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Evolving Student Conceptions of Engineering Design and Community in an Engineering for Society Course

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Abstract

This empirical, full paper examines how undergraduate students' conceptions of community-engaged engineering design evolved throughout a semester-long introductory Engineering for Society course taken by non-engineering majors. The course integrated case-based learning with an authentic community-based design challenge. Students in the course completed three concept maps at three points in time about the factors that engineers should consider when they try to address a problem faced by a community. These points were: (1) at the beginning of the course, (2) after they encountered a disruptive case study, and (3) after they engaged as engineers in a community-based design challenge. Of the 24 students in the class, 23 allowed us to examine their concept maps and accompanying written explanations. Overall, concept maps were more technocentric at the first time point and included more social components at the second two timepoints. For the 12 participants who completed all three concept maps, most maintained attention to technical considerations across the concept maps and increased in their recognition of community stakeholders as being not only impacted by the problem/solution but also valuable contributors to the design process. These findings document how pedagogical interventions may support students' movement from technocentric toward a more sociotechnical orientation.

Introduction

Engineering education seeks to prepare students not only for technical competence but also for responsible practice in an increasingly interconnected world. Engineers shape the problems they address and determine whose voices matter in defining solutions. When students learn engineering as primarily a technical challenge (e.g., focusing on optimizing materials, costs, and performance metrics), they risk perpetuating what Riley termed the "deficit model" [1]. In this model, engineers position themselves as experts delivering solutions to communities framed as lacking knowledge or resources. This technocentric position, while emphasizing important analytical skills, often overlooks the fundamentally social nature of engineering practice. Design decisions affect real people in real communities, yet engineering education has historically devoted insufficient attention to developing students' capacity to value and meaningfully engage community stakeholders their work is intended to serve [2-4].

The call for more community-centered engineering education is not new. Scholars have long argued that engineering students need opportunities to develop sociotechnical thinking, the ability to understand and address both social and technological dimensions of problems [2]. Research on service-learning, humanitarian engineering, and sustainable community development has demonstrated that well-designed community engagement experiences can broaden students' perspectives and deepen their understanding of engineering's societal impacts [5-7]. Yet questions remain about how students' thinking evolves as they encounter these experiences. How do undergraduates come to see community members as more than end users or beneficiaries but as essential collaborators with valuable knowledge? What pedagogical approaches disrupt technocentric assumptions? How do educators create learning experiences that foster genuine transformation rather than superficial acknowledgment of social dimensions?

This study begins to address these questions by documenting undergraduate students' conceptual development throughout a semester-long Engineering for Society course. We examine how carefully sequenced interventions have the potential to help students reconstruct their understanding of engineering's relationship to community. Through concept mapping at three time points, we trace individual students' trajectories as they grappled with increasingly complex views of who should contribute to engineering design processes and why.

Conceptual Frameworks

This study draws on three interconnected frameworks that inform our understanding of how students develop sociotechnical thinking in engineering education. First, we position our work within scholarship on sociotechnical thinking that challenges the separation of social and technical dimensions in engineering practice [2, 3, 8, 9]. This is a departure from the technocentric orientation that dominates conventional engineering education. Sociotechnical thinking recognizes that technical solutions are always embedded in social contexts and that social contexts shape both problem definition and solution viability. It also challenges the deficit model perspective that positions engineers as experts who deliver solutions to communities, regularly positioned as lacking knowledge or resources [1]. Rather, sociotechnical thinking requires valuing diverse forms of knowledge, recognizing structural inequities, and collaboratively defining the problem [6].

Second, and related to how students develop sociotechnical thinking in engineering education, we adopt a constructivist view of learning. This theoretical framework positions learning as a process of construction, deconstruction, and reconstruction of meaning through engagement with cognitive dissonance [10, 11]. Third, we recognize that authentic community engagement provides essential contexts for students to construct, deconstruct, and reconstruct knowledge as they develop sociotechnical thinking [5, 12, 13]. Engineering education scholars have stressed the importance of immersive community engagement experiences that help students in centering stakeholder needs and wishes, as well as support critical reflection, and asset-based framings of communities [6, 7].

Literature Review

In this section, we briefly review the research literature in three areas. These areas are (1) case-based pedagogy and cognitive dissonance, (2) community-based engineering projects and authentic learning, and (3) pedagogical sequences in engineering education.

Case-Based Pedagogy and Cognitive Dissonance

Cognitive dissonance theory suggests that contradictions between learners' expectations and realities can create productive dissonance that prompts conceptual revision [10]. Case studies serve as a powerful pedagogical tool for initiating cognitive dissonance in engineering education, particularly when addressing complex societal challenges [14]. This approach aligns with the "shock" stage in service-learning's social-psychological progression [15].

Research demonstrates that case-based instruction in engineering courses effectively disrupts students' existing worldviews by presenting authentic, real-world problems that challenge narrow technical perspectives and encourage students to consider broader community impacts and stakeholder perspectives [16-18]. The effectiveness of case studies as pedagogical interventions depends significantly on their ability to present contradictions that cannot be easily dismissed or resolved within students' existing conceptual frameworks. Cases that feature well-intentioned engineering efforts that failed due to inadequate community engagement prove particularly powerful for disrupting technocentric assumptions, as they demonstrate that technical competence alone is insufficient for successful engineering practice.

However, simply experiencing this disruption is insufficient for transformative learning. Students must be guided through the process of developing new ways of seeing the world to complete the transformative learning cycle [11]. This guidance can be accomplished through structured reflection opportunities that create discursive spaces for students to critically examine assumptions and integrate new perspectives into their thinking [19]. The role of reflection in translating cognitive dissonance into conceptual growth cannot be overstated. Without opportunities to process and make meaning of disruptive experiences, students may dismiss cases as exceptions or anomalies rather than recognizing them as revealing fundamental truths about engineering practices.

Community-Based Engineering Projects and Authentic Learning

While case studies provide valuable opportunities for cognitive disruption and conceptual change, authentic community-based engineering projects offer students the chance to apply and refine their developing sociotechnical thinking in practice. Community-based projects move beyond hypothetical scenarios to engage students in real-world problem-solving with actual stakeholders. Research in engineering education demonstrates that community-based projects support deeper learning when students engage directly with community stakeholders in defining problems, generating solutions, and evaluating outcomes [5, 12].

