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Board 376: Representation of Engineering Structures Concepts in Academic and Workplace Contexts

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Representation of Concepts in Engineering Academic and Workplace Contexts

Overview and research goals

There is broad evidence that engineers are ill-prepared for the workplace. One common assumption in engineering education is that if students know the concepts very well, they will be able to apply them in engineering practice. However, widely utilized and studied theories of situated cognition suggest that learning is highly contextual; we remember and organize knowledge based on how it was learned. This contradicts the assumption that conceptual understanding is of primary importance.

The goal of this study is to investigate the representation of structural engineering concepts specific to structural design in both civil engineering practice and academic settings through robust, in-depth, and iterative educational research methodologies. We achieved this goal with three aims. **Aim I** is to understand and compare the representation of structural engineering concepts in structural design within authentic workplace and academic settings. **Aim II** is to iteratively develop problems and solutions that structural engineers and faculty deem as authentic to building design and that faculty are willing to adopt into their curriculum, and to study this development process with a focus on barriers and affordance to adoption of authentic engineering problems. **Aim III** is to investigate the challenges associated with navigating intersecting identities in Civil Engineering, and how it affects civil engineering students and practicing engineers. The focus of this paper is on the ***second and third aims***.

Aim II

Engineering education research has identified and focused on the gap in preparedness of graduates for the workplace [1], [2]. Research has been devoted to identifying this gap and discovering why this gap exists [3]-[10]. Additional research has focused on ways to improve teaching practices through the development of a variety of teaching methods and curriculum modifications [11]-[17]. Civil engineering education research has focused on the differences and similarities between the engineering workplace and the academic context by comparing engineering practitioners and faculty and engineering practitioners and students. Results from this research has shown that workplace problems tend to be ill-structured and complex [18], engineers tend to spend more time than students with stages of the design process [9], students and engineers allocate their time differently across multiple representations when problem solving [8], [19], instructors and practitioners embed their knowledge in different contexts [20], differences exist between the conceptual understanding of engineering practitioners and students [5], [21] and there are distinct types of heuristics in the workplace and academic contexts [22].

Additional research has shown that learning and knowledge are situated in the social, cultural, and physical contexts in which it is created and used [20], [23]-[25]. This means that the engineering workplace acts as a social, cultural, and physical context that embeds learning and knowledge. In the 2019 study of 74 US civil engineering departments, Angela Bielefeldt concluded that “the percentage of licensed professional engineers among the CE faculty ranged from 12% to 100% with a median of 54%" [26]. This suggests that the civil engineering faculty without a professional license may lack the industry experience and, therefore, situated knowledge of a professionally licensed engineering practitioner. The intent of this research is not to imply that engineering faculty do not provide valuable and effective learning environments or that professional licensure should be a requirement for engineering faculty. Instead, this research suggests that one way to address this lack of engineering industry experience would be to work closely with engineering practitioners to develop more authentic contexts, design activities, related performance criteria, and other learning tools that share engineering industry experience and knowledge with educators and students.

Prior research has shown that there are educational benefits to more authentic contexts and problems through problem-based learning [27], project-based learning [25], capstone design courses [28]-[30] and supplementing course work with additional authentic engineering problems [13]. However, these approaches tend to be one-sided by either being developed by faculty or engineering practitioners rather than collaboratively [13]-[15], [17]. This study was motivated by prior research and the need to understand more about what engineering practitioners do and why they do it.

Faculty recognize the importance of innovations presented by research but are more likely to adopt if they were able to be part of the solution or development of the innovation [31], [32]. This suggests that there is a need for a *change agent* that relies on the instructor's "knowledge, skills, preferences, and teaching situation" to "make improvements and not be made to feel their ideas are being judged or discounted" [31], [33]. Including faculty in the adoption process improves the likelihood of creating adoptable materials while learning more about the underlying issues related to adoption. Limited research has focused on a collaborative effort of faculty and engineering practitioners. Through working closely with engineering practitioners and faculty, we acted as that *change agent* and iteratively developed more authentic learning tools and learned more about the barriers to adoption.

