Tangibility of representations in engineering courses and the workplace

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Abstract

Background: Situated cognition theory suggests that representations of concepts are products of the environment wherein we learn and apply concepts. This research builds on situated cognition by investigating how concepts are tangible to a professional engineering environment.

Purpose/Hypothesis: The tangibility of concepts in relation to social and material contexts was defined and explored in this study. Specifically, the conceptual representations of structural loads were examined within workplace and academic environments.

Design/Method: A researcher conducted ethnographic fieldwork at a private engineering firm and in undergraduate engineering courses. Data sources from this fieldwork included the ethnographer's participant-observation field notes, formal and informal interviews, and artifact documentation.

Results: Findings from this study described how academic representations of structural loads are more or less tangible to the social and material contexts of engineering practice. Representations documented in the workplace were found to be tangible to (1) real-world conditions, (2) project/stakeholder constraints, and (3) engineering tools. Conversely, representations documented in the courses studied exhibited various degrees of tangibility to none, some, or all of these three traits.

Conclusions: These findings explicitly identify the ways in which representations of structural loads differ across academic and workplace environments and how these differences may contribute to the education–practice gap. Specific suggestions for making academic representations more tangible to workplace environments are provided based on findings from the workplace, previous engineering education literature, and best practices observed in the courses studied. Future research considerations and the value of ethnographic methodology to situated cognition theory are also discussed.

KEYWORDS
conceptual learning, engineering curriculum, ethnography, professional practice, tangibility

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“Too often in engineering classrooms, the instructional activities required of the students are not aligned with the kind of knowledge those activities are intended to foster” (Newstetter & Svinicki, 2014, p. 43). Reinforcing this claim are studies of engineering workplaces noting misalignment between various aspects of engineering education and engineering practice (Johri & Olds, 2011; Jonassen et al., 2006; Trevelyan, 2007, 2010, 2013). Workplace studies often attribute the education–practice gap to broad claims noting that practice requires socially distributed knowledge to solve complex problems, whereas existing pedagogical methods prevalent within engineering education train students to solve problems that prioritize distributing knowledge primarily through tightly controlled forms of interaction and material resources such as lectures and textbooks (Bucciarelli, 1988; Jonassen et al., 2006; Trevelyan, 2010). These and other studies of the engineering workplace (Brunhaver et al., 2017; Sheppard et al., 2007) have contributed to the general notion that undergraduate engineering programs are not adequately preparing engineering students for the types of problems encountered in engineering practice and the distributed knowledge required to solve them (Clancey, 2006; Dunkle et al., 1995; Johri, 2011; Litzinger et al., 2011; McCracken & Newstetter, 2001; Salzman & Lynn, 2010; Streveler et al., 2008; Trevelyan, 2007, 2013). While such studies greatly contribute to a broader understanding of the education–practice gap, there is still little exploration of the unique social and material contexts characteristic of academic and workplace environments that shape students’ and engineers’ knowledge.

Given that school and workplace differ in the ways in which knowledge is used, distributed, and represented, links that tie these two environments need to be explored. One often explored link between school and work is conceptual knowledge (Litzinger et al., 2011; Streveler et al., 2008). Concepts allow people to make sense of complex ideas based on perceived relationships among equations, definitions, meanings, and other pertinent characteristics (D. Perkins, 2006; Streveler et al., 2008). Many areas of research explore concepts as being tied to individual cognition (Johri et al., 2014; Johri & Olds, 2011). However, this framing of concepts does not account for the different ways concepts are formed and represented in relation to the social and material contexts in which they are used (Johri & Olds, 2011; Litzinger et al., 2011).

Situated cognition theory offers a framework that accounts for these unique social and material contexts. Situated cognition theory posits knowledge as being distributed among an environment rather than within the minds of individual learners (Greene et al., 1996; Newstetter & Svinicki, 2014). Environment encompasses the social and material (sociomaterial) contexts embedded within the activities characteristic of a particular setting (Greene et al., 1996; Johri & Olds, 2011). Sociomaterial contexts refer to the shared understanding of tools utilized during engineering activities common to engineering education and practice (Johri & Olds, 2011). For example, when engineers utilize a graph, chart, or other visual tool, they are using that tool to represent some shared understanding of the tool’s purpose and how to use it. The material context is the visual tool itself, and the social context is the shared understanding of how to use the tool and what the tool is being used to represent (Johri & Olds, 2011). Therefore, once we engage with or create materials to represent concepts, those material contexts are inseparable from the social contexts driving their use (Vinck, 2003), hence the term sociomaterial.

Studies of engineering workplaces indicate that the sociomaterial contexts in which engineering concepts are represented in practice differ considerably from how engineering concepts are represented in engineering education (Johri & Olds, 2011; McCracken & Newstetter, 2001; Newstetter & Svinicki, 2014; Trevelyan, 2010, 2019). For example, McCracken and Newstetter observed that engineering textbooks often provide “diagrammatic representations, assumptions and simplifying details, and possibly queues [sic] or hints for solution[s]” (2001, p. 14). Similarly, other studies have noted that engineering problem-solving in the workplace requires knowledge distributed among tools and people across multiple disciplines to effectively represent concepts necessary for solving complex problems, which is juxtaposed with simpler, well-structured problems common in undergraduate engineering education (Anderson et al., 2010; Dunkle et al., 1995; Gainsburg et al., 2010; Jonassen et al., 2006; Salzman & Lynn, 2010; Trevelyan, 2010, 2013). These studies suggest a misalignment of sociomaterial contexts across engineering education and practice that, according to situated cognition, may limit opportunities for students to develop and understand representations more tangible to engineering practice (Johri & Olds, 2011; Trevelyan, 2019).

To capture a more descriptive and nuanced understanding of how representations differ across academic and workplace environments, we conducted an ethnographic study of a structural engineering workplace and undergraduate structural engineering courses to address the following research questions:
How is the structural engineering concept of loads represented within the sociomaterial contexts of the workplace and academic environments?

In what ways are these representations tangible to the sociomaterial contexts of the engineering workplace?

This study contributes to existing engineering education research through its formation and development of “tangibility” in relation to the representation of concepts, and in its use of ethnographic methods to provide a descriptive and nuanced understanding of sociomaterial contexts in both academic and practice environments. We operationalize the term tangibility to describe how representations of concepts are connected to specific sociomaterial contexts. For example, a structural engineer may represent a calculated force value as a vector in a free body diagram (FBD) of a bolted connection to understand the types of stress that force will induce on the bolts. The concept of force is represented as a vector and tangible to the material context of the FBD itself while also being tangible to the social context underpinning the need to create the FBD.