Through authentic engagement with community stakeholders, students confront the factors that shape real engineering practice, experiences that cannot be fully replicated through traditional classroom instruction or even case study analysis [13]. The ambiguity, negotiation and plurality inherent in real community partnerships, with competing perspectives and unpredictable dynamics, are not deficits compared to controlled classroom setting, rather, these are core features of authentic sociotechnical practice and provide essential learning opportunities that lecture or model building alone cannot offer. However, simply placing students in community contexts does not automatically develop their sociotechnical capacities; the quality of the engagement matters significantly.

Leydens and Lucena distinguish between "basic listening" and "contextual listening" in community-engaged engineering work [20]. Basic listening involves hearing what community members say, while contextual listening requires understanding the broader social, economic, political, and cultural contexts that shape community needs, abilities, and goals. Authentic community-based projects create opportunities for students to practice contextual listening, requiring them to understand the stated needs as well as the complex contexts within which those needs arise and solutions must function. This deeper form of engagement supports students in moving beyond simply consulting community members and toward partnership and co-creation.

Pedagogical Sequences in Engineering Education

The question of how to most effectively sequence pedagogical interventions to support conceptual development remains understudied in engineering education research. Reynante's work on learning processes in community-engaged engineering identified four primary mechanisms through which students shifted from design-for-charity toward design-for-justice mindsets: drawing upon prior experience with inequity, connecting to course content, imitating experienced team members, and empathizing with community members [4]. Each mechanism was enabled by distinct components of the educational experience, suggesting that the sequencing and combination of interventions matters significantly.

Transformational learning theory [11] and experiential learning frameworks [21] both emphasize that deep conceptual change occurs through iterative cycles of experience, reflection, abstraction, and experimentation. Applied to community-engaged engineering education, these frameworks suggest that students benefit from opportunities to encounter disruption to existing mental models (through case studies or initial community experiences), reflect on that disruption, develop new conceptual frameworks, and test those frameworks through authentic practice. The limited research comparing different pedagogical sequences suggests that the order and spacing of interventions significantly impact learning outcomes, though more systematic investigation is needed to establish evidence-based best practices.

Research Question

This study addresses a gap in engineering education literature by examining not simply whether conceptual change occurs, but how student thinking evolves through carefully sequenced pedagogical interventions. Specifically, we ask: *How do students' conceptions of the relationship between engineering design and community change throughout a course that integrates case-based learning and authentic community engagement?*

Methods

Course and Participants

This study took place in the context of a one-semester "Engineering for Society" course at a public university in the mid-Atlantic region of the United States. This was the first time that this course was offered at the university; however, the Engineering for US All (e4usa) curriculum that the course utilizes, which includes the PlayPump case study, has been in use for several years at other universities and in high schools (https://e4usa.org/). The course fulfills a core university requirement in the "creativity" category. As a core course, it is open to all students across the university, resulting in a diverse participant pool representing a range of academic majors and backgrounds. Some students were physics majors concentrating in Applied and Engineering Physics. There is no engineering major at the university.

We did not collect demographic data for this study. However, the ethnic and racial demographics of students in this course are similar to the University demographic profile, consisting of 40% White, 33% African American, 11% Hispanic or Latine, 6% Asian, 5% two or more races, and 1% international students. There were more students who identify as male in the course (70%) than at the university (41%).

Following Institutional Review Board approval, we conducted the consent process beginning on the first day of class. In total, 23 of the 24 enrolled students (96%) consented to participate in the research study. One of those students later dropped the course.

Data Collection

Data collected for the study were concept maps and accompanying written explanations collected at three points throughout the semester: (1) at the beginning of the 15-week semester (week 1), (2) in the week after engaging in an in-class case study lesson (week 3), and (3) at the end of the semester after the students engaged in a half-semester long community-based engineering design challenge (week 15). All students in the course submitted these concept map assignments as a course assignment that was graded for completeness by the instructor (not one of the authors). The authors also collected field note data that did not include students' personal information; this occurred during most class sessions related to the case study and community-based design challenge. We used field note data in this paper to provide context to describe the case study lesson and community-based challenge, as well as to interpret students' concept maps and explanations. We did not do a robust analysis of field note data.

In this section, we begin by detailing the method of using concept maps as a data collection tool. Next, we describe the three data collection time points and how concept maps and explanations were gathered at each.

Concept Maps as a Data Collection Tool

Concept maps are a widely adopted pedagogical tool that promote learning by illustrating connections between concepts and serve as an effective means of assessing student understanding [22, 23]. Generally, a concept map is a drawing used to explain a concept. The concept map displays the relationships between concepts through nodes (representing ideas), which are often circled, and links (lines or arrows representing connections between ideas) [24]. When used iteratively with reflection prompts in the context of a course or research study, concept maps enable learners, instructors, and researchers to track the development of increasingly integrated and sophisticated understandings over time.

Concept Map and Explanations Data Collected at Each of Three Time Points

Concept Map 1 at Course Beginning (Week 1). For the first concept map assignment, students were asked to respond to two questions in the first week of the course without the use of generative AI tools or outside resources. They were informed that there were no right or wrong answers, that the concept map assignment was meant to capture their personal learning and growth, and that they would only be graded for completeness. The questions were:

1. Consider a problem faced by a community and how engineers might help address that problem. What factors should engineers consider when they try to address the problem?
2. [Optional] Please use the space below to briefly explain (e.g., in a few sentences) any ideas or connections that might not be obvious in the concept map itself. For example, you might describe why you drew certain links, why some are especially important, or how you see the different ideas are related to one another.

For Question 1, students were asked to follow three instructions: (1) brainstorm terms/phrases that come to mind in response to the question; (2) draw a concept map (Concept Map 1), writing "community problem" in the center of the paper and drawing lines to other related concepts (words/phrases) and labeling the lines; and (3) take a picture of their concept map and upload it to the Learning Management System (LMS). Students were also given a link to a resource about how to create a concept map. Students were not given a required minimum or maximum number of nodes or connections, allowing for a wide range of complexity and detail in their submissions. We did not collect data on which students accessed the support of the website.

Concept Map 2 after the Case Study Lesson (Week 3). In the third week of the semester, students participated in a case study lesson during class that illustrated the consequences of engineering designs that fail to meaningfully engage community stakeholders. This case study lesson involved five parts: Introduction, Video 1, Discussion 1, Video 2, and Discussion 2. The videos were from two related *PBS Frontline/World Video* documentaries which originally aired in 2005 (re-aired on YouTube in 2009) and 2010, respectively [25, 26]. Collectively, the videos explored the rise (Video 1) and fall (Video 2) of a technology initially designed for use in southern Africa called the "PlayPump."

