Conceptual Representations in the Workplace and Classroom Settings: A Comparative Ethnography

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Abstract:

The following is a Theory paper that presents an ethnographic exploration into how concepts are situated in workplace and classroom settings. Situated cognition research demonstrates that different contexts wherein learning occurs and knowledge is applied shape our conceptual understanding. Within engineering education and practice this means that practitioners, students, and instructors demonstrate different ways of representing their conceptual knowledge due to the different contexts wherein they learn and apply engineering concepts. The purpose of this paper is to present themes on how practitioners, students, and instructors represent fundamental structural engineering concepts within the contexts of structural engineering design. By representation of concepts we mean the ways in which practitioners, students, and instructors portray and demonstrate their conceptual understanding of concepts through the social and material contexts of the workplace and classroom environments. Previous research on learning and engineering education has shown the influence that social and material contexts within these environments have on our knowing and understanding. The researchers use ethnographic methods consisting of workplace and classroom observations, interviews with practitioners, students, and instructors, and documentation of workplace and academic artifacts—such as drawings, calculations, and notes—to access practitioners', students', and instructors' conceptual representations. These ethnographic methods are conducted at a private engineering firm and in 300 and 400 level structural engineering courses.

Preliminary results indicate that instructors' conceptual representations in the classroom aim to enhance students' broader understanding of these concepts; whereas students' conceptual representations are focused towards utility in solving homework and exam problems. Practitioners' conceptual representations are more flexible and adapt to project and workplace constraints. These results seem to indicate that even when instructors emphasize broader conceptual knowledge, the academic incentives behind homework and test scores lead to more academically focused conceptual representations by students. Furthermore, practitioners' conceptual representations indicate the necessity of conceptual fluency in the workplace, which contrasts with the rigidity of conceptual representations that students develop in the classroom. This comparison between workplace and academic conceptual representations enhances our understanding of the extent to which students, instructors, and practitioners share similar or different conceptual representations within the domain of structural engineering. This, in turn, may lead to guided curriculum reform efforts aimed at better preparing structural engineering students for their professional careers.

Introduction:

Several studies of the engineering workplace have demonstrated a gap between engineering education and practice [1-4]. One reason for this education-practice gap is that "[t]oo 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" [5]. Another proposed reason for this gap is that engineering practice entails solving complex, ill-structured problems with knowledge that is distributed amongst other engineers and engineering tools; whereas engineering students are often trained to solve simple problems with little to no ambiguity using knowledge distributed amongst their instructors, textbooks, and peers [2, 4, 6]. Situated cognition theory offers a theoretical framework for studying this education-practice gap in engineering.

Situated cognition theory proposes that the social and material contexts wherein knowledge is learned and applied influences our ability to apply similar knowledge in new contexts [7]. Engineering education often focuses on transmitting conceptual knowledge to students in abstract formats with the intent of providing students a fundamental understanding of concepts so that they can apply these concepts to unique situations in their future coursework or engineering careers [5, 8]. Situated cognition challenges this ubiquitous notion of concepts and our ability to apply conceptual knowledge within novel contexts [5]. Perhaps then, differences in the social and material contexts of engineering practice and engineering education contribute to different conceptual representations in these settings and make up part of the education-practice gap. By conceptual representations, we mean the ways in which concepts are portrayed in social (dialogue) and material (artifacts) contexts.

Ethnographic methods provide a robust research method for exploring these social and material contexts that influence conceptual representations in professional and academic engineering settings. An ethnography is a qualitative research methodology that aims to gain deeper understandings of cultures by participating in and observing the social and material interactions of these cultures [9]. Thus, the researchers conducted ethnographic methods at a private structural engineering firm and in structural engineering undergraduate courses to compare the social and material contexts of these settings and how they influenced conceptual representations of fundamental structural engineering concepts.

Structural engineering students in the courses studied were exposed to many of the material resources that practicing structural engineers use in their daily work. The practicing structural engineers often had to negotiate the concepts represented in these material resources and their limitations. However, in the engineering curriculum studied, homework and lab exercises can sometimes over-simplify the concepts presented in these material resources and limit the potential for students to develop their own engineering judgment for more complicated applications of these concepts.

