and others described considering the impact on people as critical to their future careers.

While students' responses did illustrate a shift in the dominant discourse and demonstrate their changing values in engineering, students mostly reflected a surface-level consciousness in the theme of "whose problems, and whose solutions." The students' lack of language to describe energy injustice in depth may have to do more with instruction than learning, however. For example, our previous work has revealed that our modules on engineering units and ancient windmills still inadvertently prioritized. Western, colonial ways of knowing, even though we included them to do precisely the opposite. Our efforts and/or delivery may have sent the message that these other viewpoints exist but are "wrong," outdated, or not as important as what is used in White/Western cultures [15]. For this cohort, our intervention may have still been insufficient. The instructor problematized energy justice, and the students internalized the ways in which there exist injustices around energy (i.e., problems vary by country), but the class did not dig deeply into the source of the problems (e.g., racism, imperialism, colonialism). In hindsight, perhaps it was unreasonable to expect change when we did not push students toward a deeper critical awareness. The students' responses in the interviews demonstrated their attempts to engage with difficult and complex topics—they thought these topics were interesting and want engineers to do better, but they weren't quite ready and able to grapple with the meaning and reasoning behind the inequities.

Even originating at a Catholic institution that prides itself on social justice where conversations are happening regularly on campus in different contexts, this study shows that students need more scaffolding in deconstructing issues of inequity in contexts that are new to them, such as when discussed within the context of engineering. Yet, it is important to note that this is the first step along their journey, not their end point. Follow-on, more advanced courses in the program such as *Engineering* *and Social Justice* [1], [66] could discuss at a deeper level the power inequities and imbalances that create the different energy problems and solutions around the world. For example, renewable energy systems are, in a way, reinventing systems of oppression; oil is not special in its ability to create oppression [67]. Moving forward, we encourage interested instructors to focus on *how we teach* in addition to *what we teach* in trying to incorporate sociotechnical thinking in engineering [10].

4.1 Study limitations

The small sample size is an important limitation of this study. This study interviewed only five participants out of an already-small class of nine students. Of this small sample size, 4 out of 5 participants were women, and all were White or Asian American. These students chose to major in Integrated Engineering so may already have diverged from the "typical" engineering student in that they might already have a preference towards sociotechnical thinking from the start.

There are two primary limitations regarding the data collected in this study. First, one notable difference between the use of the Miro board and a traditional card sort (e.g., using the CARDS platform) is the lack of boundaries between card placement, which limits this study to qualitative analysis rather than quantitative or mixed methods.

Second, students' memorability rankings may be related to how recent the activity was, which is difficult to discern without deeper and more frequent investigation. Again, this may also be attributed to the research team becoming better at incorporating CSPs into the course materials as the semester progressed. Similarly, it is possible that the content of the lecture, in addition to how it was taught (e.g., lecture, active learning, discussions, or watching a video) played a role in determining how memorable it was to students, even though these primarily did not emerge as themes through analysis of the interview transcripts.

5 CONCLUSIONS

Engineering education has historically favored technical rigor and too often abstracts away the social dimensions of engineering problems. While this pattern has started to change in design-based courses, the majority of engineering science courses continue to focus on abstract problems devoid of societal context. The present study suggests that not only is it possible to incorporate more societal context into an engineering science course, but that students actually find these examples more memorable. Here our approach to inclusive pedagogy has a dual benefit: it helps students (1) see the sociotechnical nature of problems and (2) more clearly remember what they have learned. While our results show a single intervention in a course is not a panacea (and how could it be?), it is an important first step along the journey towards a more inclusive, sociotechnically minded pedagogy. Not only does this study inform future iterations of the course where we will place more emphasis on the "who" in engineering, but it also presents a pathway for both why and how other engineering educators can begin to move their coursework towards more of a sociotechnical realm.

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