- **Introduction**. The instructor introduced the National Academy of Engineering (NAE) Grand Challenges for Engineering, including "Provide access to clean water" [27] . The instructor then asked questions like: "How do we get water?" and "How do people in developing countries get water?" The instructor then introduced the 2005 video, which described the efforts from people from the United Kingdom to help people in rural South Africa to get clean water.
- **Video Segment 1 (7 minutes).** Students viewed the first seven minutes of the documentary about the rise of the PlayPump technology, which was portrayed as an innovative solution to rural water access. It used a merry-go-round-like device to power a water pump and was designed for children to operate. As children held onto the railing of the PlayPump and ran in circles around the center shaft of the pump, water was drawn from underground and stored in a tank. The video celebrated the PlayPump as a breakthrough, and the project gained significant international attention and funding, including support from the U.S. government and major philanthropists.
- **Discussion 1 (5 minutes).** After watching Video 1, the course instructor paused to engage students in small group and whole class discussions. The instructor said, "That's the beginning, that's the before. Do you sense any clouds [problems]?" Responses from students included that it might be expensive to maintain, children might get hurt or bored, the children are doing work/labor. Students wondered what would happen if there were no children around or if the water ran out.

- **Video Part 2 (14 minutes).** The instructor then played the first 14 minutes of the 2010 documentary, which revealed critical flaws in PlayPump implementation. The video explained that many PlayPumps fell into disrepair because of poor maintenance, and the assumption that children would consistently play enough to meet water needs proved unrealistic. In some cases, the burden shifted to women, who found the device more difficult to operate than their former hand-operated pumps. The documentary highlighted how good intentions and compelling marketing overshadowed practical challenges, making the PlayPump a cautionary tale in global development efforts.
- **Discussion 2 (22 minutes).** Students were encouraged to reflect on the intersection of engineering and community needs throughout this case study. In a whole-class discussion, students shared that there was a lack of maintenance, the project likely grew too fast and was overly ambitious. The instructor pressed students to consider the users of the PlayPump. One student shared that women who ultimately had to pump water for themselves were not asked about the PlayPumps when they were being designed or constructed. Another mentioned how the older pumps were useless once the PlayPumps were built. The instructor then asked students to formulate guidelines for dealing with users (like the children and villagers) and to avoid failures like the PlayPump. Small group discussions ensued and after about four minutes, the instructor elicited ideas, which included surveying people in the community to understand the issue, make sure the design is accessible and efficient, prioritize quality over quantity, and be honest and transparent with stakeholders.

Following this PlayPump case study lesson activity, students completed their second concept map assignment. They were given the same instructions for creating the concept map as for the first concept map at the beginning of the semester, responding to Question 1 by ultimately uploading Concept Map 2 and having the option to respond to Question 2 to further explain their map. We did not ask students to add to or edit Concept Map 1, rather, we asked them to create a new concept map, Concept Map 2, using the same prompt given their additional knowledge to this point in the course. In addition, students were asked in Question 3 to upload Concept Map 1 without any alterations and in Question 4 compare it to Concept Map 2 "consider[ing] what has changed in your thinking and any new questions, concerns, or insights you have related to the relationship between engineering and community."

Concept Map 3 Following the Community-Based Design Challenge (Week 15). During the second half of the course (weeks 8-15), students participated in a community-based design challenge. The "community" here involves a group of individuals within the science building of the university in which the course takes place. The biology department recently received two turtles—a female red-eared slider and male yellow-bellied slider—which had been kept in captivity for their lives prior to arriving at the university. These aquatic turtles are kept in a water-filled tank and are given opportunities to bask under a heat lamp. When the second author was considering a community-based design challenge in the science building, faculty in the biology department who care for and have expertise in turtles suggested that their habitats could be improved. Specifically, biologists and caretakers noted that the existing basking platform did not accommodate both turtles given their size and that the tank lacked enrichment features known to support captive turtle wellbeing. This became the basis for the community-based design challenge in the course. Part of this design challenge involves the students in the course engaging in a robust problem scoping process with input from stakeholders and experts before generating design solutions, mirroring the community input process that the PlayPump case study had shown to be essential. Stakeholders included student workers who care for the turtles; the university's vivarium director, with expertise in animal habitat design; a biologist who specializes in turtle research; and two engineers who served as liaisons in the class (both mechanical engineers, one practicing and one retired). The instructor divided the class into eight design teams, each of which identified a way to either create (a) a more accessible basking platform for the turtles or (b) a means of enrichment for the turtles. The design teams engaged in a full design process including problem scoping, brainstorming, idea selection, prototype fabrication, testing and iteration. The project culminated in a design showcase in which teams presented their process and prototypes to multiple stakeholders and experts.

Students completed their third and final concept map assignment during final week of the course. Students were asked to create a new concept map, Concept Map 3, given all the knowledge gained throughout the course, including the community-based design project, and then to compare it to Concept Map 2 (after the PlayPump challenge). If they had not submitted Concept Map 2, they were to compare it to Concept Map 1.

Response Rates

Participant response rates varied across the three data collection points. Of the 23 consenting participants, response rates were 87% (Concept Map 1), 74% (Concept Map 2), and 65% (Concept Map 3). Twelve participants (52%) completed all three concept maps, 22% completed only Concept Maps 1 and 2, 0% completed only Concept Maps 2 and 3, and 4% completed only Concept Maps 1 and 3.

Data Analysis

Coding the Concept Maps

Data analysis involved systematic coding of the concept maps, written descriptions, and field notes. Both researchers participated in all stages of the coding process to ensure reliability and rigor. We began with a set of a priori code categories derived from existing literature on community-engaged engineering design and sociotechnical thinking. We specifically drew from validated frameworks by Mazzurco and colleagues [2, 28] for assessing students' design considerations in community-based engineering contexts. These initial codes included three primary categories: technical, impact, and community involvement considerations. Technical considerations included factors such as cost, safety, material constraints, and engineering specifications. Impact considerations included impacts of the problem or solutions on people and the environment, including the environmental sustainability of proposed design solutions. Considerations related to community involvement captured the extent to which students identified opportunities for community *input* on problem definition and solution design; note that this is different than impact of problems or solutions on people. This a priori coding framework allowed us to systematically analyze student responses while remaining open to emergent themes that extended beyond these initial categories [2].