2 LITERATURE REVIEW

Johri and Olds (2011) conceptualize learning as a sociomaterial process, wherein materiality extends beyond tools and objects to also include representations. Representations are artifacts such as text, diagrams, symbols, and so forth that portray a certain meaning to a group of people within a particular setting (Lemke, 1997; McCracken & Newstetter, 2001). Representations provide a framework for comparing sociomaterial contexts that engineers and students navigate within their respective workplace and academic environments (Bornasal et al., 2018; Davis et al., 2012). Differences in how students and practicing engineers engage with representations highlight an important but underexplored area on the gap between education and practice. An example of a representation is a stress–strain curve, which conveys meaning to structural engineers about concepts such as stress, strain, plasticity, and other material science concepts. The application of this representation can yield a variety of different looking curves depending on the purpose of the representation within a given environment. For example, a stress–strain curve for steel used within the context of designing rebar in a concrete beam will conservatively plateau at the rebar’s yield strength, whereas within the context of a steel design course, the stress–strain curve will often show the increased strength of the steel beyond yielding to illustrate the concept of strain hardening. Both representations are stress–strain diagrams for steel, but the social context of their application results in different looking curves. Therefore, a stress–strain curve is an artifact (i.e., material context) used to represent (i.e., portray the meaning of) material science concepts within the social contexts of the engineering activity. Thus, representations manifest from and are inextricably linked to both social and material contexts (Johri et al., 2014).

Multiple studies have demonstrated the importance of being able to fluently navigate multiple representations in science, technology, engineering, and mathematics (STEM) learning and how engineers utilize this ability to more readily solve problems in a variety of sociomaterial contexts (Gestson et al., 2019; McCracken & Newstetter, 2001; Pea, 1993). These sociomaterial contexts not only mediate but shape our knowledge in alignment with theories of situated cognition (Johri et al., 2014; Lemke, 1998). Through this lens, representations are a product of, and tangible to, the sociomaterial contexts wherein we learn and apply concepts.

2.1 Tangibility

Situated cognition theorists would support the idea that concepts are apprehensible only within a specific context (Brown et al., 1989; Trevelyan, 2019). For example, Brown et al. (1989) note that “A concept ... will continually evolve with each new occasion of use, because new situations, negotiations, and activities inevitably recast it in a new, more densely textured form. ... Part of their meaning is always inherited from the context of use” (p. 33). Thus, within the perspective of situated cognition, all concepts are tangible to the sociomaterial contexts of the environments wherein they are represented. We operationalize tangibility to describe the ways in which concepts are represented in particular sociomaterial contexts.

While the sociomaterial contexts of academic environments are not identical to workplace environments, tangibility provides an opportunity for describing what and how conceptual representations differ across these environments as a result of their distinct sociomaterial contexts. As there can be endless sociomaterial contexts across different engineering disciplines and workplaces, it is important for tangibility to not only be descriptive of specific sociomaterial
contexts but also broad enough to be applicable to other engineering environments and future engineering education research.

While tangibility has not been explicitly identified in the previous literature, it can be used to characterize findings in similar research. For example, tangibility can be used to further describe findings from Bornasal et al. (2018) exploration of concepts at a transportation engineering firm, where it was observed that engineers recall, form, and apply conceptual knowledge within (1) project constraints, (2) negotiation with other engineers and project stakeholders, and (3) the use of material resources. Thus, how the engineers represented concepts was tangible to the material context of material resources and the social context of project constraints and negotiations with other engineers and stakeholders.

Gainsburg et al. (2010) study of structural engineering workplaces observed multiple “types” of structural engineering knowledge including fundamental design concepts and design instruments while also observing the extent to which structural engineers used these different types of knowledge throughout different phases of a project. This implies that when engineers are representing fundamental design concepts, those representations are tangible to other types of knowledge such as design instruments (material context) and certain phases of certain projects (social context).

In Stevens et al. (2008) observations of four engineering students’ curricular path, they noted that the engineering knowledge required of students began with “following a recipe to reach a single, expected result” (p. 3) to upper-level courses where students were more likely to be expected to “generate their own data, either through research or experimentation” (p. 3). Stevens et al. (2008) observed increased responsibility to define and bound open-ended problems as engineering students progressed through their majors. To solve these open-ended problems, the engineering students had to find information that would have been typically given to them in prerequisite courses, and this exposed the students to more “‘real world’ conditions” (p. 3). Thus, open-ended, complex problems required the students to form more tangible representations to those “real-world conditions” than the representations that “arose from problems worked under the ‘perfect world’ conditions of prerequisite courses” (Stevens et al., 2008, p. 3).

In summary, tangibility can be used to describe the ways in which conceptual representations are more or less embedded in the sociomaterial contexts of “real-world” engineering practice. The differences in tangibility of representations in workplace and academic environments can be viewed as a contributing factor to the misalignment between engineering education and practice but have never been explored across both environments within a single study.

2.2 Ethnographic studies in engineering education research

Ethnography emerged out of anthropology as a way to develop richer understandings of cultural practices via immersion within said culture (Case & Light, 2011). Ethnographic methods are well suited for exploring the tangibility of representations in academic and workplace environments because these methods allow for direct observation and active participation in these environments (Hultin, 2019; Niemimaa, 2014). In engineering education research, only a few ethnographies have been conducted to access richer understandings and descriptions of workplace or academic environments, let alone both within a single study (Bornasal et al., 2018; Case & Light, 2011; Gainsburg et al., 2010; Stevens et al., 2008).

Studies of sociomateriality can benefit from direct participation of the researcher because understanding of representations cannot be separated from the performative contexts that enact the representation (Hultin, 2019). Participation is also a worthwhile addition to any ethnography because it can serve as a way of challenging or validating interpretations of observations, thereby enhancing the credibility and trustworthiness of the data collected and analyzed from field research (Emerson et al., 2011; Walther et al., 2013).

The authors conducted a participant-observation ethnography to explore the tangibility of representations to the sociomaterial contexts of both a workplace and academic environments within a single discipline. Studies of this nature are valuable to engineering education research because they can build on previous literature that has recognized the value of the situated cognition perspective for explaining the impact of broad differences between education and practice by developing a more granular, descriptive, and nuanced understanding of the engineering education–practice gap from both sides of the gap.

3 METHODS

The researcher conducting the ethnography in this study was the first author and is hereto referred as the ethnographer. The ethnographer immersed himself first within the environment of a structural engineering workplace
and subsequently in four undergraduate structural engineering courses. Data collection in these environments consisted of participant-observation, interviewing, and artifact collection, which are the three main sources of data in an ethnographic study (Emerson et al., 2011; Johri et al., 2014). Collectively, these three methods allowed access to multiple interpretations from different perspectives to triangulate the data during analysis (Stevens et al., 2008; Walther et al., 2013). Data analysis occurred during and after data collection, which is common practice in ethnography to utilize incoming data to guide further inquiry (Emerson et al., 2011; Johri & Olds, 2011).

3.1 Ethnographer’s background and issues of credibility and bias

The ethnographer had no prior experience conducting an ethnographic study before, and, therefore, in preparation for this study, he enrolled in four graduate-level qualitative research method courses focused on ethnographic methods. The research team planned to conduct an ethnography for this study prior to the ethnographer enrolling in these courses, allowing the ethnographer to consult the course instructors' expertise to progress and adapt their methodology before entering the field. Furthermore, the research team consisted of two experienced engineering education researchers who had conducted a participation-observation ethnographic study before and were consulted by the ethnographer throughout the data collection and analysis process. For example, the ethnographer held in-person or phone meetings at least once a week with members of the research team while collecting data to discuss his documentation of observations, possible interpretations, and guiding future data collection and analysis. According to Walther et al. (2013), such training by and consultations with experts in the qualitative research community is one strategy for improving the credibility of the data collected.