Background:

Conceptual knowledge is defined by Rittle-Johnson as the "understanding of principles governing a domain and the interrelation between units of knowledge in a domain" [10]. A "unit of knowledge" can be thought of as a specific concept, such as force or mass; and Newton's laws are an example of the interrelation between these units [11-12]. These relationships, "such as Newton's laws and the laws of thermodynamics, are part of conceptual knowledge in the engineering domain" and this conceptual knowledge "is central to the practice of engineering" [11]. While Newton's laws and the laws of thermodynamics are in some way important to nearly all engineering disciplines, each engineering discipline has their own unique and nuanced conceptual knowledge that distinguishes their respective disciplines from one another.

Concepts can be represented by more than just laws and equations, however. Especially with engineering, concepts can be represented by artifacts such as text, diagrams, symbols, etc., and these representations are influenced by the social and material contexts of engineering activities done in the classroom and workplace [7, 13-14]. An example of a common engineering activity is design and as Bucciarelli states: "design expertise is a matter of context" [6]. According to Lemke, "[i]n these activities, 'things' [materials] contribute to solutions every bit as much as 'minds' [social] do; information and meaning is coded into configurations of objects, material constraints, and possible environmental options, as well as in verbal routines and formulas or 'mental operations. […] Our 'cognition' is always bound up with, co-dependent with, the participation and activity of Others, be they persons, tools, symbols, processes, or things" [14]. This emphasis of social and material context as being an intrinsic part of cognition is one of the main points of situated cognition [7].

Therefore, it is worthwhile to explore the social and material contexts of the design activities performed by practicing engineers and engineering students. Understanding how these contexts might differ across the engineering classroom and workplace could illuminate potential avenues and best practices for bridging the education-practice gap. Ethnographic methods provide a well-suited methodology for exploring in depth the social and material contexts of the engineering workplace and classroom because these methods situate the researcher(s) within these contexts for an extended period of time.

Methods:

The ethnographic methods employed in this study consisted of field notes of activities participated in and observed, artifact documentation, and informal and formal interviews. The research sites where these methods were conducted were within a medium-sized structural engineering department at a private architecture and engineering firm, and in two undergraduate structural engineering courses offered at a large public university. Both the firm and university are located in the Pacific Northwest region of the United States. The researchers decided to focus on the discipline of structural engineering because the researcher conducting the ethnographies has experience in this field and therefore can act as a meaningful participant in both settings. Site selection for both settings was based on geographical access to the researchers and finding a firm and instructors that were willing to participate in the study [15]. While these settings will undoubtedly have their own unique cultures that do not represent all of structural engineering education and practice, this does not mean that we cannot enhance our understanding of the education-practice gap by focusing on depth over breadth and then situating our findings within existing research.

Data Collection

The data collected during both ethnographies will be field notes from participant-observation, interviews, and artifact documentation [16]. As a whole, these methods allow the researchers to triangulate the data to enhance the reliability of their findings [17-18]. Participant-observation in the workplace setting consisted of the ethnographer working part-time as an intern, assisting in structural design efforts, while also observing design efforts and meetings amongst the other structural engineers. The architecture and engineering firm that participated in the study specializes in design and retrofits of buildings in the commercial, industrial, and public sectors. The firm employs over 20 structural engineers with experience ranging from interns/new-hires to over 30 years of professional experience. The ethnographer worked at this setting for three months.

Participant-observation in the academic setting consisted of the ethnographer enrolling in undergraduate courses as an actual student so that they could actively participate with other students during lecture, labs, on homework, and in studying. The two courses used in this study were an introductory structural analysis course and an introductory steel design course. Both courses are commonly taken in the junior and senior years of undergraduate civil engineering students. These courses met three days per week for a one-hour lecture and one day each week for a two-hour lab. Each course had a term length of 10 weeks. The structural analysis course was taught by an instructor with over 30 years of experience teaching structural engineering. The steel design course was taught by an instructor in their first year working as a professor. Both instructors typically used lecture to introduce new concepts and work example problems, and used lab for group exercises and demonstrations.