Following the initial round of coding of Concept Maps 1 and 2 with a priori codes, the major code categories remained, and we added emergent codes within those categories. These included maintenance and longevity as a technical consideration, as well as new problems caused by design solutions, ethical concerns, and benefits as impact considerations. Table 1 presents our codebook, which we applied systematically across all three concept map collection points to enable comparison of conceptual development over time. Note that in Table 1 (codebook), the third category is labeled "Community Input" to reflect the specific type of consideration being captured (students' recognition that community members can provide inputs to the design process). In Table 3 (code frequency results) and in narrative text, we refer to this same category more broadly as "Community Considerations" to parallel the "Technical Considerations" and "Impact Considerations" category labels. These terms refer to the same code category.

Table 1. Codebook

Category	Code	Description: The concept map or written explanation mentions …
Community Input	People	That people or the community should or can provide input to help the engineer understand the problem or figure out the solution
Technical	Cost	The cost of the problem or solution, which may occur as $, cost, budget, expense, etc.
Technical	Other Constraints	Constraints outside of cost, which may include materials, time, other resources, or local regulations
Technical	Safety	Safety with respect to the problem or solution, which may be expressed as safety, risk, codes, or health regulations
Technical	Local Context	The need to consider the local context when solving the problem, including the setting or location
Technical	Tools or Technology	The need for tools or technology to solve the problem
Technical	Maintenance or Longevity	The need to maintain designed solution or for the designed to last or have longevity
Technical	Goals or Criteria	Goals for the design or the criteria to be met for the design to be effective
Impact	People	That people or the community are or may be impacted by the problem or solution
Impact	Environment	That the environment (i.e., flora, fauna) is or may be impacted by the problem or solution

We also examined the difference in code categories present across Concept Maps 1, 2, and 3 for the 12 participants who completed all three concept maps. We did so by comparing percentages of participants whose concept maps were coded for each category, i.e., technical considerations, impact considerations, and community (input) considerations. We also conducted Cochran's Q tests for each of the three categories. Cochran's Q test is a non-parametric test that compares the results of binary variables for the same participants across two or more points in time. This was an appropriate test given that we were analyzing binary data [i.e., the presence (1) or absence (0) of a code category applied a participant's concept map]; the data were not normal; and each of the 12 participants completed concept maps at three points in time (i.e., in weeks 1, 3, and 15). We conducted follow-up post hoc pairwise comparisons using McNemar tests for significant results. For the Cochran's Q and McNemar tests, we used a confidence level of 0.05 and the null hypothesis was that there was no difference across all three concept maps (for Cochran's Q) or pairs of concept maps (for McNemar).

Findings

This section presents findings from our analysis of concept maps and written explanations collected at three time points throughout the semester. We begin by describing the overall approaches participants took in constructing their concept maps. We then present aggregate findings showing the frequency of codes across all three concept maps, highlighting patterns of change and persistence in students' thinking about community-engaged engineering design. Next, we examine each time point in detail and provide illustrative examples from student concept maps and written reflections. Finally, we present a longitudinal analysis of the 12 participants who completed all three concept maps.

Concept Map Approaches

Given the open-ended nature of the prompts we used, participants approached the assignment using three distinct strategies. We call the first of these "specific examples," in which participants identified particular community problems (e.g., traffic congestion, water access, pollution) and built their maps around these concrete scenarios. The second is "general factors," in which participants focused on general factors engineers should consider when addressing community problems without reference to specific examples. The third is "design process," where participants emphasized the iterative steps and collaborative processes involved in engineering design. Table 2 summarizes these three approaches for the three Concept Maps.

Table 2. Concept Mapping Strategies Employed by Students Across Each Time Point

Approach	Concept Map 1 (n=20) Number (%) of Participants	Concept Map 2 (n=17) Number (%) of Participants	Concept Map 3 (n=15) Number (%) of Participants
Specific Examples	11 (55%)	7 (41%)	7 (47%)
General Factors	7 (35%)	8 (47%)	7 (47%)
Design Process	2 (10%)	2 (12%)	1 (1%)

Frequency of Codes Across Concept Maps

Table 3 presents the frequency of each code category across the three concept map collection points, revealing both continuities and shifts in participants' attention to technical, impact, and community considerations as they progressed through the course's pedagogical interventions.

Concept Map 1: Initial Conceptions at Course Beginning

At the beginning of the semester, as shown in Table 3, initial concept maps predominantly featured technical considerations. Human-centered elements were less prominent in these initial maps. Twelve participants (60% of 20) mentioned people or community as being impacted by problems or solutions, and only 1 participant (5%) suggested that people or community members could provide input regarding problem definition or solution design.

Participant explanations of their initial concept maps reflected this technical orientation. For instance, S01 explained: "I will place a big emphasis on 2 of the nodes, littering and rising electrical costs." Similarly, S04 focused on fundamental constraints, noting: "A community problem always needs to have an understanding of the problem at hand to create a solution and learn about its constraints. Constraints can include where its located, the materials needed, and even the budget given." See Figure 1 for S04's Concept Map 1.

Table 3. Comparison of Code Frequencies across Concept Maps

Categories and Codes	Concept Map 1 (n=20) Number (%) of Participants	Concept Map 2 (n=17) Number (%) of Participants	Concept Map 3 (n=15) Number (%) of Participants
Technical Considerations	**18 (90%)**	**17 (100%)**	**14 (93%)**
Cost	15 (75%)	14 (82%)	12 (80%)
Other Constraints	6 (30%)	7 (41%)	7 (47%)
Safety	12 (60%)	7 (41%)	7 (47%)
Local Context	5 (25%)	5 (29%)	2 (13%)
Tools or Technology	3 (15%)	0 (0%)	3 (20%)
Maintenance or Longevity	1 (5%)	14 (82%)	7 (47%)
Goals or Criteria	1 (5%)	0 (0%)	4 (27%)
Impact Considerations	**14 (70%)**	**13 (76%)**	**10 (67%)**
People	12 (60%)	13 (76%)	9 (60%)
Environment	9 (45%)	7 (41%)	4 (27%)
Community Considerations	**1 (5%)**	**8 (47%)**	**8 (53%)**

Concept Map 2: Conceptions After the PlayPump Case Study

Across the participants, Concept Map 2 demonstrated notable shifts in participants' thinking about community-engaged engineering design. Technical considerations remained prominent with cost appearing in 14 maps (82% of 17), other constraints in 7 (14%), and safety in 7 (41%).

The percentage of participants who mentioned people or community as being impacted by problems or solutions rose from 60% (12 of 20 participants) in Concept Map 1 to 76% (13 of 17 participants) in Concept Map 2. The percentage of participants who suggested that people or community members could provide input regarding the problem definition or solution design increased from 5% (1 of 20) in Concept Map 1 to 47% (8 of 17) in Concept Map 2. Additionally, 6 participants included "community" as a major node within their Concept Map 2 submissions, whereas no Concept Map 1 submissions had featured community as a central organizing element.

