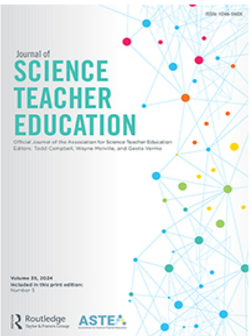

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A Case Study Comparison of Undergraduate Education and Engineering Majors' Understanding of Community Engineering

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ABSTRACT

As we prepare teachers to provide students with opportunities within STEM education, authentic experiences should guide the instruction. Unfortunately, due to the novel integration of engineering into national reform documents, there is a dearth of documentation on elementary preservice teachers' engineering ideas as they align with student goals (e.g. enrolling in an engineering program). As teachers must provide authentic science experiences to help frame the work of scientists for students, creating authentic engineering experiences should frame the work of engineers. Thus, it is important to foundationally investigate how elementary preservice teachers' ideas about engineering reflect those of novice engineers. This research uses multiple case study to investigate and compare teaching and engineering majors' understanding of engineering within their communities. Additionally, while there were some similarities across groups, engineering majors were more likely to speak to the science behind the artifacts represented in the photo novellas they authored, and the preservice teachers found a larger variety and diversity of engineering elements. Findings indicate that these groups have fundamentally different perspectives on engineering and how it is manifested within the communities. This has implications for upper tiers of education as elementary teachers lay broad engineering foundations, while middle, high school, and community colleges must methodically highlight engineering disciplines to provide more authentic experiences, highlighting the connections between engineering, science, and math.

KEYWORDS

Engineering education; elementary teacher education; photo novella; case study

Introduction

As the world becomes increasingly driven by technology and the number of complex problems facing societies grows, there will be an increased need to fill jobs in the STEM fields (World Economic Forum, 2017). Further, engineering literacy will become an important part of citizens' abilities to make informed decisions that impact their own well-being as well as society as a whole (National Academy of Engineering and National Research

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Council [NAE & NRC], 2009). These current and future demands have resulted in an increased emphasis on engineering in national and state standards, meaning that most elementary teachers are now tasked with including engineering in their science curriculum (Moore et al., 2015). Many elementary teachers, however, report being unfamiliar with engineering (Hammack & Ivey, 2019; Rogers & Portsmore, 2004; Yasar et al., 2006), and teacher preparation programs often do not require preservice teachers to complete coursework on engineering or engineering teaching. If preservice teachers are unfamiliar with engineering, it could be difficult for them to teach their students about this field (Sun & Strobel, 2013). Further, this knowledge gap between content and pedagogical enactment limits opportunities for students to make informed decisions about their careers or their communities. Because engineering impacts the daily lives of all citizens, a basic understanding of engineering is required in a scientifically literate population. To achieve this, elementary teachers will play a role in helping children develop that understanding generally and within their local spheres. We are particularly curious about how this occurs at foundational levels, and our research investigates how elementary preservice teachers view engineering in local communities. Further, we wondered how elementary preservice teachers' views compared with the views of engineering majors at the same university. We sought to answer the following research questions:

(1) How are elementary education and engineering majors conceptualizing the concept of engineering within their communities?
(2) What are these groups' conceptual alignments and disconnects?

Conceptual framework & background

Engineering and STEM education

Given society's reliance on technology, many future jobs are predicted to be connected to technology and engineering (World Economic Forum, 2017). To prepare students for these future jobs, students will need to begin developing knowledge and skills related to technology and engineering during the compulsory education years. For decades, countries such as Australia, Canada, and the United Kingdom have provided students with *technological design* and *design and technology* learning opportunities. For example, in 1990, the UK introduced a national curriculum that requires students learn design and technology beginning in Key Stage 1 (age 5 to 7) (Atkinson, 1990). In the United States, where the current study is situated, technology and engineering were not included within the K-12 curriculum standards (NAE, 2009) until the last decade. Recent shifts in USA science education now require the integration of engineering within K-12 science instruction through the Next Generation Science Standards (NGSS Lead States, 2013). Nearly 80% of states have either adopted or adapted NGSS, resulting in the required inclusion of engineering within many K-12 classrooms nationwide (National Academies of Sciences, Engineering, and Medicine [NASEM], 2020). This inclusion of engineering within K-12 classrooms requires that teachers of science (at all grade levels) have an understanding of the field of engineering.

There are four broad goals of engineering education in the K-12 grades: (1) develop engineering literacy, (2) improve science and mathematics achievement, (3) enhance college and career readiness, and (4) prepare students for success in postsecondary engineering programs (NASEM, 2017, 2020). Based on these goals, students who are engineering literate would possess a basic understanding of how the human-designed world came about and be able to think creatively about problems that they are faced with every day. Further, they would be prepared to make informed decisions about important issues (e.g., health care, energy consumption) as adults. Given the importance of engineering literacy, elementary teachers, who often teach multiple subjects to their students, are in an opportune position to begin building engineering literacy by connecting engineering design activities to introductory mathematics and science concepts that students should be learning in the early grades (NASEM, 2020). To accomplish this, however, elementary teachers will need to have an understanding of the Nature of Engineering and its associated Engineering Habits of Mind.

Social learning theory, nature of engineering, & engineering habits of mind

Bandura's (1977) Social Learning Theory (SLT) posits that individuals acquire knowledge through observing and interacting with others and suggests that learning and behavior are shaped by environmental and cognitive factors. The development of perceptions and habits of mind, then, is influenced by the people and places around us. This study connects SLT with a conceptual framework centered around engineering habits of mind and place-based learning to explore how undergraduate students perceive engineering in their communities.

For K-12 education, there is no consensus on what constitutes the Nature of Engineering ([NoE]; Karataş et al., 2016). However, according to NASEM (2020), engineering exhibits a set of essential qualities: it is systematic, purposeful, iterative, depends on teamwork, embraces failure, inherently creative and optimistic, quintessentially human, and attentive to social and ethical concerns (p. 33). While engaging in these essential qualities of engineering, engineers also display a set of Engineering Habits of Mind (EHoM), or internalized dispositions and ways of thinking that individuals draw upon when confronted with problems (Costa, 2008).