Methods

This study iteratively developed case study design activities and rubrics through semi-structured interviews with engineering practitioners and engineering faculty. Three civil engineering faculty who teach a junior or senior level fluid mechanics, hydraulics, or hydrology course provided syllabi for their courses with course learning outcomes. Three civil engineering practitioners were paired with a faculty member based on their experience that is most relevant to the course learning outcomes. These three pairs (one engineering practitioner and one engineering faculty) worked together to create one design activity and rubric per pair. Interviews were conducted independently with analysis between each interview to develop the design activities and rubrics. Design activities were developed using Activity Theory for Task Analysis [34], [35] with rubrics developed based on the performance criteria of engineers and faculty. Interviews were analyzed using qualitative research methods that included inductive in-vivo coding [36] and thematic analysis [37]-[40]. We worked closely with engineering practitioners and faculty across multiple semi-structured interviews as a mediating *change agent* to understand the reasons *why* characteristics of the design activities are relevant to engineering knowledge.

Results

The data collected through the interviews led to the development of two publications and a workshop. The first publication was motivated by the goal to understand how engineering practitioners and faculty define and operationalize what engineering knowledge is in the context of iteratively developing a design activity and rubric. The guiding research question was, *what is the meaning of an answer?*

The results of this study led to understanding how the development of design activities and rubrics can define and operationalize the meaning of an answer. The analysis of the interviews led to emergent codes and themes that address the goal to understand how engineering practitioners and faculty define and operationalize what engineering knowledge is. Nineteen in-vivo codes emerged that led to the generation of two themes. The codes describe reasons for how certain characteristics of the design activities relate to the meaning of an answer for both engineering practitioners and faculty.

Analysis of these codes led to two emergent themes. The engineering practitioners aligned more with the *solution-based approach* theme that emphasizes the overall process and reasons for *why* decisions are made in the design process. Engineering practitioners see answers based on the utility of the solution as presented through meeting stakeholder needs, having an appropriate number of alternatives to justify their solutions, and addressing constraints such as cost and safety. Why the solution was appropriate or required takes precedence over how the solution was developed.

Engineering faculty aligned more with the *answer-based approach* that emphasizes the final knowledge gained, competence, and helping the faculty member evaluate the design process. Answers should be gradable, meet course learning outcomes, and provide a means to evaluate student learning through precision and developing confidence. The answer is an indicator of understanding and a means of sharing what needs to be done and how to do it.

The second publication was motivated by the goal to understand more about engineering practitioner and faculty beliefs with respect to the barriers to adoption related to design activity and rubric. The following research questions guided this publication: *What barriers to adoption exist when collaborating on an innovation with an engineering practitioner, faculty member, and mediating change agent? What does it mean to be an engineer?* and *What does it mean to prepare a student to be an engineer?*

To understand more about the observed differences between the academic and workplace contexts, this paper focused on the barriers to adoption and related epistemic beliefs that engineering practitioners and faculty hold and how those beliefs relate to engineering knowledge. Multiple themes emerged and were mapped across the three overriding concerns and five dimensions of epistemic beliefs that led to inherent similarities and differences between the engineering practitioners and faculty. This mapping allows for further examination of overlapping, contradicting, and characteristics of beliefs relating to what it means to be and prepare to become an engineer. Table 1 displays this mapping and provides an overview for how the last two research questions (what does it mean to be an engineer and what does it mean to prepare a student to be an engineer) map onto the three overriding concerns (columns) and five dimensions (rows).