A new code emerged in Concept Map 2: maintenance or longevity (14 participants, 82%). This code was not part of our initial a priori coding framework but emerged inductively from the Concept Map 2 data: it was then applied retroactively across all three concept map collection points. This code captured students' recognition that engineered solutions require ongoing upkeep and support, a key lesson from the PlayPump case study since a lack of maintenance contributed to the technology's failure. See Figure 2 for Participant S04's Concept Map 2, which included the question "who can repair it?," as well as a community node.

Concept Map 3: Conceptions Following Community-Based Design Challenge

Following the community-based design challenge, 15 participants submitted Concept Map 3. While fewer participants completed this final assignment, the data reveal continued development in participants' sociotechnical thinking about engineering design. Technical considerations remained the most frequently mentioned consideration category (14 of 15 participants; 93%). People or community being impacted appeared in 9 maps (60%) and people or community providing input appeared in 8 maps (53%). The community input percentage (53%) remained similar to Concept Map 2 (47%), while the impact percentage (60%) returned to a level comparable to Concept Map 1 (60%), below that of Concept Map 2 (76%). Notably, environmental impact considerations also declined across time points (45% in Concept Map 1, 41% in Concept Map 2, 27% in Concept Map 3), which may reflect the specificity of the turtle habitat project, which students may not have framed as an environmental problem in the broader ecological sense. An example is Participant 04, which included nodes with "opinion from community" and "stakeholder requirements" (Figure 3).

Figure 1. Participant S04 Concept Map 1

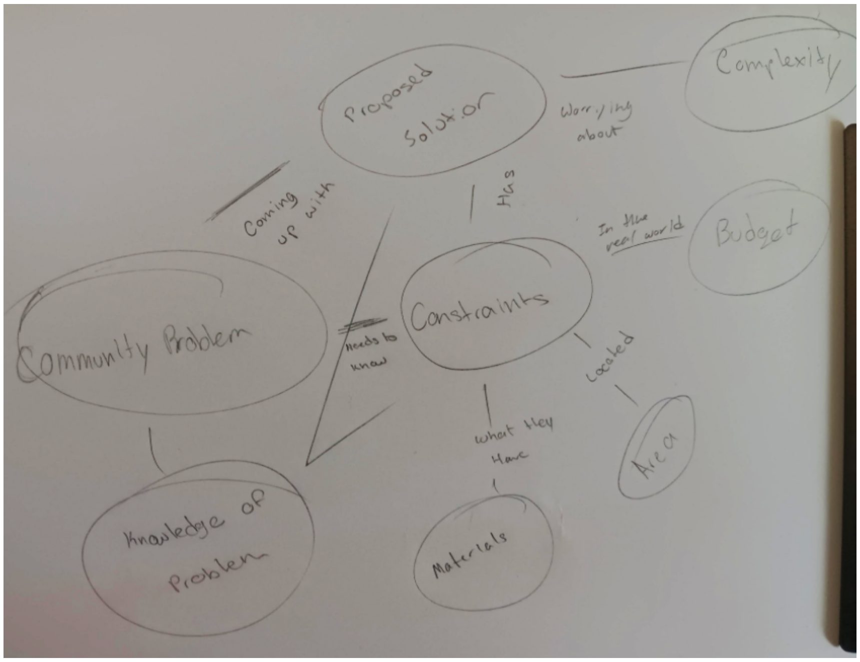


Figure 2. Participant S04 Concept Map 2

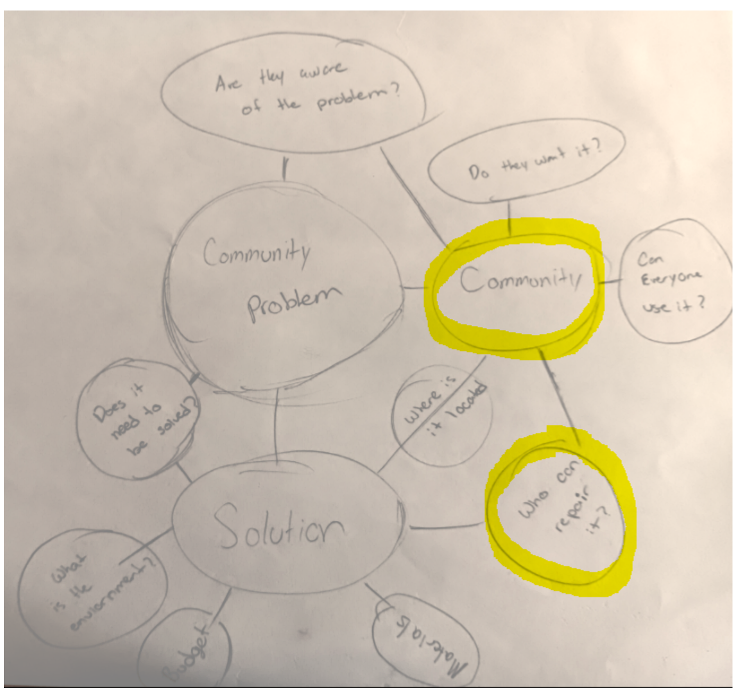
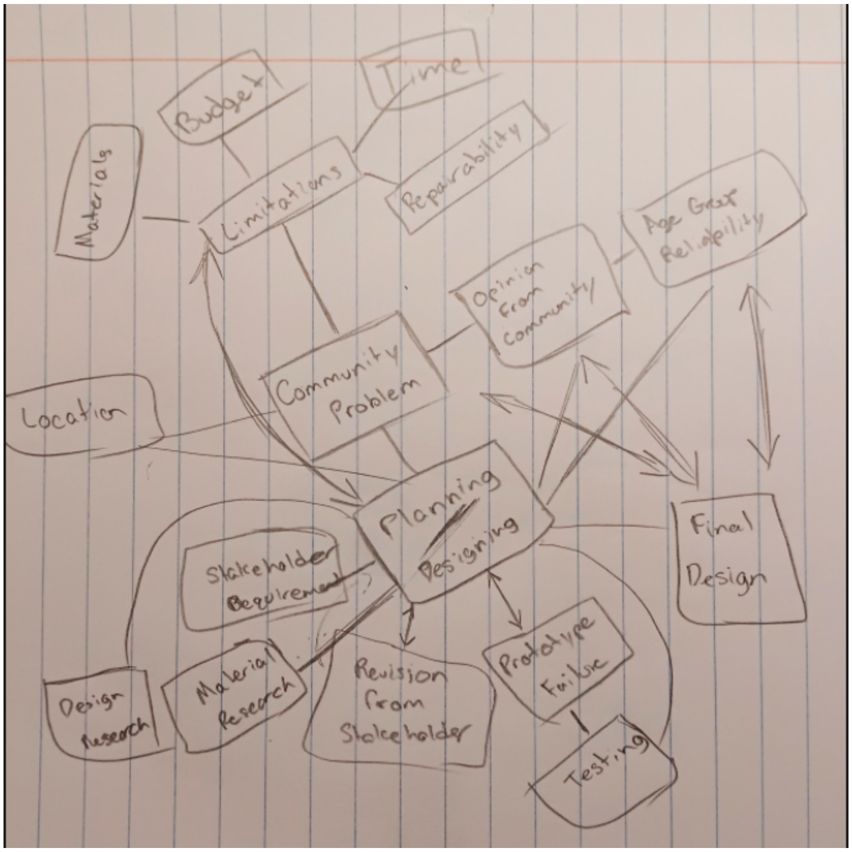