When thinking about habits of mind specific to engineering, the NAE (2009) called for the promotion of six EHoM: optimism, persistence, collaboration, creativity, systems thinking, and attention to ethical considerations. As with all habits, the development of EHoM is a gradual process, so students should be provided with opportunities to develop these ways of thinking beginning in elementary school (Advancing Excellence in *p*-12 Engineering & American Society for Engineering Education [AEEE & ASEE], 2020; Van Meeteren, 2018). Similarly, elementary teachers must be given opportunities to learn about and practice EHoM to effectively develop these habits in their students (Hanson et al., 2021). We align with current research (AEEE, 2020) defining these EHoM to form a conceptual framework for use in this paper. Optimism frames a positive perspective for engineering in which anything can be improved, and these ideas can come from anywhere and anyone (e.g., simple everyday objects can be made to fit the needs of the consumer better). Persistence reflects how engineering highlights the importance of failure within the process toward achieving a design solution, particularly within the optimization cycle (e.g., using multiple cycles of trials to gather data toward improving future iterations). Collaboration indicates how teamwork and communication are essential to success in engineering (e.g., individuals must be willing and able to communicate effectively with stakeholders and other members of their team in order to address a design challenge).

Creativity encompasses thinking about and imagining new ways of doing things (e.g., considering patterns in data in a novel way and then applying that knowledge toward the development of innovative solutions). Ethical considerations or conscientiousness requires an awareness of how engineering impacts living and nonliving parts of the environment and making ethical design decisions (e.g., agricultural technology such as irrigation systems can impact neighboring lands and wildlife due to changes in water flow and runoff). Systems thinking involves recognizing that engineering solutions are a part of interacting systems (both natural and human-made) that connect to and interact with each other (e.g., an interstate highway consists of systems of interacting parts such as on/off ramps, vehicles, lighting, drainage, etc.).

Undergraduate perceptions of engineering

Engineering students

The broad field of engineering continues to grow more and more diverse, with 16 disciplines identified for professional engineering licensure. Consequently, there is perceived ambiguity around the engineering profession, especially for those outside the discipline. Engineering students tend to refine their conceptualizations of the profession during their academic careers and begin to self-identify their roles within them. In fact, engineering identity development in students has been demonstrated as a key predictor for their academic performance, retention, and integration into the larger engineering community (Andrew et al., 2008; Foor et al., 2007; Godwin & Potvin, 2015; Juan & Gary, 2002; Matusovich et al., 2010; Stevens et al., 2005, 2008; Tonso, 2006a, 2006b; Walden & Foor, 2008). Engineering identity can be defined as a professional identity within engineering (Morelock, 2017) or a type of role identity that engineers (students and practitioners) author during their engineering experiences (education and practice; Godwin, 2016). Studies focusing on engineering undergraduate students' perceptions of engineering suggest frequent associations with technical problem-solving aspects, leveraging math and science knowledge and creativity, and significantly fewer associations with engineering aspects of communication, ethics, and social impacts (Morelock, 2017). Some studies suggest that students' interest in public welfare concerns may actually decline over the course of their academic experience, which can result in disengagement in engineering education (Cech, 2014). With most engineering coursework focused on applying math and science knowledge, many students may associate the engineering profession with that narrow view, especially while engaged in the coursework.

Elementary preservice teaching students

Elementary pre-and in-service teachers, like many adults, are prone to preconceptions about the nature of engineering (Liu et al., 2009), with many holding broad or limited views of the field (C. Cunningham et al., 2006; Hammack & Ivey, 2017; Nadelson et al., 2016; Pleasants et al., 2020; Vo & Hammack, 2022). In fact, preservice teachers have been found to hold similar perceptions as middle school-aged students (Knezek et al., 2011). Further, few elementary teachers describe engineering as being a creative endeavor or being linked to mathematics and science (Lambert et al., 2007). Elementary teachers also tend to confuse engineering with the work of skilled laborers (C. Cunningham et al., 2006). This lack of teacher familiarity may stem from a lack of personal familiarity with or exposure to engineering. According to the National Survey on Science and Mathematics Education (Banilower et al., 2018), only 3% of elementary teachers report having any college coursework in engineering. In addition to lacking college coursework in engineering, elementary teachers have reported that their preservice curriculum did not prepare them to teach engineering. These same teachers reported low confidence in teaching engineering (Hammack & Ivey, 2017; Yasar et al., 2006).

According to Dalvi et al. (2021), most students enrolled in elementary education preparation programs have had little exposure to engineering design during their own compulsory education experiences, suggesting a lack of familiarity with engineering. Similarly, prior studies utilizing the Design, Engineering, Technology survey (Yasar et al., 2006) found that in-service teachers reported low familiarity with engineering, which they partly attributed to a lack of exposure to engineering in preservice education coursework (Hammack & Ivey, 2019; Hsu et al., 2011; Yasar et al., 2006). Elementary teachers who are unfamiliar with engineering may shy away from teaching it (Brophy et al., 2008) or pass on inaccurate perceptions to their students (Cope & Ward, 2002). To that point, the *Framework for p-12 Engineering Learning* (AEEE, 2020) describes two potential consequences of delivering engineering instruction based on a limited understanding of engineering. First, teachers may provide engaging activities to their students that excite them to participate in engineering; however, these activities may not accurately represent engineering. Second, teachers may present disengaging activities that are misrepresented as engineering, which may lead to students adopting negative views of the discipline. In both cases, teachers' lack of authentic understanding of engineering could misrepresent the discipline to students (AEEE, 2020).

Situating photo novellas within place

Place influences the context in which knowledge is built and applied because "Teaching and learning always are placed endeavors regardless of attempts to ignore or overcome its context" (Eppley, 2015, p. 69). Place "makes us" by shaping our culture and identity (Gruenewald, 2003), and teacher preparation programs should provide opportunities for preservice teachers to situate teaching and learning within the communities in which they will live and work (Goodnough & Mulcahy, 2011). Place-based learning is fundamentally multidisciplinary, connecting the individual to the community (Woodhouse & Knapp, 2000) and serves as a "lens for disciplinary engagement" (Theobald, 1997, p. 137). This type of learning has been widely used for environmental science instruction and has been shown to enhance students' science content knowledge and skills, as well as foster relationships between the school and local community (Emekauwa & Williams, 2004; Howley et al., 2011; Keller, 2017). To ensure equitable access to the quality engineering curriculum, *The Framework for P12 Engineering Learning* (AEEE, 2020) calls on teachers to look "to their students' communities for examples of projects and applications of engineering learning that can intentionally teach desired engineering concepts" (p. 43). Given this call for *in situ* engineering education, we leverage photo novellas to elicit students' authentic ideas about engineering.