The ethnographer has also focused his undergraduate- and graduate-level coursework in structural engineering, which provided the disciplinary knowledge to understand and participate in the environments he was studying. This was the main reason the researchers chose to focus on the discipline of structural engineering as it lends credibility to the ethnographer “see[ing] what they think they see” and “call[ing] things by the right names” (Walther et al., 2013, p. 640).

It should be noted that the ethnographer had never practiced structural engineering in a professional setting before this study. This lopsidedness in the ethnographer’s academic experience over his professional experience instills bias that has valid arguments for its hindrance and benefit to the credibility of the study (Guba & Lincoln, 1989; Maxwell, 2013). For example, the ethnographer’s lack of professional experience created a preconceived notion of structural engineering practice based on his academic training; however, this also situated him in the engineering education–practice gap being explored.

The sequencing of studying the workplace environment before the academic environments was purely a product of when access to these environments was made available to the ethnographer. The researchers also acknowledge how this sequencing could bias the collection and interpretation of data. Awareness of this bias guided the researchers to focus their data collection on identifying representations as they emerged in their unique sociomaterial context, only to be compared with other representations and/or sociomaterial contexts during data analysis (Emerson et al., 2011; Maxwell, 2013). Figure 1 illustrates the sequencing of data collection from each environment.

3.2 Data collection

Data were collected in the field for 9 months (3 months in the workplace plus 6 months in the classroom), which allowed the ethnographer to collect data from diverse perspectives, experiences, and settings (Case & Light, 2011; Johri, 2011). This prolonged exposure and diversity of data collection sources, settings, and participants are all considered strategies for enhancing the credibility of data collection (Case & Light, 2011; Maxwell, 2013; Walther et al., 2013).

The workplace environment selected for this study was a private architecture and engineering firm that employs structural engineers to perform structural analysis and design of existing and new commercial, industrial, and public buildings. The firm was located in the Pacific Northwest region of the United States. The academic environment selected was four courses at the ethnographer’s higher education institution. The four courses selected make up the backbone of most undergraduate structural engineering programs (B. Perkins, 2016). Tables 1 and 2 summarize demographic information for each site used and the participants interviewed in the study.
3.2.1 | Participant-observation

Ethnographies wherein the researcher not only observes but also participates can offer an even richer understanding of the sociomaterial contexts that influence representations (Case & Light, 2011; Emerson et al., 2011; Hammersley & Atkinson, 2007). Immersing oneself within the daily activities of those they are studying allows for a more descriptive account of participants’ experiences through personal exposure and fosters rapport that can be capitalized on in future observations and interviews (Burt, 2019; Maxwell, 2013). Furthermore, being a participant-observer allows the researcher to bounce back and forth between these roles depending on what is the more appropriate data collection method for the respective environment (Emerson et al., 2011). For example, if an engineer preferred not to be observed while working on something, the ethnographer could participate in his own engineering tasks until the engineer was available for an interview to discuss what they were working on. Conversely, if while the ethnographer was working on one of his engineering assignments, he overheard a discussion among other engineers or students that was worth observing, he would approach the participants and ask if it was ok to observe their discussion.
In the workplace environment, the ethnographer worked approximately 16 h/week as an engineer-in-training (EIT) on portions of 18 different projects. The ethnographer participated in design meetings with engineers and other project stakeholders, performed calculations, created and reviewed structural drawings, and responded to contractor requests for information and submittals. During the remaining hours of a typical workweek, the ethnographer stepped away from his EIT role and observed other engineers engaging in similar activities. In the academic environment, the ethnographer enrolled in the four courses as an actual student and participated in all curricular activities while also observing and documenting the sociomaterial contexts of representations as they emerged in these activities. The ethnographer had taken the equivalent of each of the courses approximately 5 years prior during his own undergraduate engineering education, which afforded him the ability to focus his observations on the sociomaterial contexts wherein conceptual representations emerged rather than having to learn the course content simultaneously.

Data collected during participant-observations took the form of jottings during and after activities in which the ethnographer participated or observed. Jottings were quick notes handwritten in the field by the ethnographer while an event was ongoing or immediately after. These jottings focused solely on capturing the sociomaterial contexts of the representations being observed in activities with descriptive, nonevaluative language to prevent any value judgments from seeping into the data collected (Emerson et al., 2011).

In the courses studied, these jottings were weaved into the ethnographer’s own lecture notes. Similarly, in the workplace, jottings were weaved into meeting notes. This was done because notes from lectures and meetings are, in essence, jottings aiming to capture information so that it is not forgotten later (Emerson et al., 2011). Therefore, the ethnographer took notes as a student or EIT would in their respective environments to document information such as representations, presented by an instructor or engineer while also synchronously documenting the sociomaterial contexts wherein representations emerged. This provided the ethnographer with documentation explicitly connecting representations to sociomaterial contexts for later analysis. For example, if a student asked a question during lecture that led to the instructor drawing a representation to help answer the student’s question, the ethnographer would jot the instructor’s drawing and annotate it with the student’s question and instructor’s answer to capture as much of the sociomaterial context that yielded that representation in his notes.

To capture as much information as possible during his participation-observation, the ethnographer’s jottings were often written in shorthand and were indecipherable to others but aimed to provide enough detail for the ethnographer to recall significant aspects of an event later when creating field notes (Emerson et al., 2011). Field notes were the immediate follow-up to jottings and ensured that shorthand and abbreviations in the jottings were converted into full sentences and ideas while the ethnographer still recalled the meaning behind the jottings (Emerson et al., 2011).

This process of converting jottings to typed field notes allowed the ethnographer to stay close to the data, develop interview questions to fill in information he might have missed or did not fully understand in the jottings, and to identify artifacts that needed to be documented and included within each episode, thereby enhancing the credibility of data collected in the jottings (Emerson et al., 2011; Hammersley & Atkinson, 2007). Figure 2 shows an example of jottings from a workplace observation and their conversion to field notes with documented artifacts integrated and follow-up interview data added.

3.2.2 | Artifact collection

Artifact collection consisted of taking pictures of representations encountered during engineering activities (Hammersley & Atkinson, 2007). Typical items documented with pictures included sketches drawn by participants, screenshots of engineering activities being conducted on a computer, structural drawings, design aids and standards, homework and exam problems, and lab exercises. As previously mentioned, representations are dependent on sociomaterial contexts and, therefore, it was not only important to capture the material contexts with pictures but also to situate them within their social context (Johri, 2011). Thus, pictures were integrated into the field notes where appropriate to connect them with the social context documented in the field notes for later analysis. For example, if a field note episode was about using a design aid during one of the engineering activities at the firm, a picture of the design aid was copied and pasted into the typed field notes, making these episodes an annotated account of the sociomaterial contexts wherein the artifact is being used. Furthermore, social context extends beyond the particular episode wherein a representation is used, but also to how the user(s) understood and interpreted the representation (Johri, 2011). Accessing interpretations was done through interviews with participants.
3.2.3 | Interviews

The ethnographer conducted both informal and formal interviews with each engineer located at the workplace environment and with each instructor for the four courses. Informal interviews were also conducted and include spontaneous discussions with engineers, architects, students, teaching assistants, and instructors before, during, or after an activity. These informal interviews typically consisted of the ethnographer asking brief clarification questions to member check his jottings before converting them to field notes (Emerson et al., 2011; Walther et al., 2013). Formal semistructured interviews with engineers and instructors were recorded when the ethnographer had additional questions arise from the creation and analysis of field notes. These formal interviews were aimed toward one or more of the following goals: additional clarification, filling missing information in field notes, member checking, accessing participants’ interpretations, and/or assessing the reliability of the ethnographer’s interpretation of an event/artifact (Emerson et al., 2011; Guba & Lincoln, 1989; Walther et al., 2013).