Figure 3. Participant S04 Concept Map 3



Longitudinal Analysis: Growth Patterns in Students Who Completed All Three Concept Maps

Of the 23 consenting participants, 12 completed all three concept map assignments throughout the semester. Table 4 shows the percentage of participants for whom we applied one or more codes within each of the three categories, i.e., technical, impact, and community (input) considerations.

Table 4. Category Code Frequencies for Participants who Completed All Concept Maps (n=12)

Category	Concept Map 1	Concept Map 2	Concept Map 3
Technical Considerations	92%	100%	92%
Impact Considerations	58%	75%	67%
Community (**Input**) Considerations	8%	58%	67%

We used the Cochran's Q test to determine the significance of differences for each code category across the three concept maps. The test showed no significant differences for technical considerations [$Q(2) = 2.000$, $p = 0.368$] or impact considerations [$Q(2) = 0.857$, $p = 0.651$], accepting the null hypothesis. In other words, participants maintained a similar amount of attention to technical considerations and the impact of problems and solutions on community members across the three concept maps.

However, we rejected the null hypothesis with respect to community (input) considerations. For this category, the Cochran's Q test indicated a significant difference across the three concept maps [$Q(2) = 12.286$, $p=0.002$]. Post hoc pairwise comparisons using McNemar tests indicated that participants' inclusion of the community (input) consideration category in Concept Map 1 was significantly different from that in Concept Map 2 ($p=0.031$) and Concept Map 3 ($p=0.016$), respectively. However, the frequency for Concept Map 2 was not significantly different from that of Concept Map 3 ($p=1.000$). In summary and collectively—and taking the percentages in Table 4 into consideration—there was significant growth in participants' inclusion of community input between Concept Map 1 in week 1 and Concept Map 2 after the PlayPump case study in week 3, and (b) the level of inclusion in Concept Map 2 was maintained in their third concept map in week 15.

The data also provide valuable insight into individual trajectories of conceptual development regarding the role of people and community in engineering design. For the purposes of this analysis, we defined "growth" as movement toward increasingly recognizing and valuing community members' involvement in the engineering design process across the three concept map submissions.

We operationalized growth using two codes: (1) *People* in the Impact Considerations category, which captured instances where students mentioned that people or community members are impacted by problems or the proposed solutions, and (2) *People* in the Community Considerations category, which captured instances where students suggested that people or community members should provide input to help engineers understand the problem or develop appropriate solutions. Hereafter, we will refer to these two codes together as "people codes," with the first being about *impact* on people/community and the second about *input* from people/community. We considered participants to have demonstrated growth when they progressed from having neither code present to including one or both codes in subsequent submissions, or when they advanced from recognizing people as affected parties to additionally recognizing them as valuable sources of input for the design process.

Table 5 presents the presence or absence of these two codes across the concept maps for each of the 12 students who completed the full sequence. Of these 12 students, 8 (67%) demonstrated clear growth in their recognition of community involvement in engineering design, 2 (16%) showed some growth, and 2 (16%) did not exhibit growth according to our coding framework.

Table 5. People/Community Codes for Participants who Completed All Concept Maps (n=12)

Participant	Concept Map 1	Concept Map 2	Concept Map 3	Evidence of Growth
S01	—	Impact	Input	Yes
S04	—	Impact and Input	Impact and Input	Yes
S08	Impact	Impact and Input	Input	Yes
S09	Impact	Impact	Impact and Input	Yes
S10	Impact	Impact	—	Unclear
S12	—	Impact	—	Unclear
S13	—	—	—	No
S14	Impact	Input	Impact and Input	Yes
S17	Impact	Impact and Input	Impact and Input	Yes
S19	Impact	Impact and Input	Input	Yes
S21	—	—	Impact	Somewhat
S22	Impact	Impact and Input	Impact and Input	Yes

Note. — means neither code present

Among the eight participants who demonstrated clear growth (i.e., with "Yes" in the "Evidence of Growth" column in Table 4), several distinct developmental trajectories emerged. Two participants (S01 and S04) began with neither code present in Concept Map 1, suggesting an initial focus on technical or resource-based considerations without attention to the community or stakeholders, but then incorporated people-centered thinking in their subsequent concept maps. While S04 included both impact and input in Concept Maps 2 and 3, S01 included impact only in Concept Map 1 followed by input only in Concept Map 2.

The six others with clear evidence of growth included impact in their first concept maps, input (or input and impact) in their third concept maps, and one or both codes in their second. For example, S14 began with impact alone, shifted to input alone after the PlayPump case study, and finally integrated both impact and input after the community-based engineering design challenge. S17 described the progression toward recognizing community feedback as an ongoing, essential component rather than a one-time consultation:

> Now, after the community-based design challenge, I'm thinking more specifically about categories like cost, public health, sustainability, and equity. I see how these areas are not just separate concerns but actually overlap and influence each other. One new insight I had is that community feedback should be part of every stage, not just at the beginning. It made me wonder how engineers can make sure they're really listening to the people they're trying to help. Overall, I feel like I'm starting to see engineering not just as problem-solving, but as a process that has to be inclusive and responsive to real human needs. (S17 Concept Map 3 Written response)

Participant S21 showed modest growth, beginning with no people codes in Concept Maps 1 and 2, but including recognition of people as being impacted by problems or solutions by Concept Map 3. While this represents progress toward human-centered thinking, the student had not yet incorporated the notion of community input into their conceptualization by the end of the semester.