Highly explored within nursing education, the photo novella creates empirical data providing participants the ability to "document and discuss their life conditions as they see them" (Wang & Burris, 1994, p. 171). Wang and Burris define this methodology, also known as photovoice, as a way to centralize and prioritize issues that are important to the participant, and this is typically always nestled within their community (1997). Hurworth et al. (2005) further helped define the use of photo novellas, along with a series of other photo-driven data collection techniques, by highlighting the benefits (e.g., allowing the combination of visual and verbal language, producing unpredictable outcomes) and the limitations (e.g., problematic photo selection; difficulty relating to individual photos) of photos as tools for research. Photo novellas provide a unique intersection of an individual's connection between their spaces, their learning, and themselves. Finally, this tool provides a unique opportunity to understand student's engagement with place, asking them to engage with their local communities and environment. Using photo novellas, we sought to articulate how students with different career backgrounds understood and approached the abstract idea of engineering within their personal lived spaces.

Methods

This multiple-case study was funded, in part, by an NSF grant focused on supporting teachers to understand and teach engineering education within elementary contexts. This research seeks to understand nascent conceptualizations that undergraduate preservice elementary teachers have in relation to similar undergraduates focused on engineering. The cases within this descriptive multi-case study (Yin, 2017) are bound by two small groups of undergraduate participants who have self-selected into the majors of education and engineering. These students are enrolled in a medium-sized university in the Mountain West, and their ideas about engineering within their communities also help bind the cases. Further, the cases are also bound by a single semester in which both groups were enrolled in coursework for their respective degree programs. Additional participant information is provided below, along with a description of the cross-case analysis based on these two small-group cases. For this study, all elementary preservice teachers were undergraduate education majors with similar educational levels to that of engineering majors (e.g., years in school, number of credits). We use the language of preservice teachers to align with the larger body of literature around preservice teacher education. We chose a multiple case study methodology to create baseline descriptions for each group's ideas of place-based engineering and to investigate similarities and differences between cases.

Participants & context

This study occurred at a large state university in the northwestern United States. The research project examined two cohorts of undergraduate students' ideas about engineering. The first group consisted of declared undergraduate elementary preservice teaching majors (nPST = 33), and the second group consisted of declared undergraduate engineering majors (nEM = 13). Both groups were composed of students within their junior or senior years of a 4-year college progression. The students in both groups were predominantly white (one engineering student was of more than one race). The preservice teachers were largely female (nF = 27, nM = 6), and the engineering students were evenly split by gender (nF = 6, nM = 7) and approximately split among engineering majors (e.g., civil, chemical, computer, mechanical and electrical). Preservice teachers were enrolled in a required science methods course while engineering students were enrolled in an optional engineering course focused on mentoring first-year engineering majors through a program called "Engineering Peer Academic Leaders, or ePALS." The junior/senior ePALS students have completed both basic and disciplinary engineering coursework, as well as a peer mentoring training module. At the beginning of this project, students' groups were similar in size (i.e., 34 education & 30 engineering students); however, data was only collected for students who had completed the entire activity and returned their IRB consent paperwork ($N = 46$).

Data collection

Through a collaboration between two education faculty members and two engineering faculty members, an identical assignment was created for the students who focused on engineering within their community in the form of a photo novella. These types of artifacts can provide insight into cultural features and provide broader perspectives, considering students' conceptualizations far beyond what can be directly observed in the classroom (Yin, 2017). This photo novella assignment was one of many items created as part of the larger grant, using an advisory board that consisted of science and engineering teachers and engineers.

To complete this assignment, both groups of students were asked to create a photo novella depicting examples of engineering within their communities using images, videos, and audio. Both groups of students were given a written description by the instructors of their respective courses. Instructions asked students to go into their communities to find and photograph at least five examples of engineering and write a short explanation of why they chose what they chose. Once they had finished creating their photo series, they were asked to include a voice description. Full examples of photo novellas can be found in the findings section of this paper. Students used this assignment to identify and communicate their conceptualization of engineering using concrete examples of their space. Figure 1 represents one of many examples provided by a participant (PST_CB). This student also provided an audio file that goes on to describe how engineering supports her local community. Each student in both groups provided at least five images with descriptive text (Figure 1), along with one longer audio file (~30 seconds – 1 minute) discussing their ideas about engineering within the context of their community. A majority of students used Adobe Spark to submit their assignments, but there were also instances of PowerPoint with voice-over and Word Documents with attached audio files. The images, descriptive texts, and companion audio files comprise the data used for this project. It is of note that these (i.e., images, texts, audio) data were kept together, holistically representing students' understanding of engineering. This artifact was then analyzed as described below.

Data analysis

Data analysis for this project happened in three phases: codebook development, training, and interrater agreement. First, to develop the codebook, researchers (two engineering professors and two education professors) created a series of photo novellas and conducted an inductive content analysis (Elo & Kyngäs, 2008) as a part of the larger NSF-funded project (Hammack et al., 2020), prior to data collection. As experts in their respective fields, they believed that this work would act to capture some but not all ideas that could exist. The photo novella assignment was then given to elementary children to see what additional

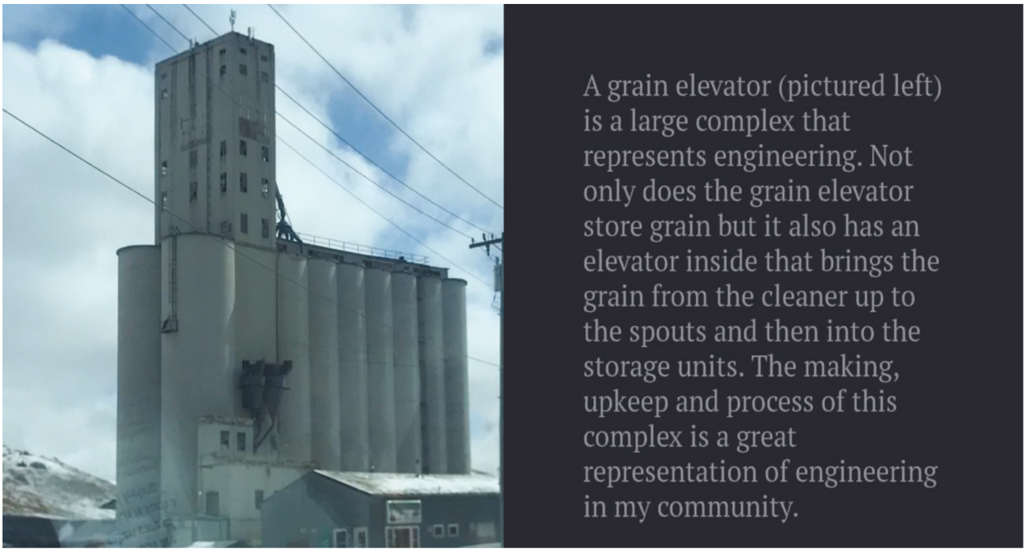


Figure 1. Example of student's community-based engineering identification.