3.3 | Data analysis

The analysis process began with the conversion of daily jottings into typed field notes (Emerson et al., 2011). Field notes were organized into episodes of distinct activities such as a lab exercise, office hour visit, or a design task assigned
to the ethnographer as an EIT. This resulted in 197 workplace episodes and 168 academic episodes. Each episode could then be used as a source of analysis for identifying themes in the sociomaterial contexts of representations across other episodes (Emerson et al., 2011).

The process of integrating documented artifacts and interview excerpts into their relevant episodes of the field notes served as a means for confirming or refuting the ethnographer’s initial description of an episode (Emerson et al., 2011; Hammersley & Atkinson, 2007). If a description of an episode was not agreed upon by the participants or research team, the data were examined again for re-interpretive analysis (Emerson et al., 2011; Walther et al., 2013).

Interviewing during and after the data collection process provided the primary means for confirming, modifying, or rejecting interpretations. The analysis of the interview transcripts was synchronous and grounded in the field notes and artifacts collected throughout participant-observation to prevent an overreliance on excerpts out of context (Johri, 2011; Walther et al., 2013).

Therefore, coding of the interview transcripts was iterative, with initial iterations seeking participants’ mentioning of certain representations and/or episodes that could be integrated into the field notes (Miles et al., 2014). These coded excerpts were then reviewed in tandem with field notes and artifacts to holistically describe emergent themes in the sociomaterial contexts of representations in both environments. These themes could then be confirmed, refuted, or revised in subsequent coding iterations and data collection (Emerson et al., 2011; Miles et al., 2014; Walther et al., 2013).

Within any given episode, several conceptual representations were present and could be delineated in a multitude of different ways. For example, an episode of a lecture could entail several conceptual representations for multiple concepts. Within the hundreds of episodes documented, there were countless concepts and representations depending on the level at which one concept was delineated from another within a single representation and whether multiple related representations were counted together or independently. Also, not all concepts were equally represented across environments due to different academic goals in each course and depending on the nature of work encountered in the workplace. Therefore, it was not only important to identify concepts that were adequately represented in all environments, but that could also be considered a prevalent concept in structural engineering regardless of environment. The structural engineering concept identified by the researchers as best fitting these criteria was the concept of loads. Loads are the forces that structural engineers design structural systems to resist. Examples include a structure’s self-weight (dead loads), occupancy (live loads), and environmental loads (e.g., snow, wind, and earthquakes). The concept of load is ubiquitous to structural engineering activities because the essence of a structure is to support and/or resist loads. Given that loads, as a concept, emerged in both the academic and workplace environments, and is ubiquitous to other structural engineering environments, it served as the concept of interest for this study because of its transferability (Guba & Lincoln, 1989). Thus, the analysis of the episodes focused on identifying themes in the sociomaterial contexts that conceptual representations of loads were tangible to.

Lastly, as ethnographies focus on specific cultures and their unique attributes, the goal is to frame findings in a way that is meaningful to external customers (e.g., the engineering education community) by guiding future research and positioning findings within broader contexts and the existing literature (Godfrey & Parker, 2010; Walther et al., 2013). Thus, we aimed to enhance the transferability of this research to other engineering environments by defining tangible traits of the sociomaterial contexts of representations in our findings so that others can assess how and to what extent our tangible traits are transferable to broader contexts and within the existing literature (Guba & Lincoln, 1989; Walther et al., 2013). By tangible traits, we mean the themes identified in how concepts were represented across sociomaterial contexts.

4 | FINDINGS

Conceptual representations of loads were found with varying degrees of tangibility in both the workplace and academic environments. Representations that were more tangible were found to be situated within and distributed across three tangible traits: (1) real-world conditions; (2) project/stakeholder constraints; and/or (3) engineering tools. For example, in the workplace environment, loads were determined and represented through real-world conditions (e.g., material weights, snow, and/or earthquakes), project/stakeholder constraints (e.g., architectural requirements and/or framing options), and engineering tools (building codes, standards, and engineering drawings). We recognize that the term “real-world” is often used in nebulous ways that may cause confusion. To be clear, by “real-world,” we are strictly referring to conditions in which quantifiable values derive their magnitudes from actual physical phenomena.
In the following two sections, we will present four representations from the workplace environment and four representations from the academic environments. The workplace representations presented were chosen to provide examples from both observational and participatory episodes that exhibit all three tangible traits. The academic representations presented were chosen to provide a range of examples from each course, different sociomaterial contexts such as homework assignments, exams, recitations, and lectures, and exhibiting various degrees of tangibility to the three traits.

4.1 Representations in the workplace environment

One of the most common engineering tools observed representing loads in the workplace were structural and architectural drawings. Figure 3 (Workplace Example 1) is an example from the workplace of a roof framing plan illustrating additional loads along the perimeter due to snowdrift and ballast loads.

The additional snowdrift and ballast loads represented in the legend and on the roof framing plan in Figure 3 (Workplace Example 1) were determined by a structural engineer and could then be used to analyze and design the roof framing. The structural drawing presents loads in a way that is tangible to real-world phenomena (e.g., snow and ballast loads), identifies previous project/stakeholder constraints that influenced the roof framing plan and location of the additional snowdrift loads (e.g., column spacing and parapet locations, respectively), and an engineering tool (the structural drawings that they are represented on). Thus, the drawings are a representation of where the loads were sourced and illustrate how the loads are tangible to workplace sociomaterial contexts.

Loads were not always explicitly represented on a drawing, but the ability to read and interpret drawings was still necessary in the workplace environment to obtain magnitudes and locations for certain loads. Figure 4 (Workplace Example 2) shows a wall and post on a floor plan that the ethnographer participated in analyzing to ensure the wall and post’s footing could support the loads of the floor above being converted to a mezzanine.

Thus, the loads used to assess the demand on the post, wall, and footing were tangible to the real-world live and dead loads for the mezzanine and structural framing, the project/stakeholder constraints dictating the function of the space (converting to a mezzanine), and to engineering tools including a referenced standard for quantifying loads (American Society of Civil Engineers (ASCE), 2008, ASCE Standard 7-10) and the drawings presented in Figure 4.

**Figure 3** Workplace Example 1: A roof framing plan illustrating additional snowdrift and ballast loads along the perimeter of the building
This exercise of using drawings to determine how much load is distributed to various structural elements is referred to as tributary area. In an interview with one engineer, she described determining tributary area for loads as one of the main reasons she utilizes drawings:

The work I'm doing frequently on plan sets is finding tributary areas, so if you think of tributary area as a concept, you use a plan set to figure that out, so you can then figure out your loads.