We did not see evidence of growth for three participants (S10, S12, S13). S13 showed no people codes across all three concept maps, maintaining their focus on technical considerations throughout the semester. S10 and S12 both showed the people impact code in earlier concept maps but not in their final submissions, suggesting either a shift in focus to other aspects of engineering design or possibly a more implicit integration of human considerations that was not captured by our coding scheme.

Discussion and Conclusions

In this discussion, we address the way in which the PlayPump case study helped create conceptual change, how the community design challenge may have reinforced and deepened student learning related to the sociotechnical nature of engineering, and how technical considerations were maintained even while impacts on and input from community changed for many participants. We situate these findings within the scholarship on sociotechnical integration and transformational learning. We then share limitations and thoughts about our own and others' future work on supporting students' development of community-centered engineering mindsets.

The PlayPump Case Study and Cognitive Dissonance

The PlayPump case study served as a powerful catalyst for conceptual change by creating cognitive dissonance in a seemingly effective technical engineering solution. The dramatic shifts observed between Concept Map 1 and Concept Map 2 provide evidence for the effectiveness of this pedagogical approach. These shifts were most evident with respect to the maintenance and longevity code, with in the Technical Considerations category, as well as for the Community Considerations code (i.e., the people and community input code).

The PlayPump case study seemed to be an effective tool for disrupting technocentric assumptions. It presented a real-world engineering failure with documented, consequential outcomes rather than a hypothetical scenario or a polished success story. Participants confronted actual communities whose lives were negatively affected by well-intentioned but poorly conceived technology. This authentic failure narrative challenged the "deficit model" that engineers possess expert knowledge that communities lack and merely need to receive [1]. The PlayPump's failure stemmed not from technical inadequacy but from fundamental misunderstanding of community needs, daily practices, and social structures. As S14 articulated, "A system that doesn't match how people actually live and use water may not be used at all."

The specific features of the PlayPump case made it particularly suited to disrupting deficit model thinking. The project had all the hallmarks of "good" engineering from a traditional technical perspective: creative use of existing resources (children's play), mechanical design, and apparent sustainability. Yet it failed precisely because engineers did not adequately engage with community members to understand their actual practices, preferences, and constraints. The irony that women, who were not consulted, ended up doing more difficult manual labor to operate the PlayPump than they likely had with traditional hand pumps illustrated the consequences of excluding end users from the design process. Participants could not dismiss the failure as stemming from inadequate technical skill or resources; the problem was fundamentally one of inadequate community engagement. We acknowledge, however, that the PlayPump case involves designers from a developed country delivering a solution to communities in rural southern Africa, a geopolitical framing that risks reproducing the very global north/south deficit dynamic it is intended to critique. Instructors using this case should supplement it with explicit discussion of these embedded power asymmetries, and where possible pair it with cases drawn from more varied contexts, so that students understand inadequate community engagement as a universal failure mode in engineering practice rather than a problem confined to international development projects.

The participants' reflections reveal the nature of this conceptual disruption. S22's recognition that "no matter how creative a solution can be, it can fail if people don't actually wanna use it" demonstrates understanding that technical excellence is necessary but insufficient. This aligns with the framework for sociotechnical integration discussed by Reddy and colleagues which characterizes progression from treating social and technical as independent domains (Category 1) toward understanding them as mutually shaping (Category 2) and eventually as informed by social context (Category 3) and eventually fully integrated (Category 4) [3]. The PlayPump case helped participants begin moving from Category 1 thinking—where technical and social considerations exist in parallel—toward Category 2, where they recognize that social factors fundamentally shape technical outcomes.

From Case Study Disruption to Community Design Challenge Practice

While the PlayPump case study disrupted technocentric assumptions, the authentic community-based design challenge provided essential opportunities for participants to apply and refine their developing sociotechnical thinking. The longitudinal data from students who completed all three concept maps demonstrate that most students who showed growth after the case study sustained and often deepened that growth through the community project.

The case study provided the conceptual framework, illustrating why community engagement matters, while the authentic project enabled concrete experience and practice with community-engaged design practices. The community-based design challenge moved participants beyond hypothetical scenarios to engage with real stakeholders who had genuine needs, and perspectives about both the problem and the solution. As Schön argued, professional competence develops through "reflection-in-action" [29]. The participants were challenged to think critically about practice while engaged in that practice. Participants working on the turtle habitat project had to navigate actual conversations with biology faculty and animal care staff, respond to real constraints and feedback, and see their designs evaluated by people who are among the end users.

Participants' reflections following the community-based project reveal how authentic engagement reinforced and extended lessons from the PlayPump case study. S14 explicitly connected both experiences: “After the community-based design challenge and the PlayPump example, I now see that community involvement, culture, and education are just as important as the design itself.” This participant recognized that the project provided validation of principles introduced more abstractly through the case study. Similarly, S19 noted learning from “field experts … [who] can give insight regarding whether or not the idea will actually work in reality.” This insight seemed to extend beyond the maintenance concerns raised by the PlayPump case study to appreciate diverse forms of expertise held by community members.

The Persistence of Technical Thinking

One of the most important findings from this study is what did not change: students maintained consistent attention to technical considerations across all three concept maps. For example, Cost appeared in 75% of Concept Map 1 submissions, 82% of Concept Map 2 submissions, and 80% of Concept Map 3 submissions. Safety, environmental concerns, and other technical factors similarly persisted throughout the semester. This continuity is not a failure of the pedagogical interventions but rather evidence of their success in fostering integration rather than replacement of existing knowledge.

The goal of sociotechnical engineering education should not be to diminish students’ attention to technical excellence but to help them understand technical competence as necessary but insufficient for effective community-engaged practice. As Mazzurco and Daniel argue, sociotechnical thinking involves understanding and addressing both social and technological dimensions of problems, not privileging one over the other [2]. Students who develop robust sociotechnical thinking recognize that technical solutions must be economically feasible, physically safe, and sustainable while simultaneously being culturally appropriate, community-accepted, and maintainable within existing structures.

The participant reflections support this interpretation of integration rather than replacement. S09 articulated this clearly:

> In Concept Map 1, I mostly focused on technical and practical factors such as safety, cost, sustainability and reliability. These were important, but they were largely limited to the functional side of engineering. I now see that social and cultural dimensions are equally critical. (S09 Concept Map 1, Written Response)

The crucial phrase here is “equally critical” not “more important” or “instead of” but “equally.” This participant has expanded their engineering toolkit to include social considerations alongside technical ones, understanding both as essential to effective practice.