codes could be added, grouped, and categorized to abstraction. Researchers consider this work pilot data for the codebook presented in this study. Once the pilot data was coded, the four researchers discussed the codes, subcodes, and categories while considering the NoE within multiple frameworks (C. M. Cunningham & Carlsen, 2014; Pleasants & Olson, 2019; Sheppard et al., 2007). These discussions were also influenced by the professors' goals of valuing diversity and place-based ideas and working against stereotypical views of engineering (Capobianco et al., 2011; Lightner et al., 2021). An *a priori* codebook was created of what was found and what could be found (Hammack et al., 2020). This included codes for NoE and EHoM. A more detailed example of the code book is provided in Table 1.

The second phase of data analysis required the training of graduate students and additional research personnel. This training occurred before and during data collection for this project. One educational researcher worked to train a graduate student on the use of the codebook. They did so by using five cultivated examples of the pilot data and having discussions over which codes and sub-codes were applied. This training took place over three meetings, each meeting lasting for approximately an hour, approximately 3 hours total. By the end of the training, the group had reached 100% agreements on the codes based on pilot data. An example of this negotiation occurred in Figure 1. The educational

Table 1. Examples of codes and subcodes.

Code	Subcode	Description
Engineering Habits of Mind	Systems thinking	Thinking about the interconnectedness of different systems and how they impact each other
	Creativity	Imagining new ways to do things
	Optimism	Belief that things can be improved
	Collaboration	Teamwork
	Communication	Sharing work/ideas with others
	Ethical considerations	Considering the broader impacts of work on others and the natural world
	Persistence	Learning from failure and trying again

researcher coded this image and descriptive text as "systems thinking" because the undergraduate student described the inner workings of a grain elevator and how those pieces are connected. The graduate students coded this image and text as "systems thinking" and "ethical considerations" because they thought the undergraduate student was indicating that grain elevators impact the surrounding farmland. While the latter might be true, the student artifact does not make reference to the broader impacts of the grain elevator on the natural world, and that code was not included.

The final phase of data analysis required a graduate student to begin coding this data set containing photo novellas from the undergraduate participants. The research trainer provided oversight to the coding processes, checking in when the graduate student had completed coding 50% (approximately 25) of the photo novellas. During this check, the agreement was approximately 80%, with 100% agreement after negotiation. Upon completion of the coding, all photo novellas and associated codes were provided to the other researchers on the project, who agreed the codebook had been applied with fidelity. Once these checks had been completed, the authors of the project worked to create conceptually ordered cluster matrixes (Miles & Huberman, 1994). These matrices were created within cases, based on the *a priori* codes and subcodes, and were used to make within-case themes based on the content of each cluster by itself and in relation to other clusters. Once each case had been created and looked at individually, a content-analytic summary table was created and used by the research group to note patterns and define themes across cases.

Findings

When investigating the research questions, multiple themes emerged from looking across both cases. In this section, we'll describe each group's ideas about engineering as derived from the within-case themes and then look across cases for comparison.

Elementary preservice teachers

Figure 2 shares an example of one PSTs full photo novella. The first five images and accompanying descriptions are verbatim of what was presented. The last image is a screen capture of the opening frame of the video and a transcription of the associated video. Maggie (all names have been changed) chose to represent five diverse examples of engineering in their novella and proceeded to explain that each image was engineering because it was designed by an engineer. The diverse examples provide evidence that when Maggie stopped to observe her surroundings, she noticed the ubiquity of engineering around her. Within these examples, Maggie identifies the specific components of each of the artifacts but does not describe a purpose for them (i.e., a specific need or problem that these examples address). For example, Maggie identifies the components of the light fixture but not the purpose of those components or of the light fixture itself. One exception to this is in the video of the sink. There, she notes that the sink has multiple components that allow the sink to function and partially describes the purpose of the sink when she mentions that the drain carries the water away, but she stops short of fully describing the purpose of the sink (i.e., deliver and remove water) or the problem or need that it addresses (i.e., access to clean drinking water, improved hygiene), and instead focuses the majority of her narrative on identifying the different parts of the sink.