The spacing of beams and columns in framing plans influences their tributary area, and these spacing dimensions were sometimes initially determined with the architects and architectural drawings at the workplace. Figure 5 (Workplace Example 3) shows a common practice observed in the workplace environment wherein an initial framing plan was drawn on tracing paper over an architectural drawing.

When asking one of the structural engineers in an interview about this process of tracing framing plans, he said the following:

When you're switching between beams and columns, you can see that distributed load on a beam ends up in two reactions. Those reactions are actually going somewhere, they need columns beneath them to support it. Beneath that you need a footing to support that. Tracing loads down with trace paper ... we do it a lot in schematic design when the architects will bring a building layout and we have to find out where we can put columns and then come up with a framing plan.

Thus, the architectural drawing themselves are not a representation of loads, but the sociomaterial context of the architectural drawings influences the engineers' framing plan and its loads. This process of determining a framing plan with the architects and architectural drawings, therefore, made the structural engineers' representations of loads more tangible to the real-world load quantities based on the tributary areas of the elements in the framing plan, the project/stakeholder constraints of the architect's and their plans during schematic design, and the engineering tool of the tracing paper and architectural drawings to create a viable framing plan.

In another workplace episode, the ethnographer was participating in the design of steel stringers for a staircase, and this activity exemplifies the workplace sociomaterial context of keeping different load types (e.g., dead vs. live) separate in their representations. It was important for the ethnographer to keep the dead and live loads separate when determining the support reactions at the upper and lower ends of the stringers because these loads would transfer into the...
base connections, landings, and subsequent structural elements. These subsequent elements may have to support other loads and could be governed by different load combination equations than the one used to determine the demand on the stringers. Figure 6 (Workplace Example 4) shows an FBD that the ethnographer drew to analyze the demand on the stringers due to the live and dead loads.

Some of the calculations shown in Figure 6 (Workplace Example 4) illustrate the ethnographer keeping the vertical support reactions due to the dead and live load separate at the upper and lower end of the stringers (e.g., $R_{uDL}$ = The upper vertical support reaction due to dead load [DL]). These support reaction loads were then used to determine the demands on the connections and landings at the upper and lower end of the stringers. By keeping the loads separate, they had a greater degree of tangibility to the history of the design effort so that the engineer responsible for the design of the subsequent structural elements had a better idea of where the loads acting on those elements were sourced. By being tangible to the history of the design effort, this representation is tangible to the three traits. The loads were tangible to the real-world conditions of the separate live and dead loads. The magnitude, direction, and location of these separate loads are tangible to the project/stakeholder constraints dictating the size, location, and function of the stairs. Lastly, the engineer who designs the subsequent supporting elements will reference the engineering tool of the ethnographer’s FBD and calculations shown in Figure 6 (Workplace Example 4) to maintain a consistent history of the design effort.

The following excerpt from an interview with one of the structural engineers further illustrates the importance of keeping the values of different load types separate throughout a design to maintain this tangibility to the three traits.

**Engineer:** You go through it [a design] a couple of times and you have to go back and break apart a [load] value you’ve been using for your whole calculation. You do that a couple times and you learn that, okay, I just need to keep these [loads] separate.

**Ethnographer:** It’s worthwhile to do that?

**Engineer:** Well there are different load combinations that apply, right? So am I looking to maximize the uplift on my footing? Okay, well that’s one load count though. Am I looking to maximize the compression...
on my footing? Okay, well it's a different load count though. One of those has live load in it, and one of those
doesn't have live load in it, and they have different factors on the dead loads, and with the same factors on
the earthquake loads. So yeah, you learn, you make the mistake and then you just don't do it in the future.

In this excerpt, where the engineer refers to load count, he is referring to different load combination equations. Load
combination equations account for the variability in quantifying certain load types and the probability that various load
types occur simultaneously. The various combinations are provided in multiple engineering standards and design aids,
making them a load representation tangible to these engineering tools.

The excerpt finished with the engineer stating how you learn from the “mistake” of combining load types at the
onset and then having to go back and decouple them because of how load combinations change throughout the
analysis of various subsequent elements in a structure’s load path. Thus, keeping loads separate in representations
was a bookkeeping practice of sorts that makes loads more tangible to their original source in the real-world condi-
tions, project/stakeholder constraints of the various structural elements in the load path and the analysis they
require, and the engineering tools of standards that dictate which load combinations are applied throughout the
design of a structure.

Aside from loads, many other concepts were represented through and became tangible to the diagrammatic nature
of FBDs and structural/architectural drawings. Structural and architectural drawings conveyed meaning, specifically
design intent, and thereby helped structural engineers represent many different concepts to other structural engineers
and project stakeholders when working through a design problem. Loads can be explicitly represented in drawings
(as shown in Figure 3, Workplace Example 1) or implicitly as a result of the framing plan (Figures 4 and 5, Workplace
Examples 2 and 3). Figure 6 (Workplace Example 4) demonstrates how loads are represented through FBDs and calcu-
lations of load combinations equations to assess demand on structural elements. In each of these examples, the loads
used in design and analysis were entirely tangible to real-world conditions, project/stakeholder constraints, and engineering tools. This was not always the case for how loads were represented in the academic environments.

4.2 Representations in the academic environments

Loads in the academic environments were observed to be represented with various degrees of tangibility to the three traits. To demonstrate this range in tangibility, Figure 7 (Academic Example 1) shows a representation that was more tangible to the three traits than the other academic representations presented in this section.

Figure 7 (Academic Example 1) displays a recitation exercise from the structural theory I course. For this exercise, students were required to determine the magnitude of the live load from reading and identifying the relevant framing plan notes listed on the far left of Figure 7 (Academic Example 1), and then measuring the dimensions of the framing plan to trace how much of this load would be distributed to various beams, girders, and columns on the zoomed-in framing plan (right image in Figure 7, Academic Example 1). Thus, the loads represented in this exercise were tangible to real-world conditions (live loads for the building their class was in), project/stakeholder constraints (the structure's existing framing and function), and the structural drawings/notes (i.e., engineering tools) for the classroom.

When the structural theory I instructor was asked in an interview why he incorporated drawing sets in his course, he replied:

You have to be able to do it [read drawings]. That's the prime way that structural engineers communicate with their designs.

Here the instructor expresses his opinion that structural drawings are a significant sociomaterial context that engineers operate within in the workplace environment and that he has students engage with concepts represented through drawings to learn how to read them. This instructor's emphasis on drawings and the weekly 2-hour recitation period this course provided were sociomaterial contexts of this academic environment that enabled such opportunities for students to learn the concept of loads in a more tangible way to the workplace environment.

![Figure 7](academic-example-1.png)

**Figure 7** Academic Example 1: A structural floor framing plan (left image) and conceptual representation of load path—arrows pointing to where the load goes from the floor deck to various beams and columns—drawn over a zoomed-in portion of the floor plan (right image). Drawing the arrows illustrating the load path on the right image was part of a recitation exercise for the structural theory I course.
Figures 8 (Academic Example 2) and 9 (Academic Example 3) are examples of representations of loads with lesser degrees of tangibility to the workplace tangible traits than Figure 7. In a homework problem from the reinforced concrete design course (Figure 8, Academic Example 2), students were given the dead and live load acting on a beam and asked to determine the flexural demand ($M_u$) on the beam as a result of these loads.