The ethnographer wrote field notes on what they did and observed in these settings to capture as much detail in the moment. These field notes serve as an initial bearing for the ethnographer and frequently revisiting them provided the ethnographer with interview questions and what to focus on in later observations.

The ethnographer documented artifacts that they used or created in their participation and that they observed others using/creating. Artifacts were primarily documented through pictures and then integrated into the field notes where the artifacts were noted by the ethnographer during their participation and/or observations. These artifacts help ground the ethnographer's field notes to tangible, real-world objects that engineers, students, and instructors use to demonstrate their conceptual knowledge. The ethnographer also uses the artifacts to help facilitate interview questions so that participants may use the artifacts to aid in their explanations of concepts.

Formal and informal interviews were conducted with engineers, students, and instructors. Informal interviews occurred spontaneously in the field when the ethnographer had the opportunity to ask clarifying and follow up questions. Formal interview questions are developed for specific participants based on data collected in the field notes and served as a means for member checking the ethnographer's observations and interpretations [17].

Data Analysis

Data analysis for an ethnography occurs during and after data collection [16]. The ethnographer revisited their field notes after leaving the field site each day to stay close to their data and have it guide them each subsequent day in the field. Frequently revisiting the field notes provided the ethnographer with reminders of artifacts to document and questions to ask participants during interviews. Field notes, pictures of artifacts, and interview excerpts are then synthesized into narratives of activities for the purpose of comparing with narratives of other activities and identifying themes in the data. The ethnographer worked to create these narratives and begin identifying themes while still in the field so that they could continuously check the reliability of their themes and/or develop new ones as more data emerged [16-17].

Results

While many concepts emerged as relevant in both settings, for the purpose of this paper the authors' chose to focus on the concept of loads. Loads are the forces that structural engineers design structures to withstand, such as snow, wind, and seismic. Determining the magnitudes of these loads is an essential step for designing structures and was one of the most frequently documented concept in both settings. This section provides an example of how loads were presented and discussed in the workplace setting and in both course settings to illustrate broader themes about social-material contexts and conceptual representations in these settings.

Workplace Setting

In the workplace setting, structural engineers frequently used a standard published by the American Society of Civil Engineers (ASCE), called *ASCE 7: Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, for guidance in determining their loads. This standard provides prescriptive methods for calculating load magnitudes such as how many pounds per square foot snow places on the roof of a structure. During one design effort at the workplace setting, two engineers were discussing how to account for the amount of snow blowing over a parapet on the roof of a taller, adjacent structure and onto the roof of a lower structure they were designing. This concept of wind blowing snow from one structure to another is called snow drift and creates concentrated areas with larger snow loads on adjacent structures. ASCE 7 provides methods for determining the magnitude of this snow load when the snow drifts up against an adjacent structure, such as a parapet, but not for how much snow could drift up and over a parapet onto a lower adjacent roof. This lack of nuance in the standard caused the two engineers to question how much snow could blow over the parapet and pile up on their structure's roof below. These two engineers sought a more senior engineer's help on this problem and drew a picture (see Figure 1) to explain what they were dealing with. For additional context, Figures 2 shows the diagrams used in ASCE 7 for illustrating snow drift.