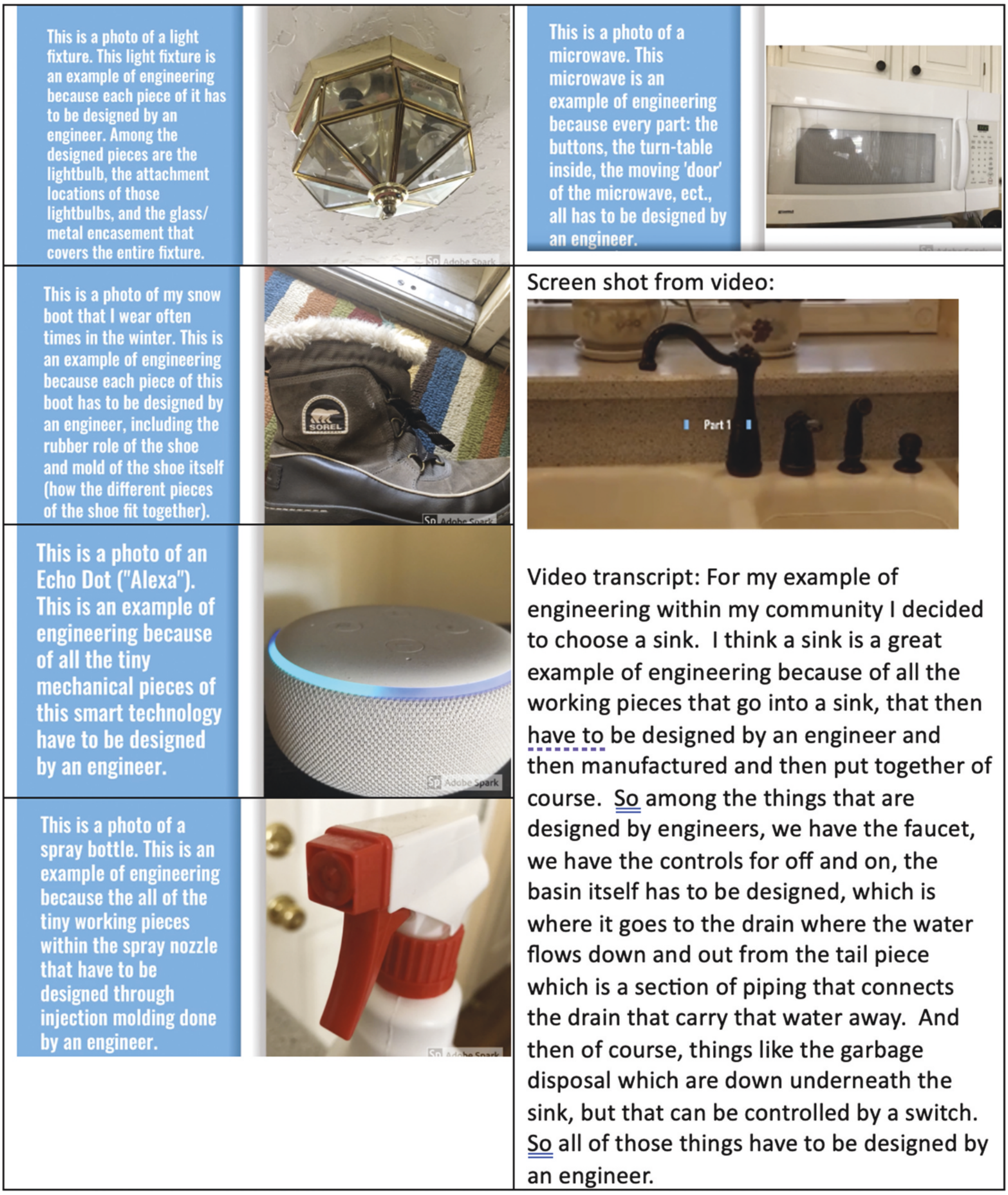


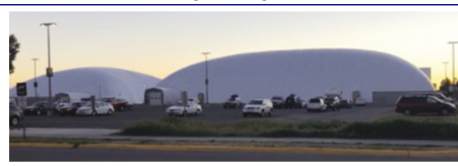
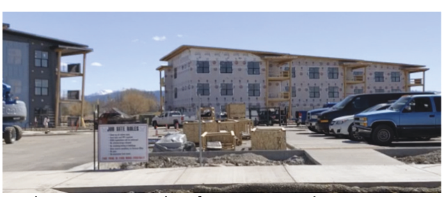
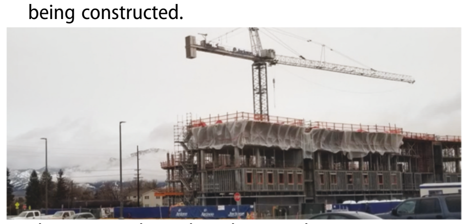
Figure 2. Example of an engineering major's full photo novella.

When coding Maggie's novella, we identified minimal evidence of EHoM. The closest connection we identified to EHoM was systems thinking, though the evidence was limited. While Maggie wrote about the many different pieces of artifacts in each of the five pictures, she did not discuss how those pieces interacted with or impacted each other. In the transcript of the video, there was one segment where Maggie did begin to talk about how the different parts of the sink are connected, "which is where it goes to the drain where the water flows down and out from the tail piece which is a section of piping that connects the drain that carry that water away . . . " However, the extent of the description is limited to one portion of the path that water might take. In the remainder of the description, Maggie just mentioned all of the different parts of the sink. While it is likely that Maggie was thinking about the interconnectedness of the sink parts, there is limited language in the video transcript that showcases this. We did not identify examples of creativity, optimism, collaboration, communication, ethical considerations, or persistence within Maggie's photo novella.

The lack of EHoM was common across the PSTs' photo novellas. Only 12% of PSTs included items in their photo novellas that were coded as EHoM, and two-thirds of those were examples of systems thinking. The grain elevator in Figure 1 is an example of a PSTs inclusion of systems thinking within their photo novella. In this case, the PST describes how the elevator located inside the "large complex" lifts the grain to the spouts and into the storage unit. It is clear from this example that this PST was thinking about the interconnectedness of the different parts of the structure.

Many PSTs (64%) indicated a purpose of at least one of the items they depicted in their photo novellas. We saw this with Maggie's example of the sink. Figure 1 also shows an example of how a PST connected the example of engineering to its purpose; in this case, the purpose was to transport and store grain. There were also examples where PSTs did not include a purpose for the engineering examples in their photo novellas. For example, in Table 2, the PST describes that the inflatable building is designed to stay up, but there is no description about what the purpose of such a building might be. This does not mean that they did not understand the purpose of the item, but rather, they did not see the importance of discussing the object's role in connection to the larger context. For example, one student provided a picture of an intersection and a stoplight. They described the role of civil

Table 2. Comparison of similar pre-service teachers' and engineering majors' photo novella.

Elementary Pre-service Teacher	Engineering Student
 This represents engineering because it is a building that is held up by air. An engineer designed this structure so that it was durable enough to stay up.	 Engineering is about adaptability and learning from mistakes. In this image, the North and South Inflatable domes are shown that are temporarily serving as gyms after the XXXXX gyms collapsed while the new gym is being constructed.
 This is an example of engineering because it is apartments that are being built. They are designed by architect and built by an engineer.	 This picture shows how large scale engineering projects can greatly improve the well being of people within our community. For example, without engineers time and thought designing this new building it is unlikely we would have enough living spaces social distance during the COVID-19 pandemic.

engineers in creating it and placing it on the road but did not describe the reason it would be designed or developed (e.g., to help protect pedestrians, control traffic, or collect data). Overall, elementary preservice teachers pulled from all engineering disciplines and spoke very generally about the connections.