Table 1: Epistemic Beliefs Framework Mapped to the Overriding Concerns

Epistemic Beliefs Dimension	**What constitutes or counts as knowledge?**	**Where is knowledge located?**	**How is knowing attained?**
Structure of knowledge	Applied math (faculty)		
Certainty of knowing	Value of their engineering (faculty)		Understanding the problem (faculty)
Source of knowledge		Real world experience and intuition versus technical knowledge (engineer); Practical real-world experience (faculty/engineer)	Research and data acquisition (faculty/engineer); Broader Experience (faculty/engineer)
Justification of knowledge	Consequences (engineering)		Critical thinking (faculty/engineer)
Social process of knowing		Consequences (engineer)	

This mapping highlights the similarities and differences between engineering practitioners and faculty. The first column presents beliefs related to what constitutes or counts as engineering knowledge. Engineering practitioners place emphasis on the outcome or consequences (real-life detriments related to poor design that led to property damage, loss of life, or other personal and professional consequences) of a design. Faculty believe technical skills such as ***applied math*** and the confidence students have in the ***value of their engineering*** as contributing factors to this overriding concern. There is little overlap between these epistemic beliefs which suggests that additional research and consideration should emphasize this overriding concern when developing new learning innovations.

The second column presents beliefs related to where knowledge is located. Faculty and engineering practitioners indicate belief that the source of knowledge is related to some form of experience with the real-world that leads to practical experience (faculty) and intuition (engineers). Even though the faculty have identified their courses as being abstract or partially removed from practical experience (***applied math***), they still believe that providing these experiences for students helps prepare them to be engineers. The engineering practitioners see this experience as building intuition, and this is contrasted with having only technical knowledge of the content that is often associated with the abstract nature of coursework. Engineering practitioners believe that ***consequences*** are related to where knowledge is located through a social process of knowing. Through the interaction with stakeholders (e.g., communities, environment, clients), consequences become relevant and begin to control the outcome of a design when there is risk to those stakeholders. This social process of knowing then situates where knowing is located within the interactions and navigation of stakeholder needs and any inherent risks.

The third column presents beliefs related to how knowing is attained. While ***understanding the problem*** is a faculty-only code, the rest of the codes show how both engineering practitioners and faculty agree that attaining knowledge is related to ***research and data acquisition***, ***broader experience***, and ***critical thinking***. If faculty are meant to prepare students to become engineers, the emphasis on the attainment of knowledge should be expected. Considering that engineering practitioners share a similar belief, additional emphasis should be placed on this epistemic belief when considering how new innovations are developed.

Results indicate that both engineering practitioners and faculty believe that where knowledge is located and the source of knowledge are related to practical, real-world experiences. Differences in epistemic beliefs show that faculty emphasize the abstract learning and confidence of their students in their classroom. This contrasts with how engineering practitioners' beliefs emphasize the consequences of their designs in the workplace. Results also present multiple barriers to adoption related to time, complexity of the innovations, incentives, and differing teaching styles.

The goals of the second publication also led to overcoming a primary step in the adoption process by creating adoptable course materials. The results present a robust narrative related to the development of these design activities that should help faculty better understand barriers to adoption and help bridge the gap in preparedness that students face when entering the engineering industry. The process sheds light on ways to improve efficiency and subsequent adoptability of design activities by exploring a non-isolated collaborative development where faculty and engineering practitioners work together with a change agent acting as a mediator.

Subsequent to the results of these two papers, we ran a collaborative workshop session at the 2022 NSF EEC Grantees conference with the goal of collectively developing with session attendees a shared understanding on how and why sociomaterial contexts differ across workplace and academic settings. We also aimed to address when workplace sociomaterial contexts can and should be replicated in academic settings with the goal of developing examples and next steps for attendees to take back to their classrooms.

The workshop content presented our research and existing literature on sociomaterial representations of concepts in academic and workplace contexts. Attendees were also provided with examples from our research on how workplace sociomaterial representations could be integrated into new and existing problems. Throughout the session, attendees were given multiple opportunities to discuss in small groups and across groups their interpretation of and thoughts on our research and examples. Attendees were encouraged to extrapolate our research findings to their own engineering experiences across academic and workplace settings.

When discussing such topics such as the similarities and differences between workplace and academic settings, an expected response is that they are radically different and that the different goals within academic and workplace settings create a culture gap that is challenging to bridge within existing academic settings. Reframing this topic with the preface that it is ok for these settings to be different and that not all academic settings can or should even try to replicate workplace contexts allows for a more open discussion of what opportunities exist for greater alignment. By focusing on examples of sociomaterial representations of concepts that exist within both settings, it becomes easier to see what features of a workplace representation can be appropriately adopted in an academic setting. In this way, attendees were able to brainstorm and discuss more specific and attainable goals in aligning their curriculum with workplace knowledge and expectations.