This finding addresses a common concern sometimes raised about community-engaged engineering education: that emphasizing social, ethical, or community engagement dimensions will come at the expense of technical rigor. The persistence of technical considerations across all three concept maps suggests that well-designed community-engaged learning experiences can expand students’ thinking without diminishing attention to technical fundamentals. This supports Nieusma’s argument for “conducting the instrumentalists”- not replacing technical education with liberal arts content but rather orchestrating their integration in ways that enhance both technical and social competencies [8]. Students did not abandon their understanding of the importance of cost, safety, or materials constraints; they added community involvement, maintenance, and ethical considerations to their existing frameworks.

Limitations

While this study provides valuable insights into student conceptual development, several limitations must be acknowledged. First, the study sample is relatively small (n=23) and drawn from a single course and institution. The participants came from a diverse range of academic majors, but the course fulfills a specific university requirement, which may limit generalizability to other institutional contexts or course structures. Notably, this course was offered at an institution without an engineering college, and students enrolled were non-engineering majors. Engineering programs at institutions with engineering colleges may carry distinct cultural norms around technical identity and expertise that could moderate the effects of community-engagement interventions. Research suggests that students in traditional engineering programs may experience a narrowing of empathy and social concern over the course of their students potentially making the kind of conceptual shifts documented here more difficult to achieve or sustain [30]. Future work should examine whether and how findings from this context transfer to students in engineering degree programs, where technocentric culture may be more entrenched.

Second, the number of participants completing concept maps decreased across the three time points. This attrition made it difficult to articulate trends across all three time points with confidence. The declining participation also complicated efforts to infer how the application of each specific pedagogical intervention affected students' conceptions of sociotechnical thinking.

Third, interpreting the concept maps themselves presented challenges, particularly for maps in which participants chose to identify specific problem contexts such as water access, renewable energy, or transportation instead of a general community problem. In these cases, participants embedded their thinking about sociotechnical dimensions within the details of a particular design scenario, making it difficult to distinguish between domain-specific considerations and their broader conceptual understanding of community engagement in engineering. For example, a participant who focused on a transportation problem included accessibility as a node, but it was not clear from the visual representation alone whether this reflected genuine recognition of a consideration that impacted people as essential to design processes or simply acknowledged that people would be using the road. The written descriptions that accompanied the concept maps were therefore critical for interpretation, as they provided essential context for understanding what students meant by particular nodes and connections. The quality and depth of these written explanations varied considerably across participants. This variability meant that our ability to interpret student thinking was uneven across the sample. Maps accompanied by sparse or ambiguous descriptions were more difficult to code reliably, introducing potential inconsistency in the analysis. This limitation acknowledges the challenge of using student-generated visual representations as research data. The format allows for considerable flexibility and creativity, which is valuable pedagogically, but that same openness creates interpretive challenges for researchers attempting to draw systematic conclusions.

Fourth, the community-based design challenge involved stakeholders, who were institutionally proximate and most of whom were professionally credentialed (university faculty, vivarium staff, and engineering liaisons). This reduced some of the power asymmetries commonly present in community-engaged engineering partnerships that cross institutional, class, race or geopolitical boundaries. As a result, the challenges students encountered, while genuine, may not have fully prepared them for the more complex dynamics of community partnerships with historically marginalized or under-resourced communities. Future implementations might seek community partners whose relationship to the university involves greater power asymmetry or explicitly scaffold student reflection on the forms of power present even in institutionally proximate partnerships. We also note that a key lesson of the PlayPump case was the importance of engaging end users in the design process: in the turtle habitat project, the primary end users were the turtles themselves, whose preferences and wellbeing could only be inferred through expert proxies rather than direct communication. Instructors should acknowledge this limitation with students and use it as an opportunity to discuss how engineers navigate design for non-human or non-verbal stakeholders.

Future Work

The limitations identified in this study inform several directions for future research, both in our own continued work and for the broader community of engineering education scholars. To address the interpretive challenges with problem-specific concept maps, we will model the concept map creation and provide a sample concept map that uses an intentionally broad neutral topic (e.g., "how to be effective in college") and showing practices, characteristics, and behaviors that align with the topic. This revised prompt mirrors the structure we want students to apply to community problem-solving but removes the domain-specific complications that made interpretation difficult in the current study. We will retain the written explanation component, as these descriptions proved essential for understanding intent.

Beyond our own methodological refinements, this study raises important questions for others investigating how students learn to engineer in community contexts. First, additional research is needed to identify and evaluate other case studies that might effectively provoke cognitive dissonance prior to authentic community engagement. The PlayPump case proved powerful in this study, but what other examples of well-intentioned engineering that failed due to inadequate community participation might serve similar pedagogical functions? Case studies drawn from different engineering domains (e.g., infrastructure, product design, technology development) or different global contexts might resonate with diverse student populations or address different aspects of sociotechnical thinking. Systematic investigation of which cases work best for which learning objectives, and under what conditions, would provide valuable guidance for curriculum development.

Second, longitudinal studies that track students across multiple courses or into early professional practice would help establish whether the conceptual shifts documented in single-course studies like this one persist and transfer to new contexts. Do students who develop community-centered thinking in an introductory course maintain those perspectives when they encounter more technically demanding coursework? How do they navigate potential tensions between efficiency or optimization goals and community participation principles in design projects?

Finally, comparative research examining different pedagogical sequences would be valuable. This study employed a specific ordering—case study followed by community engagement—but other sequences might prove equally or more effective. Experimental or quasi-experimental designs that vary the timing, sequencing, and intensity of interventions could provide evidence to guide curricular choices and help the field understand how to promote socio-technical thinking.

Conclusion

This study suggests that undergraduate students may develop more sophisticated sociotechnical thinking within a single semester when provided with carefully sequenced pedagogical interventions. The persistence of technical considerations in company with a growing recognition of community participation suggests that the goal is not to replace one form of thinking with another, but instead to expand students' understanding of what constitutes engineering competence. Perhaps the most significant finding is that students integrated "community" in ways that prompted some to reorganize their conceptual frameworks around relational rather than purely technical considerations. This raises a weighty question for engineering educators: if we successfully teach students that meaningful engineering requires deep partnership with communities, are we prepared to restructure curricula, assessment practices, and professional pathways to support that understanding? The gap between recognizing the importance of community engagement and creating institutional structures that genuinely value and reward such work remains one of the field's most pressing challenges.

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