Elementary preservice teachers identified a diverse array of engineering in their communities, including artifacts that are connected to disciplines ranging from structural engineering to environmental engineering. For example, one student, Megan (all names have been changed), showed railroad tracks, neighborhood children who had built a plywood skateboard ramp, wooden bleachers from her high school football field, and the fire department's building update. Another student, Jessica, included a "comfy" rocking chair, road work, a dryer, a car, and a dresser in her photo novella. She impressively connected some of the images to a specific discipline of engineering (e.g., civil, electrical, mechanical). This broad inclusion of multiple types of engineering is representative of an

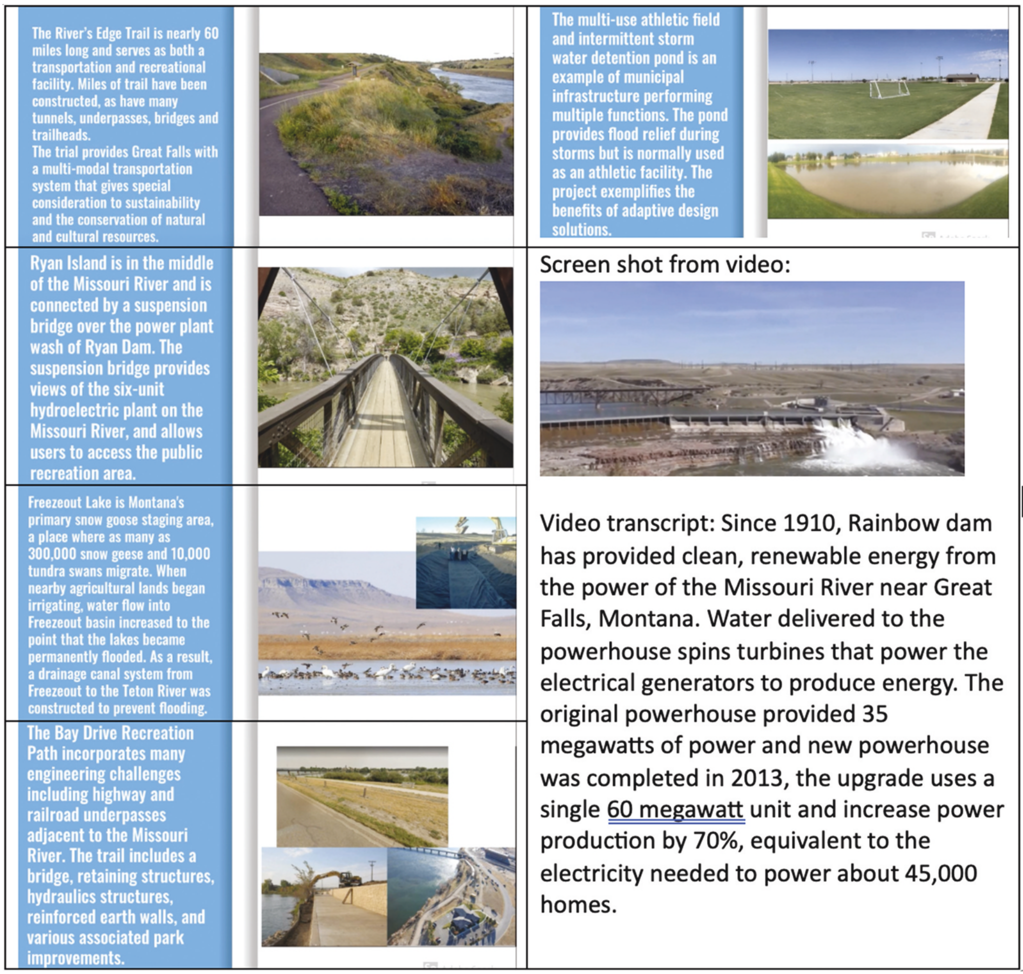


Figure 3. Example of an engineering major's full photo novella.

"engineering is everywhere" mind-set but likely also indicates a limited knowledge about the topic of engineering/engineering disciplines.

Engineering majors

Figure 3 shares an example of one engineering undergraduate's full photo novella. The first five images and accompanying descriptions are verbatim of what was presented. The last image is a screen capture of the opening frame of the video and a transcription of the associated video. Olivia is a civil engineering major, and each of the examples she provided are connected to civil engineering. For each engineering example, Olivia described a specific purpose for the engineering, and in some cases, also described the specific problem or need that was addressed by the engineering. For example, she writes that the multi-use athletic field "provides flood relief during storms but is normally used as an athletic facility," indicating the specific purpose of the complex to not only provide recreational facilities but to also address flooding issues in the community. Olivia's examples also contained technical knowledge or statistics related to the engineering that was presented. This can be seen in the video transcript when she describes the megawatt output changes resulting from updating the powerhouse.

Olivia's photo novella contained multiple examples of EHoM. The multi-use athletic field provides an example of a complex system, one of multiple examples of systems thinking that Olivia included within her photo novella. Olivia's description of the multi-use athletic field also demonstrated evidence of optimism, or the belief that things can be improved, as she noted, "The project exemplifies the benefits of adaptive design solutions." Her description of the 70% increase in power production from the dam update is another example of optimism. In the description of the first photo, Olivia wrote, "The trail provides [region name] with a multi-modal transportation system that gives special consideration to sustainability and the conservation of natural and cultural resources," an example that she was demonstrating the EHoM of Ethical Considerations by considering the broader impacts of work on others and the natural world.

At least one example of EHoM was present in every engineering major's photo novella, with many continuing multiple examples. Across the engineering major's novellas, communication was the only EHoM that was not represented; ethical considerations were the most frequently applied EHoM code (54%), followed by systems thinking (46%), persistence (31%), creativity (23%), optimism (8%), and collaboration (8%). In addition to EHoM, the prosocial nature code, which was applied to examples that presented engineering as helpful or beneficial to people, nature, or society, appeared in the majority (92%) of engineering majors' photo novellas.

Engineering majors often focused on a specific category or subset of engineering throughout their photo novella. For example, Kevin, an engineering student focused on chemical engineering, presented images of a coffee maker and how heat causes liquid movement, a toaster and heat distribution across food, and a refrigerator and the thermodynamics needed to keep food storage safe. Another engineering student, Lauren, who is studying civil engineering, focused on different construction projects around their town, presenting a half-built gas station, grocery store, hospital, athletic center, and a remodel of an older building in town. This group of students were often highly focused on a single engineering discipline, tying their photo novella to the underlying science (see dam example in Figure 3). For example, one student, Emily, focused their entire novella on "roundabouts." They said, "For me, engineering has always been about finding and implementing ways to make people's lives easier, safer, or more efficient. So when thinking about engineering in my community, roundabouts are the first thing to come to mind . . . ." They go on to describe the different benefits roundabouts provide to the community, how there are teams of engineers working to develop roundabouts, and how roundabouts add to the larger road system in positive ways. This example shows that this engineering major was thinking about ethics, collaboration, and systems thinking. Overall, engineering students had a very narrow focus on an individual discipline of engineering, including references to the purpose of the items in the pictures and how they were associated with specific sciences.