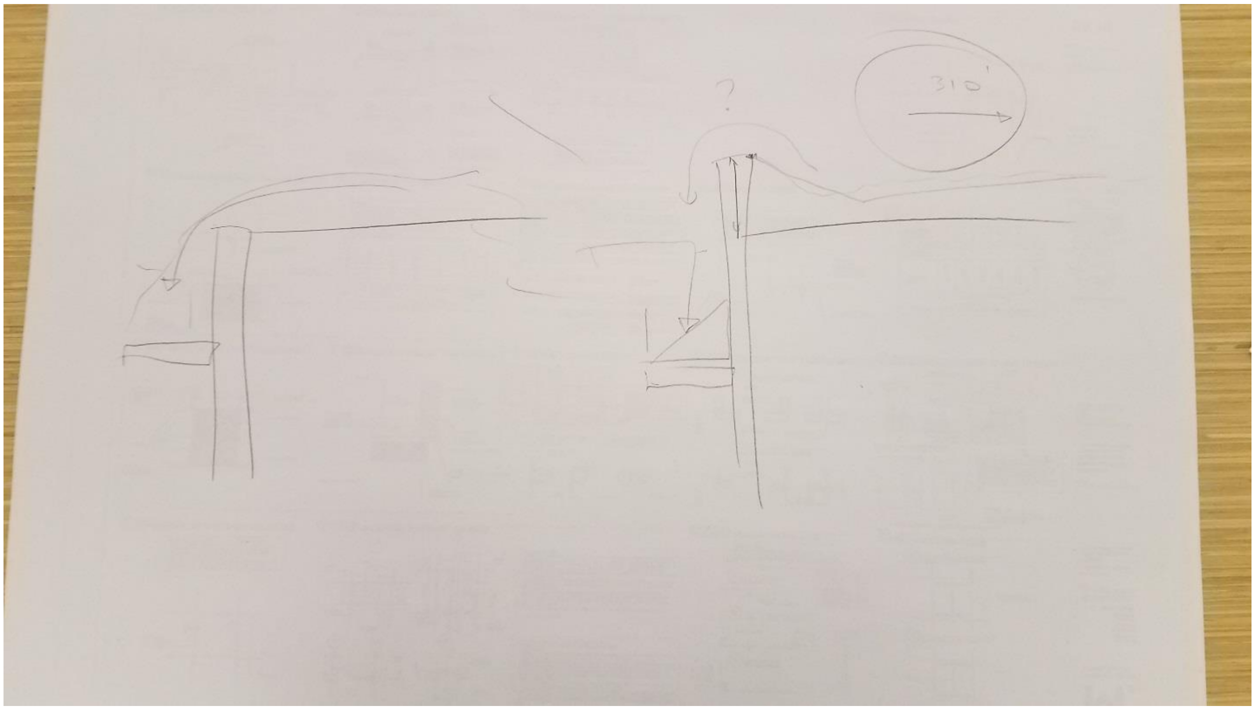

Figure 1: An engineer's sketch of snow drift. The left sketch is a diagram of how ASCE 7 presents snow drifting from a higher roof, without a parapet, to a lower one. The right sketch represents the additional nuance of the taller roof having a parapet, and the engineers being unsure how much snow could drift over the parapet and onto the lower roof.

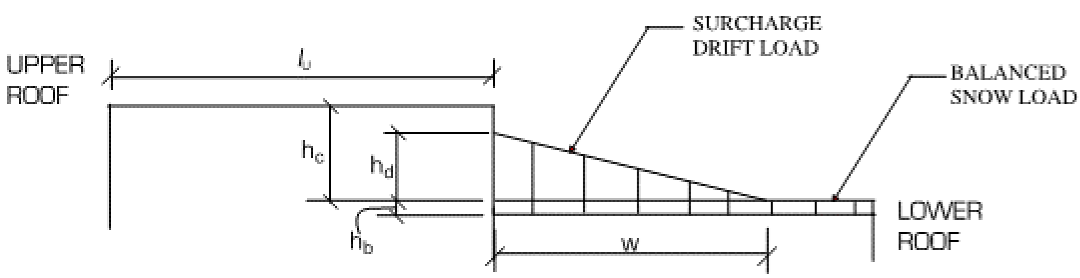

Figure 2: Diagram in ASCE 7 depicting the variables that go into accounting for snow drifting from an upper roof to a lower roof.

In a later interview with the more senior engineer, the ethnographer asked the senior engineer how they helped the other two engineers resolve this snow drift problem. The senior engineer said:

> *"They're [the other two engineers] hung up in the technical portion of it, which is how does the equation work. But the question they should be asking is: how does the principle apply here? Because the equation won't really answer that question. How do I apply drift blowing over a parapet down onto a lower roof? There are cases where you should do that, right? […] The trick becomes […] how can I convince myself as a professional that*

it's okay to say that this will not have drift on it? I gave you an example of where you shouldn't because it's [the lower roof] seven stories down, six in this case. […] There is no conceivable way for drift to get blown off the side of the building and fall straight down for seven stories and pile up the drift. […] If it has any horizontal force [from wind] at all, it's going to get blown further out. […] So I'm using my judgment when it's six stories down. When it's three stories would I make the same call? Maybe. When it's one story down? No. When it's one story down I put drift on it. There's a gray zone in there where I would have to question myself and either take a conservative approach or really justify to myself why, but the principle…it's not so much about what's the equation, it's what's the underlying principle behind the equation."