Aim III

The goal of the study for Aim III is to gain further understanding of how underrepresented engineering students and practitioners navigate their identities in school and in the workplace. We sought to answer the following questions: *What are the challenges associated with navigating one's identity in Civil Engineering*? and *How does navigating identities affect one's experience in Civil Engineering*?

Underrepresentation is a well-known and researched topic in academia, specifically for engineering that remains a White male- dominated field [41]. Underrepresentation affects students' ways of experiencing engineering education and practice and creates unique sets of challenges compared to their majority-representing peers. Experiences such as "cold" campus social climate, lack of cultural relatability from curriculum context, or difficulty finding belonging in professional settings are well documented and often related to some specific parts of the engineer's identity, including race, gender, culture [42]-[45].

Since reported challenges for underrepresented engineers relate to their identity, gaining further understanding of how engineers navigate their identities in education and practice would prove to be a valuable insight. This knowledge could assist in developing learning and work settings that include and utilize a wider range of perspectives and expertise. Ultimately, understanding how the intersectionality of engineers' identities manifest in education and workplace settings will help improve the engineering workforce's ability to find creative solutions to important problems [46].

Methods

Using narrative analysis methods [47], two participants' narratives were collected over the course of three interviews. One participant was a civil engineering student, and the other was a recent civil engineering graduate working as a professional. The first identified as a Filipino-American woman and the second identified as a Mexican-American man. The three interviews were semi-structured and based on identity and intersectionality theories. We used thematic analysis and inductive coding [36] to gain a better understanding of how engineering students and practicing engineers navigate their identities within civil engineering. Based on the analysis results, we constructed each participant's narrative according to the principal emerging themes throughout the interviews.

Results

Results from the narrative analysis uncovers the complex nature of identity navigation for historically marginalized civil engineers. The participants' narratives were divided into three themes: development of their social identities, development of their engineering identities, and navigating their intersectional (i.e., social and engineering) identities. Both participants mentioned expressing or repressing various identities depending on their social environment. Further, the influence of cultural environment and outside perspective showed to have a significant impact on our participant's sense of engineering and social identities. For example, both participants discussed how they felt "stuck between two worlds," suggesting that the intersection of multiple social identities prevented them from fully experiencing belonging within one of their identities. This behavior was accentuated in the context of engineering, where both participants felt that other engineers tended to relate their social identities to their competence as an engineer. Such interpretation from others, based on social norms and cultural stereotypes, impacted the participant's sense of engineering identity and could lead to further their sentiment of isolation [48], [49]. The importance of diverse social and cultural representation was expressed by both participants as a way to consolidate their engineering identity and reconcile it with their various social identities.

Conclusions

Aim II

Our study for Aim II sought to understand how engineering practitioners and faculty define and operationalize engineering knowledge through iterative development of a design activity as well as to understand the barriers to adoption related to the design activity. We found that, while there are differences between academic and workplace contexts, iterative development of new innovations between faculty and engineering practitioners led to preliminarily adoptable learning materials while also allowing the epistemic beliefs of both participants to emerge. Our study aligned with prior research goals to create more authentic learning experiences for students [13]-[15], [17] and to involve faculty in the development process [31], [32]. We also addressed concerns related to the epistemic beliefs associated with the adoption of new learning materials [50]-[53] and highlighted barriers to adoption that have been identified in previous research [32], [51], [54]-[60]. The results can be used by engineering educators to address the gaps between workplace and academic definitions, operationalization, and practice of engineering knowledge to better prepare engineering students for the workplace.

Aim III

Our study for Aim III explored the challenges of navigating one's identity in civil engineering. We found that there is a complexity with which underrepresented students and recent graduates in civil engineering navigate and reconcile their various intersectional social and engineering identities. The results can be used by engineering educators to address the equity and inclusion of historically marginalized populations in engineering to improve the students' experience and retention in the field, particularly as they transition into the engineering workforce.

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