Comparison

By using elementary preservice teachers' and engineering majors' photo novellas to examine how each group conceptualizes engineering within their communities, it becomes important to look across both groups' patterns to elicit a comparison. At this point, the researchers would like to note that this comparison is not intended to indicate that either group has privileged or deficit knowledge. The career outcomes of both the education and the engineering majors differ greatly. This comparison is intended to highlight how different groups of students have conceptualized engineering and EHoM. This wider understanding can inform how we educate people on both career paths.

Differences

When looking across both groups of students, it became evident that there were differences in how each group conceptualized the concept of engineering. First, it was clear that elementary preservice teachers presented a broader, all-encompassing idea of engineering, while engineering majors often focused on a specific discipline of engineering. Second, elementary preservice teachers shared shorter, more colloquial descriptions of their community engineering locations. In contrast, the engineering majors often provided longer, more science-based explanations for why they chose specific ideas/elements/locations for their novella. While the engineering majors' extended explanations seem beneficial, it is important to note that a research-team engineering faculty member pointed out that the engineering students' descriptions appeared to be lifted directly from course lectures or introductory texts. This could be indicative of a limited understanding of the topic or a lack of communicative ability on the topic.

Similarities

Interestingly, there were some overlaps between both groups' photo novellas. This overlap represented a shared understanding of engineering between both groups. For example, members from both groups of students provided images and audio about a local building being constructed in their community, and there were multiple images of hydroelectric dams. While the co-occurrence of choosing identical or similar architecture occurred often enough to be significant, it should be noted that both groups did discuss the shared images very differently (Table 2). Again, the examples in Table 2 highlight how engineering majors were more likely to include a purpose for the example (i.e., serving as a temporary gym; providing adequate living space) as well as EHoM (i.e., persistence; ethical considerations) and connections to the prosocial nature of engineering (i.e., "greatly improve the well being of people"). At the same time, elementary preservice teachers were more likely to mention that something was engineering because an engineer had designed it.

Discussion

This research comparing elementary preservice teachers' and engineering majors' ideas about engineering is relevant to the field of science teacher education, given the role that engineering literacy plays in effective science instruction. In this paper, we explored photo novellas for undergraduate elementary preservice teachers and undergraduate engineering majors and found that between groups, there were differences (e.g., broader all-encompassing examples provided by preservice teachers as opposed to more discipline-specific examples from engineering majors) and similarities (e.g., examples of structures such as dams or specific buildings that hold meaning for the community). This section discusses the importance of those artifacts, their comparison, and how they fit into the larger body of literature.

First, when exploring students' place-based knowledge through the use of photo novellas, the findings in this study report on the detailed ideas two different groups of undergraduates have when engaging in the same assignments. While the assignment occurred at the same university during the same semester, students' job goals, along with the training and coursework they had, influenced their engagement with the assignment. This finding is aligned with larger arguments around the usage of place-based learning (Eppley, 2015; Gruenewald, 2003) that describe the unique ways identity can shape our perceptions and perspectives around the places we inhabit and vice versa. We agreed with research (Goodnough & Mulcahy, 2011) that asks preservice teacher preparation programs to provide students the opportunities to engage with the community and add to the literature by challenging the engineering preparation programs to similar commitments. As it would benefit teachers to understand the communities their students are a part of, it would also benefit engineers to understand the places they are designing for. Additionally, we found that using photo novellas was an elegant way to encourage students to think about and engage with their community (Hurworth et al., 2005; Wang & Burris, 1994).

Second, we framed the two groups of undergraduate students' works within the photo novella; these findings echoed work already being done in the field. The undergraduate elementary preservice teaching students had little exposure to engineering prior to this assignment (Dalvi et al., 2021; Hammack & Ivey, 2019; Hsu et al., 2011; Yasar et al., 2006) but were able to engage with the assignment fully and provided insightful observations about some aspects of engineering in their community, without ever being explicitly taught about the topic. In contrast, they could provide a breadth of engineering examples in their communities; very few of them (12%) had EHoM represented in their photo novellas. This is not necessarily surprising, given the limited formal exposure preservice teachers have to engineering, and it highlights a shortcoming in current approaches to preservice teacher preparation. While our research indicates that elementary teachers are immensely capable when provided the opportunity to engage with engineering, they need direction. These findings speak to the lack of research around EHoM and the NoE compared to topics like the Nature of Science (Hanson et al., 2021; Pleasants & Olson, 2019). We have extended this literature by providing data on how such engagement could begin and discuss the limitations of this in our implications section. Next, while undergraduate engineering students could engage with most aspects of EHoM to a degree, we found that some aspects of EHoM were underrepresented, particularly communication. This does not necessarily mean that engineering students do not recognize the importance of communication in their discipline; simply, they did not choose to prioritize communication as much as ethical considerations, systems thinking, and persistence. Various stakeholders throughout the entire scope of an engineering project are necessary for developing a design solution that solves problems in meaningful ways for the people in that place. Communication is vital to designing and implementing engineering solutions, especially when determining the appropriateness of those solutions (Lappalainen, 2009) to a particular place.

Finally, as we dug into our findings, teasing out the similarities and differences between the groups of students, we must look back to the first and fourth broad goals of engineering education (NASEM, 2017, 2020): 1) develop engineering literacy . . . (4) prepare students for success in postsecondary engineering programs. The two cases presented in this work represent a continuum of where students start, elementary education working on engineering literacy, and where we hope some of our students will end, some seeking degrees in engineering, with all students, regardless of profession, having a level of engineering understanding. While there is some literature documenting work around elementary preservice teacher engineering (C. Cunningham et al., 2006; Hammack & Ivey, 2017; Nadelson et al., 2016; Pleasants et al., 2020; Vo & Hammack, 2022), this paper adds to the other end of the continuum; showing and connecting where these learning opportunities could and should be heading. These findings become important when considering that the ways K-12 teachers think and frame science and engineering can impact career choices and learning outcomes.

Implications

This study provides empirical data around engaging multiple populations of undergraduate students in opportunities that explore engineering in their community. We believe this is a generative direction worthy of further investigation. To this end, we believe there are major implications to consider, including the importance of EHoM disentangled from NGSS, how undergraduate teaching opportunities can create space for EHoM, and the specific challenges elementary education should consider.