Here the senior engineer discusses the importance of understanding the underlying principles in ASCE 7 in order to be flexible in their application of the concepts represented in the standard and using it in tandem with their engineering judgment when dealing with more complex scenarios.

Academic Setting

In both structural engineering courses, students were taught the tools and procedures for determining snow loads on a structure. In the steel design course, students were assigned a group project for designing the structural steel elements of an office building and in one of their labs were expected to work with their groups to determine the snow loads on their roof. The exercise entailed having the students navigate portions of ASCE 7 to determine a variety of input values for calculating the magnitude of their flat roof snow load and the drift snow load formed from snow being blown up against a penthouse structure on the roof. The lab assignment is presented in Figure 3.

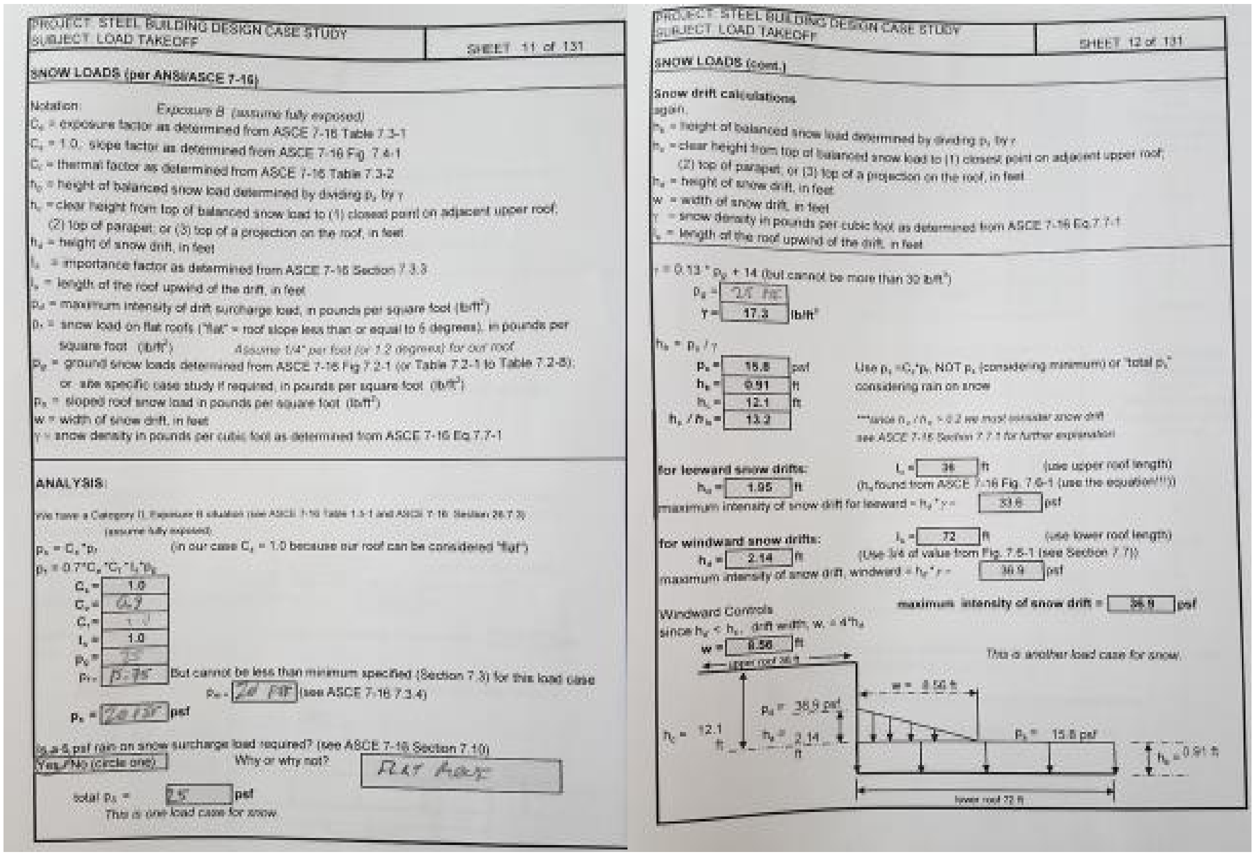

Figure 3: Load takeoff lab exercise for determining snow loads in the steel design course.

To complete this exercise, students were given print out sections of ASCE 7 relevant to determining snow loads. Students were expected to find the values for various variables pertaining to snow load equations in ASCE 7, write them in where relevant on the sheets shown in Figure 3 and work through the procedure outlined for them.

This exercise exposed students to the concepts presented in ASCE 7 that are relevant for determining snow loads and provided them with a relevant resource for navigating step-by-step through ASCE 7's procedure for determining flat roof snow loads and drift snow loads. The student group that the ethnographer worked with on this exercise often navigated the ASCE 7 printouts and filled out the sheets in Figure 3 on their own. Students checked their answers within the group each step of the way before moving to the next step. If everyone got the same answer, there was no discussion as they moved to the next step. If someone got a different answer or was unsure where a value was obtained, the students would discuss their interpretations of ASCE 7 and why that led them towards a certain value.

Having the students complete this exercise in groups, for an authentic structure, and using ASCE 7 aligns with many of the social-material contexts present in the workplace. However, the exercise requires little to no exploration of the underlying principles for calculating snow loads in ASCE 7 and becomes more of a plug-and-chug exercise for the students.