The given loads for the problem in Figure 8 (Academic Example 2) were to some extent tangible to the real world because they were distinguished by their load type (dead vs. live). This representation was also somewhat tangible to project/stakeholder constraints via the information provided in the problem statement as well as in the practice of engaging students to determine total dead load by calculating the self-weight of the beam from its existing dimensions. The factored (combined) load that the students were asked to calculate was also tangible to engineering tools because students were required to determine appropriate load combination for the dead and live loads from an engineering standard (American Concrete Institute (ACI), 2014, ACI 318-14).

A braced frame problem from an exam question in the steel design course (Figure 9, Academic Example 3) explicitly defines where the loads acting on the frame came from and subsequently asked students to determine the axial force acting on one of the columns.

In the FBD of the braced frame presented in the exam problem (Figure 9, Academic Example 3), the vertical loads were explicitly defined as dead and live loads and the lateral load was explicitly defined as an earthquake load, making them somewhat tangible to real-world conditions. To solve this problem, students had to keep these loads separate and determine how each one individually contributed to the axial demand of column B. By keeping the loads separate, the students were then able to determine the appropriate load combination for determining the axial compression load acting on the column. Furthermore—even though the students were not asked to do this on the exam problem—it would be important to keep these loads separate for other reasons such as if they were required to determine the demands on the left column, diagonal brace, connections, and/or or foundations supporting both columns. Thus, not only were the loads provided in this problem more tangible, the resulting answer was subsequently more tangible as well. The very act of keeping loads separate as they flow through a structure innately created the paper trail of tangibility to the real-world conditions and project constraints of the structure/problem.
In an interview with the steel design course instructor, she noted the distinction of when to keep loads separate and when to combine with load combinations and how the sociomaterial contexts of some problems can miss this distinction:

There are applied forces versus internal forces versus reactions, and the load combinations are really for those internal forces. They’re not for the applied forces. It’s the demand on a member by member level, different combos that cause the maximum tension force in a column, and the reason they [students] think to combine the applied forces right away is because they typically just see a simply supported beam.

This excerpt illustrates an important distinction between the representations in Figures 8 and 9 (Academic Examples 2 and 3, respectively) and their tangibility to the three traits. While both present loads separately and subsequently ask students to use the appropriate load combination to determine their demands, Figure 8 (Academic Example 2) is a simply supported beam in isolation from other structural elements, allowing students to combine loads at the outset of the problem. Contrast this with Figure 9 (Academic Example 3), where the element of interest (column B) is part of a braced frame, and thus requires loads to be kept separate while determining their load path to the column before combining with the appropriate equation. Thus, Figure 9 (Academic Example 3) is more tangible to the real-world conditions of how the different load types flow from element to adjacent element. Figure 9 (Academic Example 3) is somewhat tangible to project/stakeholder constraints because the implied purpose of the braced frame is to resist the lateral earthquake load, and thus the need for the brace influences how the different load types act on column B. The representation could be made more tangible to project/stakeholder constraints by explicitly stating this purpose of the truss within an overarching structure/project similar to how Figure 8 (Academic Example 2) does in its problem statement. Lastly, solving the problem in Figure 9 (Academic Example 3) does require using the appropriate load combination from a design manual or standard. Also, by having to keep more loads separate throughout the problem, there are more combinations to consider for the demand on the column than the demand on the beam in Figure 8 (Academic Example 2), making Figure 9 (Academic Example 3) more tangible to these engineering tools.

While the representation of loads in Figure 9 (Academic Example 3) could be made more tangible to the three traits by explaining how the magnitudes were derived from real-world conditions and/or project stakeholder constraints, or...
even having students use engineering tools such as the standards for determining the load magnitudes; the sociomaterial context of this being an exam problem for a steel design course limits the scope of the representation to allow students time to solve the problem and focus the problem’s evaluative purpose.

In all four courses, loads were often given with no explanation for how they were determined, limiting their tangibility to the three traits. Exemplifying this was an example problem used during a lecture for the structural theory II course (Figure 10, Academic Example 4). In this example problem, the instructor demonstrated analyzing a braced frame by determining the forces on the diagonal braces and at the base supports due to vertical and lateral loads.

The instructor was demonstrating with this example how to determine the axial forces acting on the braces and the necessary vertical and horizontal reactions at the supports (A and D) due to the 20 kip (1 kip = 1000 lbs) lateral load and two 10 kip vertical loads. As none of these loads were explicitly defined as dead, live, earthquake, wind loads, they were not tangible to real-world conditions or project/stakeholder constraints, and the only engineering tool they could be considered tangible to was the FBD provided in the example. This results in the subsequent forces being calculated for the braces and the supports being less tangible to the three traits. In the workplace environment, these loads would need to be defined based on their type and kept separate to analyze the brace elements and foundations beneath the supports at A and D with the appropriate load combinations. That being said, the sociomaterial context of this example problem was to demonstrate how to interpret and simplify the FBD to determine how the vertical and lateral loads flow through the braces and down to the supports.

Based on the representations presented above, the significance of our findings is in the sociomaterial contexts described by the three tangible traits (real-world conditions, project/stakeholder constraints, and engineering tools) that can be used to assess a representation’s tangibility to the sociomaterial contexts of engineering practice. While we prescribed these traits to the representation of loads, they can be defined more broadly so as to be useful for other conceptual representations in structural engineering and other disciplines. For instance, real-world conditions are the physical phenomena that give numerical values their magnitude, locations, and/or direction. Project/stakeholder constraints are any preexisting or emergent constraints associated with the project requirements or stakeholder requests that bound and guide an engineering problem. Engineering tools are the artifacts practicing engineers use and/or create to aid them in solving an engineering problem.

Overall, the representations presented above demonstrate how representations of the concept of load can be made more or less tangible to the engineering workplace through the tangible traits of real-world conditions, project/stakeholder constraints, and engineering tools. The load representations situated in the academic environments had varying degrees of tangibility ranging from having none, some, or all the tangible traits. In the workplace environment, load representations were never provided without some degree of tangibility and always had to be formulated by an engineer at some point based on some or all three tangible traits. Conversely, load representations in academic environments were often provided to students, thus yielding less tangibility to the three traits. While the sociomaterial contexts

![Figure 10](image-url)  
**Figure 10** Academic Example 4: An example problem for analyzing a braced frame experiencing both vertical and lateral loads from the structural theory II course.
of academic environments sometimes dictate the extent to which representations can be made more tangible to the workplace environments, the more tangible examples presented above demonstrate some simple practices that can be easily implemented to make representations more tangible to the three traits. This is discussed further in the following section.