First, NGSS (2013) explicitly ties science and engineering practices together. This reform document presents a progression of K-12 science and engineering practices toward supporting science and engineering literacy (Chae et al., 2010) and increasing the number of authentic science experiences within STEM. While the inclusion of engineering within NGSS is a step in the right direction, scholars have pointed to the science-centric ways that engineering has been included with the NGSS (C. M. Cunningham & Carlsen, 2014) and the focus on technical framing (Hoeg & Bencze, 2017). Focusing on science and engineering practices that are science-centric and performance-based may limit students' engineering engagement to technical aspects that leave out the humanistic side of engineering. This may also result in a lack of recognition of the creativity and optimism that are associated with engineering design (C. M. Cunningham & Sneider, 2023), which could further reinforce misconceptions about engineering.

Additionally, as the field of engineering education continues to grow, so will the expectations for teachers, who could shy away from teaching engineering (Brophy et al.,

2008) or pass on inaccurate perceptions to their students (Cope & Ward, 2002) if they are unfamiliar with the discipline. By providing teachers support for thinking and learning about engineering early within science teacher induction (e.g., preservice teacher science methods), teachers can eventually use engineering to ground abstract science ideas. However, for science educators to provide engineering opportunities for their students, teachers and researchers should understand the span between how and why we present engineering ideas to students and how engineers operationalize the engineering field. Authentic experiences can set students up for success as they consider careers as future engineers and build engineering identities (Godwin, 2016).

The wide range of ideas presented in this research illuminates potential challenges to elementary science education. As elementary teachers get children excited about engineering, the types of opportunities they provide might cause a disconnect as students get older and consider engineering as a career or consider the implications of engineering on the natural world. One way to ameliorate this incongruence is through engagement with EHoM. NGSS practices and the Disciplinary Core Idea (DCI) of Engineering, Technology, and Applications of Science (ETS) provide a starting point for this work. Practices like consensus modeling allow teachers to discuss pieces of EHoM, like communication, by supporting students to share their ideas with others (NASEM, 2020). Further, ETS allows students to discuss and consider the human impact on the natural world, which is related to the EHoM ethical considerations. We must acknowledge that while NGSS provides a platform to begin engagement, students' thinking should be pushed further. For example, in ethical considerations, engineering is often positioned as a solution to problems; students must also be shown how engineering can cause problems, as well as the important role of engineers in making design choices that minimize the negative impact of engineering on society and the natural world. Students should also be made aware that there are multiple stakeholders that are impacted by engineering solutions in different ways.

Additionally, while elementary engineering opportunities can be very broadly aligned to science, it is important for upper tiers of education to connect engineering to specific disciplines and provide stronger connections to science and math (AEEE, 2020). Further, by providing students with opportunities to look to their communities for examples of engineering, educators can build connections between school and the places where students live (Goodnough & Mulcahy, 2011) and develop their culture and identities (Gruenewald, 2003). If teachers have an incomplete understanding of EHoM, it may limit how they help bridge the NGSS to help students develop their own EHoM.

Engineers are faced with tackling the world's grand challenges, which are complex, multifaceted, and have great social and ethical implications (NASEM, 2017). Future engineers must embody EHoM (Costa, 2008) to address these engineering grand challenges. Today's elementary students are tomorrow's engineers; providing them with opportunities to develop EHoM across multiple years (Van Meeteren, 2018) is paramount to supporting their development as engineering-literate citizens. Not presenting engineering to children in a way that connects to EHoM is a missed opportunity, which can occur because EHoM is not directly tied to the NGSS standards but rather is more subtly linked. Concepts like persistence, optimism, and creativity exist within the framework but should be explicitly acknowledged and tied to engineering opportunities. While the elementary preservice teachers in the present study may have been aware of EHoM, their photo novellas often did not present evidence of their thinking around EHoM. This is an important finding for teacher educators because it highlights areas that warrant additional focus in teacher preparation programs. Many preservice teachers leave their teacher preparation programs with little exposure to engineering (Dalvi et al., 2021), often resulting in a lack of familiarity with the discipline (Hammack & Ivey, 2019; Hsu et al., 2011; Yasar et al., 2006) and low confidence for teaching engineering. Teacher educators should provide opportunities for preservice teachers to explore the presence of EHoM and ways to develop EHoM in their own classrooms (Hanson et al., 2021).

Finally, there were limitations to this study that should be addressed, which include the use of an a priori code book and timing. While the use of an a priori codebook for analysis is a common tool, these findings would have been made more robust by having follow-up interviews with the students to provide additional opportunities for reflection on the photos and narratives they provided. Future work should provide iterative opportunities for students to engage with engineering within their communities. Finally, we should acknowledge that the timing of this project coincided with the initial COVID-19 quarantine recommendations. This might have impacted students' willingness to explore their community or their mental capacity to engage with the work. We recommend conducting similar studies to see if the global pandemic has impacted how students perceive engineering in their communities or their EHoM.

Conclusion

Engineering does not exist in a vacuum—it is intricately connected to the needs of society and has both positive and negative impacts. Recruiting future engineers who understand this connection to society and who practice EHoM, such as attention to ethical considerations, is imperative to addressing the engineering grand challenges (NAE, 2017), which are global in nature (Mote et al., 2016). Teachers are expected to engage their students in engineering design and provide students with information that will inform their decisions about engineering as a potential career path. If the information presented to students is incomplete or misaligned with how professional engineers view their discipline, then students may have limited ability to make informed career choices. Much of the knowledge children gain about engineering comes from engineering teaching in schools. It is important, then, to know teachers' perceptions of engineering and how those align/do not align with the ways engineers perceive the discipline. The current study takes an initial step toward understanding the similarities and differences in the ways in which future teachers and engineers view the engineering around them.

As the field of engineering education strives to provide more authentic experiences for students, teachers' educational engineering opportunities must also be considered, given their limited exposure (Hammack & Ivey, 2019; Pleasants et al., 2020; Rogers & Portsmore, 2004; Vo & Hammack, 2022; Yasar et al., 2006). This limitation is often seen as a deficit; however, this research indicates that elementary teachers have a broader, more inclusionary idea of engineering when compared to engineering majors. We believe that this perspective, when fostered in elementary teachers, is more aligned with the goal of engineering literacy, particularly in lower grades. Differences do not necessitate the need for hierarchy (e.g., positing the knowledge of engineering majors as better) but rather can provide teachers with additional perspectives and tools to engage diverse populations of students. Perhaps it is better for elementary teachers to help young children see engineering in everything, knowing that future grades and subjects will help students find a specific career path.

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