In the structural analysis course, students were given a homework problem for calculating snow loads on a high school roof in Portland, Oregon (see Figure 4). This problem required students to use and interpret sections of the Oregon Structural Specialty Code (OSSC), a document that practicing engineers in Oregon use in tandem with ASCE 7. ASCE 7 is not a required text for this course, and no handouts of sections of ASCE 7 were provided for students to solve this problem. Instead, pertinent sections of ASCE 7 to snow loading are referenced for the students to know where certain variables and their values are coming from, but with minimal explanation.

Problem #5:
GIVEN: Benson Polytechnic High School in Portland, Oregon. Assume that it has an ordinary flat roof with roof drainage not constrained (roof is able to drain).

FIND:
Design snow load for the roof (psf).

Notes:
- Determine latitude/longitude of this location using Google Maps or Google Earth, for example.
- Snow loads are determined using Section 1608 of the 2014 OSSC.
- Information from the Snow Load Analysis for Oregon published by the Structural Engineers Association of Oregon can be obtained from: http://snowload.seao.org/lookup.html

- Obtain the design ground snow load from this site.
- The Importance Factor for Snow Load, I_S =1.10, as found in ASCE 7-16 Table 1.5-2. A secondary school is in Risk Category III (from OSSC Table 1604.5) if the occupancy load is greater than 250. Benson HS has approximately 1000 students and faculty, plus staff.
- For flat roofs, the design snow load (on the roof) is given by:

a) Hibbeler Equation (1-5) (this is Eq. 7.3-1 in ASCE 7-16)
b) C_e = 0.9 (fully exposed roof in surface roughness B - urban area with numerous closely spaced obstructions) (Table 7.3-1 in ASCE 7-16).
c) C_t = 1.0 for heated building (Table 7.3-2 in ASCE 7-16)

Also, read the Map Usage Notes on Minimum Roof Design Snow Load and apply these as well. If the minimum is greater than the value from Hibbeler Equation (1-5) (this is Eq. 7.3-1 in ASCE 7-16), then the minimum applies. Lastly, include the rain-on-snow surcharge load if appropriate. Explain your logic in considering it.

Figure 4: Homework problem on calculating snow loads in the structural analysis course.