5 | DISCUSSION

The notion that academic problems in engineering education often do not resemble the types of problems engineers encounter in the workplace has been well established in previous engineering education research (Jonassen et al., 2006; Litzinger et al., 2011; Newstetter & Svinicki, 2014). We sought to build on this previous literature by exploring the academic and workplace environments of a specific engineering discipline to provide a more nuanced and descriptive understanding of differences across these environments that emerge through conceptual representations. From this exploration, we were able to more broadly define three tangible traits for describing how conceptual representations were tangible to engineering workplace sociomaterial contexts that engineering instructors could use as identifiers for making their curriculum more tangible to engineering practice. These three traits were real-world conditions, project/stakeholder constraints, and engineering tools. Within our own thematic analysis of the sociomaterial contexts in the workplace episodes, these three traits broadly describe how a representation was tangible to workplace sociomaterial contexts while also being related to the findings from existing research presented in the literature review (Bornasal et al., 2018; Gainsburg et al., 2010; Stevens et al., 2008). For example, real-world conditions can be defined as information within a representation that is not theoretical or abstract and is similar to how Stevens et al. (2008) describe “real world” conditions. Project/stakeholder constraints are the impelling factors either innate to the project or imposed by stakeholders that influence a representation and is similar to Bornasal et al. (2018) observations of engineers applying conceptual knowledge within project constraints and negotiations with other engineers and stakeholders, and how Gainsburg et al. (2010) describe different phases of projects influencing the different types of knowledge engineers use. Finally, engineering tools are the material objects engineers leverage or create themselves to represent concepts and is similar to Bornasal et al. (2018) observation of engineers applying conceptual knowledge through material resources and Gainsburg et al. (2010) description of “design tools” as a type of knowledge engineers use.

As students engage in engineering activities using representations less tangible to these three traits, their ability to apply these representations in engineering problem-solving may be exclusive to academic scenarios, thereby limiting their ability to navigate and leverage similar representations within the sociomaterial contexts of the workplace (Brown et al., 1989; Johri & Olds, 2011; McCracken & Newstetter, 2001). It could be reasonably inferred that representations of loads with less tangibility to the three traits do not prepare students to think critically about where loads come from and how they permeate throughout the design of an entire structure. For example, when load values are just given with no information as to where they come from, students may not develop a quantitative sense of common, reasonable, and/or acceptable values for certain loads. We potentially limit the opportunities of their academic training to simultaneously develop engineering intuition for sensible load values with representations that are less tangible to the three traits (Aparicio & Ruiz-Teran, 2007; Barner et al., 2021).

Representation of concepts less tangible to workplace environments, however, may be the result of typical learning outcomes, structure of academic courses, and the purpose assigned to conceptual representations in academic environments. This was evident in the academic courses studied herein. The two structural theory courses studied are primarily focused on teaching structural analysis and, therefore, dedicate significantly more time teaching students how to determine the effects of loads on structures rather than determining the loads acting on the structures. The steel design and reinforced concrete design courses are primarily focused on design and, therefore, dedicate significantly more time teaching students how to design safe and economic structures for resisting loads and their induced effects rather than determining those loads acting on the structures.

Furthermore, often the activities within these courses and other engineering courses are introducing single or a limited number of concepts at a time and are meant to give students initial exposure and practice with those concepts in an isolated, simplified manner, which inevitably leads to representations less tangible to the three traits. By simplifying, or reducing, the workplace sociomaterial contexts of these activities, instructors can expose students to more and a wider variety of activities (example problems, homework problems, lab exercises, etc.) so that students are provided with multiple opportunities to practice each concept. For example, the homework problem presented in Figure 8 (Academic Example 2) is meant to give students practice analyzing the
beam that is already designed for them and assessing if it is sufficient in carrying the given applied loads. Asking students to determine those applied loads and then keeping the loads separate so that they could be then used to determine the demand on the columns supporting the beam is beyond the scope of the problem. Asking students to do this would make the problem more robust and authentic to design activities in practice, but would take longer and potentially limit the amount of practice and exposure the students get with other beam design and analysis problems and concepts.

Thus, it is not surprising that academic representations are not always tangible to workplace engineering sociomaterial contexts, but what is interesting is how academic representations differ from workplace representations. The goal of this research was to understand how representations differed across these environments based on their unique sociomaterial contexts and then describe ways that academic representations could be made more tangible to workplace sociomaterial contexts.

Viewing conceptual representations as influenced and shaped by the sociomaterial contexts in which they are applied requires framing conceptual knowledge beyond the individual (Johri & Olds, 2011; Stevens et al., 2008; Streveler et al., 2008). This study engages learning and application of knowledge from this perspective, both theoretically and methodologically. Situated cognition has offered the framework for identifying the influence differences in the sociomaterial contexts have on cognition (Johri & Olds, 2011; Newssetter & Svinicki, 2014). Ethnography offers a means for accessing these sociomaterial contexts firsthand, allowing for more authentic insights into the phenomenon of situated cognition. Situated cognition and ethnography are not new to the engineering education research community, but they are theoretical and methodological frameworks, respectively, which complement one another in powerful ways that have received limited attention (Case & Light, 2011; Johri & Olds, 2011). Simply put, as situated cognition argues that knowledge is bound to environment, then what better methodology complements this perspective than ethnography, wherein researchers embed themselves in environments of learning and practice as participant-observers? The authors argue that such a marriage in theoretical and methodological frameworks has been underutilized in engineering education research for a field that has frequently recognized the value of the situated cognition perspective on learning (Johri et al., 2014; Johri & Olds, 2011). If knowing is truly inseparable from doing, then research on engineering education and practice could benefit from the unique approach of methodologies that combine emic and etic perspectives in both education and practice environments. This methodological approach provided a meaningful way of understanding and describing workplace sociomaterial contexts with specific tangible traits to identify how concepts in education can be represented in more authentic sociomaterial contexts to engineering practice. From this theoretical and methodological framework, tangibility of representations was found to be a means for comparing the sociomaterial contexts of conceptual representations across academic and workplace environments, and offers a framework for leveraging fundamental concepts represented in school toward utilization in practice by framing them within certain tangible traits.

Tangibility may sound similar to relevancy—the idea that if something such as a representation is useful in performing a task, then that thing is relevant to that task (Hjorland & Christensen, 2002). Tangibility differs in that it is not about the utility of a tool or representation toward a task but instead focuses on grounding the abstract notion of concepts to specific sociomaterial contexts. Therefore, tangibility of representations can be further defined in terms of not only relevance and utility but also in its relationship to specific sociomaterial contextual traits of engineering practice. The findings from this study indicate that the representations of loads in the workplace environment were more tangible to the traits of real-world conditions, project/stakeholder constraints, and engineering tools; however, future studies could employ similar methods in other engineering environments to confirm or refute the broader application of these traits and/or define new ones.

Additional future research could seek to understand how representations more tangible to the workplace could be developed for academic environments and contribute to students’ learning. For example, students could be interviewed or surveyed immediately before and after an internship experience to assess whether they develop a more tangible understanding of certain concepts as a result of the internship. Future research could also use similar ethnographic methods to access the representations engineers use within the sociomaterial contexts of practice while utilizing the interview component of ethnography to elicit the practicing engineers’ thoughts and ideas on how the representations they engage with could be developed for academic environments. Such a method aligns with situated cognition by leveraging the situated mind of the practicing engineer for curriculum development in relative real time with practice, compared with asynchronous surveys or focus groups where engineers’ suggestions are provided in isolation from their engineering work (Johri et al., 2014).
5.1 Recommendations

So how can instructors and curriculum improve the tangibility of loads to enhance the utility of the student’s academic experience in preparing them for the workplace? How do we balance valuable time in class for other course outcomes? The following recommendations are presented in order of their ease of adoptability for instructors into their existing curricula. To start, some of the academic examples presented above demonstrate ways for integrating greater degrees of tangibility to the structural engineering concepts students engage with during problem-solving. For example, integrating drawings provided students with greater exposure to tangible load representations through engineering tools, real-world conditions, and project/stakeholder constraints so that loads are less likely to be a nebulous concept when they enter the workplace (Lemke, 1997; McCracken & Newstetter, 2001; Trevelyan, 2019).