Similar to the steel design lab exercise, this homework problem required students to navigate some resources pertinent to structural engineering practice, but most of the problem statement provided students with the remaining inputs and the problem becomes a plug-and-chug process eliminating any considerable need for engineering judgment or thought behind the process.

Both the steel design course lab exercise and this homework assignment for the structural analysis course relegate important concepts pertaining to snow load determination to relevant codes and standards. These exercises help expose students to important resources that will be relevant to them in practice, but represent important concepts as rigid, procedural calculations that limit the opportunity for students to understand the principles behind these procedures and hone their engineering judgment.

It should be noted that the main focus of a structural analysis course is determining the demands on a structure as a result of loads and the main focus of a steel design course is learning to design steel structures with enough capacity to resist such demands. Neither course is meant to spend a considerable amount of time on determining the loads that act on structures. While these curricular constraints limit the amount of time that students can be presented to all the nuances of loads, such constraints should not lead to unresolved oversimplifications.

Discussion:

Previous studies of the engineering workplace have identified the collaborative problem solving and distributed knowledge amongst people and tools required in engineering practice to solve more complex problems than the simplified problems typically asked of students in undergraduate engineering education [2, 4, 19-23]. These studies focused on engineering more broadly and not all collected data from engineering classrooms for means of direct comparison. However, our ethnographic research of both workplace and academic settings for structural engineering specifically appear to echo similar findings.

One similar ethnographic study on engineering concepts in a transportation engineering workplace found the following five themes: 1) engineers identify project constraints before applying relevant technical concepts, 2) abstract concepts are contextualized to these project constraints, 3) engineers frequently negotiate meanings of concepts to enhance their own conceptual understanding, 4) concepts manifest in multiple representations in practice, and 5) engineers use material resources to efficiently address complex processes and problems associated with engineering concepts [8]. These themes echo our findings of the structural engineering workplace, implying that regardless of engineering discipline, practicing engineers engage with technical concepts in similar ways. This is promising for a field such as civil engineering because civil engineering students may end up practicing in multiple different sub-disciplines of civil engineering with vastly different technical concepts, but perhaps can all still be trained to engage with these concepts in similar ways.

This is not to say that engineering curriculum can entirely prepare each student for all the problems they will encounter in their career, but that there exist opportunities to enhance the ways students' engage with concepts to prepare them for the complexities and nuances of real-world engineering problems. Group design projects, such as the one used in the steel design course provide students with the opportunity to engage with concepts in similar social-material contexts as practicing engineers. Homework problems and lab exercises, however, that over-simplify engineering concepts into plug-and-chug procedures can make even hand calculations and design guides/manuals as much of a black box as software.

Conclusion:

The purpose of this research was to explore the social and material contexts that influence conceptual representation and understanding in the engineering workplace and academic settings for a specific engineering discipline—structural engineering. The education-practice gap in engineering is a well-documented phenomenon often attributed to some of the differences in these social and material contexts across academic and professional settings, such as the simplicity of textbook-type problems versus the complexity of real-world engineering problems. Little to no research has explored this phenomenon in-depth, in both settings, and in a specific engineering discipline to understand how context influences conceptual representations and subsequent understanding. Using ethnographic methods, the researchers were able to participate with and observe engineers and students in their various design related activities over an extended period of time to enhance our understanding of how differences in social-material contexts and conceptual representations contribute to the education-practice gap. Overall, structural engineers solve real-world engineering problems relying on a variety of material resources, but frequently discuss and negotiate their interpretation and utilizations of the conceptual representations in these resources with other structural engineers. It is important for structural engineering students to be exposed to these material resources so that they are aware of them and know how to use them when entering their careers, but curriculum that encourages students to engage with the limitations of these resources' conceptual representations may help develop their engineering judgment for handling the complicated problems encountered in the engineering workplace. The significance of these preliminary results suggests that there are differences between how students and practicing engineering interpret concepts embedded in material resources. We suggest that understanding more about how traditional engineering curriculum contributes to these differences can help educators find ways to improve students' understanding of concepts and the limitations of these concepts and the design codes associated with them.

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