Another example of tangible representations that aligns with workplace practices is to represent loads in an FBD as itemized values (i.e., explicitly defined as a dead load, live load, or an environmental load). Furthermore, instructors could consider the size, location, and purpose of the structure the FBD is representing to conceptualize a sensible magnitude for the load type acting on the structure. This simple addition to any representation of load adds no additional time for the student in solving the problem but increases their exposure to different load types and relative magnitudes. Another relatively efficient practice to implement is to reinforce the practice of keeping loads separate throughout and briefly demonstrate how these separate loads transfer to subsequent elements. Combining loads for any element of interest is then a simple matter of arithmetic and can be demonstrated in a short amount of time.

A somewhat more time-intensive but valuable pedagogical activity is exposing students to workplace sociomaterial contexts and activities through projects entailing design and analysis of full structures. Of the courses included in this study, one included a term-long building design project and another had two smaller projects wherein one dealt with quantifying and locating all the potential loads acting on a structural system. Projects in structural engineering education could revolve around students working in groups to design all the columns and beams (and perhaps other structural elements depending on time) for a low-rise building throughout an entire term. This process would expose students to quantifying and locating all their different loads and keeping those loads separate as they move through designing the elements from the roof down to the ground floor, and perhaps even do some preliminary analysis on the foundation elements. Providing students with preliminary architectural drawings for the structure as their starting point would allow students to gain experience reading drawings and grappling with various architectural constraints such as floor heights and clear space, which further enhance the tangibility of their loads and other structural engineering concepts by connecting them to project/stakeholder constraints and engineering tools. Such project-based learning has been demonstrated to better prepare students for the workplace environments they will encounter as professionals (Prince & Felder, 2006; Thomas, 2000).

Provision of tangible representations such as structural plan sets of actual structures and subsequent use of those representations throughout a course may also be beneficial for students. Instead of textbook problems that ask students to analyze and/or design beams, columns, and frames in isolation, the instructor could assign analysis and design problems of actual beams, columns, and frames that could be found in the structural drawings. This would expose students to reading and interpreting structural drawings to determine loads and boundary conditions on their FBDs. Such a practice could also expose students to complexities of design induced by project/stakeholder constraints like architectural changes that require them to go back and reevaluate their loads and demands on previously designed structural elements and determine whether they need to be redesigned. In this way, loads as well as other structural engineering concepts would always be tangible to real-world conditions, project/stakeholder constraints, and engineering tools.

These recommendations are, however, all focused around structural engineering education, but it is important to frame the value of our findings within the broader engineering education community. The idea behind tangibility is not unique to the concept of loads. All concepts can always be represented with some degree of tangibility to the three traits. For example, engineering problems given to students in other disciplines can be made more tangible to the workplace by contextualizing any given numerical value within real-world conditions, project/stakeholder constraints, and/or deriving from an engineering tool as opposed to those values being given as an arbitrary number and unit (Brown et al., 1989; McCracken & Newstetter, 2001). This is not to say that the more abstract representations have no purpose, but more of an argument for instructors to consider how concepts are represented after the initial abstract representation is introduced.

Another avenue that may make concepts more tangible to the workplace is to have problems framed from the perspective of stakeholder and project constraints. Often, problems are presented as isolated issues with set steps for answering the questions (Jonassen et al., 2006; McCracken & Newstetter, 2001; Stevens et al., 2008). By introducing
constraints (whether they are budgetary, spatial constraints, desires of stakeholders, etc.) that require the students to focus and define the steps of the solution as part of the problem-solving process, students may be able to identify how they can utilize their conceptual knowledge to solve engineering problems that go beyond the technical (Trevelyan, 2013).

Another potential avenue is in the implementation of design scenarios throughout the engineering curriculum. For example, in capstone courses, students are often assigned open-ended design projects that are provided and sponsored by industry. These industry representatives often engage with students throughout the design process, potentially exposing them to tangible representations of concepts to the sociomaterial contexts of engineering practice. Can and should this infusion occur at different levels of the curriculum before the capstone experience? Project-based learning (PBL) is one way of exposing students to the sociomaterial contexts of working on a holistic project (Prince & Felder, 2006), but not all projects in a PBL curriculum need to be of the same scale as a capstone project. Multiple smaller projects that implement to some extent some or all three of the tangible traits identified in this paper could be one way of gradually exposing students to more workplace sociomaterial contexts throughout the entirety of their engineering education so that the bulk of these contexts are not left to a singular capstone experience. Ideally, projects would have to incorporate more than isolated design problems, but aspects of practice and access to people and tools used in practice that can help increase the tangibility of the design problem to the three traits. One potential way of facilitating this is through learning management systems and/or forums wherein students can engage with and ask questions of practicing engineers about their design and engineers can share the tools they would use to solve similar design problems.

It is unrealistic to expect engineering curriculum to perfectly mirror the workplace and nor should it as all workplaces are different and not all students will end up at the same workplace. There is value in some degree of abstract curriculum to prepare students for the myriad of professions they might explore in their careers. This is the value behind exploring the workplace of different engineering disciplines because tangibility begins where the abstractness ends, and tangibility can be different depending on the workplace environment. Through such explorations, we can identify which tangible traits are common within and across disciplines and begin mapping where tangibility is a worthwhile pursuit in the curriculum.

6 | CONCLUSION

The purpose of this research was to explore in depth how loads, a core structural engineering concept, were represented in a workplace environment and multiple structural engineering courses. Previous research has broadly explored the engineering workplace, but little to no research has focused on exploring a specific engineering discipline within both academic and workplace environments for means of comparison. By exploring these environments within a specific discipline using ethnographic methods, we were able to provide a more nuanced description of the education–practice gap unique to structural engineering, but also provide potential value in the broader discussion of improving engineering education from a situated cognition perspective. Through this exploration, we developed the notion behind tangibility to express how the concept of loads was represented through tangible traits to sociomaterial contexts of the engineering workplace. Tangible traits provide explicit avenues for how academic representations can be brought in greater alignment with workplace sociomaterial contexts. It should be noted that the ways in which representations were described as being tangible in this paper are not exhaustive, and representations can be tangible in other ways that may be more or less unique to specific engineering disciplines. Therefore, we suggest that within a situated cognition framework, tangibility of representations be further explored within other engineering disciplines to better understand how, where, and when concepts can be represented in more tangible ways in the curriculum. Finally, the authors contend that ethnographic methods are well suited for understanding and promulgating the situated cognition perspective in engineering education that could be utilized more in future research.

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