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Exploring Student Engagement and Project Outcomes in Capstone Design: Insights from a Grounded Theory Study

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Background, motivation, and objectives.

Capstone courses, a staple of engineering education, serve as a pivotal experience between academic learning and professional practice. These courses are designed for students to integrate and apply the knowledge they have acquired throughout their undergraduate studies while simultaneously fostering the development of important professional skills such as teamwork, problem-solving, project management, and communication [1, p. 8]. Capstone courses are often designed to represent a "culmination of work" [2] project for engineering students, serving both as a representation of one's engineering skillset and as a formative experience preparing students for their future engineering careers.

Despite the prominence of capstone courses in engineering curricula [2], there is an important gap in the literature studying how and why students engage with design activities within this context. Design activities are central to engineering practice, and include complex cognitive [3], [4] and social processes [5], [6] enabling engineers to translate theoretical knowledge into practical solutions for complex problems. Thus, engagement in design activities within capstone is critical in exposing students to open-ended and professional-like engineering processes[7].

Understanding the nuances of student engagement in capstone design activities is essential to optimizing these courses to better align with professional engineering practices. This study contributes to a larger study aiming to develop a model of design activity engagement and identity motives in students and professionals, using the inductive approach of Constructivist Grounded Theory (CGT) [8] to conduct data analysis.

The specific research-focused aims of this project are to:

Objective 1: Develop a model of design activity engagement and identity motives of students and professionals.

Objective 2: Expand our model to account for the resistance and synergies, alignment, and tension, between academic and workplace settings and across disciplines.

In this Empirical Research Brief, we present selected findings from a grounded theory study examining student engagement in design activities within an engineering capstone course. We address our larger study's objective 1 by presenting our grounded theory framework of capstone design activity engagement. Our findings highlight how students' design activity engagement is affected by processes of identity affirmation, which in turn depends on aspects of the course such as feedback, design processes, and design outcomes. More specifically, the data from interviews illustrated how students' agency over design outcomes can lead to identity affirmation and a higher level of engagement with capstone design activities.

Methods:

In this research, we aim to develop a context-specific theory of design activity engagement within capstone courses. Specifically, we aim to answer the question: How do engineering students connect their identity motivations to design activity engagement? The contextual and inductive nature of our findings make Constructivist Grounded Theory (CGT) a method of choice to "identify causal conditions while emphasizing their contextual and contingent nature" [9, p. 98].

CGT is described as an iterative process relying on "systematic, yet flexible guidelines for collecting and analyzing qualitative data" [8, p. 1]. Our use of CGT involved collecting participant data, analyzing this data through subsequent rounds of "coding", and extracting theoretical insights from these codes. This process was repeated until "data saturation" was reached, at which point our current theoretical framework was finalized. The following paragraphs provide further details of these processes.

Sampling:

In this study, we focused on the experiences of civil and mechanical engineering students engaged in capstone courses. Both convenience (recruiting from easy access) and snowball (recruiting using current or past participants) were employed in this study [10, p. 159].

Data collection:

We conducted two to three in-depth semi-structured interviews [11] with 31 students over the course of 3 different capstone course sessions. Interview protocols were developed by the research team and contained questions touching on various aspects of the capstone experiences such as project selection, design processes, team collaboration, and relationships with sponsors. Semi-structured interviews allowed us to broadly approach various topics of interest while giving participants the ability to orient the conversation toward what reflected their experiences in capstone the most.

Analysis:

In this CGT study, our data analysis began with transcription of and familiarization with interview content. This process ensured our familiarity with the data and informed improvements to interview protocols for subsequent rounds of data collection.

Coding, a key step in data analysis, involved assigning labels to segments of data to summarize and categorize their meaning. We focused our initial coding on actions and processes rather than themes, often using gerunds to maintain attention on participant-driven insights [8, p. 15], [12].

Following initial coding, we identified the most significant codes via focused coding. These codes could explain broader data patterns and contribute to identifying emerging theoretical categories. This step marked the transition from descriptive analysis to conceptual understanding.

Memo-writing was also an integral part of our CGT analysis, providing a way to document analytical insights throughout data collection and analysis. We employed two types of memos: interview summaries, which reflect various aspects of participant narratives and emotional context, and analytical memos, which explore emerging codes and theoretical ideas. These memos help refine the analysis and support theory generation [13, p. 118].

The development of a theoretical framework occurred through iterative data collection and analysis, where the previous steps of initial and focused coding were repeated. This iterative process helped us identify the emergence of relevant theoretical categories across various data sets, which represented the basis for our theoretical framework. After multiple rounds of iteration, theoretical saturation was reached, meaning that no new insights emerged from further data collection and analysis. After saturation, our emerging theoretical framework was developed by identifying interactions between theoretical categories.

It is also important to note our considerations for research quality throughout the CGT process. Our methodology takes into account Walther and Sochacka's framework of qualitative research quality [14], employing strategies like theoretical, procedural, and communicative validation. Such considerations include interviewing participants multiple times, focusing our analysis on rich descriptions, and reflecting on the researcher's role and biases. Identifying and accounting for sensitizing concepts (preconceived ideas informed by the researcher's background) also contributed to improving the validity of our findings. These measures ensure that the study captures and accurately represents the participants' social realities.

Results

Larger study findings:

Our CGT analysis demonstrates a novel framework (Figure 1) for understanding how students engage in capstone design courses. Our framework suggests that design activity engagement is intrinsically linked to processes of identity affirmation. Specifically, three aspects of students' experiences in capstone lead to identity affirmation and engagement: feedback, design processes, and design outcomes. The influence of feedback and design processes will be further discussed in a future journal article currently in writing. In this paper, we focus on the influence of design outcomes on student design activity engagement. Further, to remain within the scope of a research brief paper, we anchor the report of this finding in a few illustrative quotes and indicate participant accounts who informed our understanding by their pseudonym.

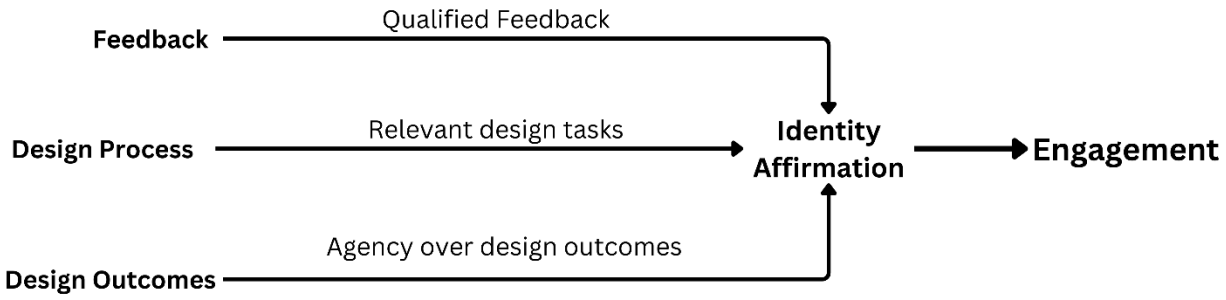

Figure 1: Design activity engagement framework

Design outcomes and capstone engagement:

We define design outcome as the final product (physical or not) emerging from a student's capstone design work. Since capstone is a culminating design experience and aims to prepare students for the professional world, it can be expected that the realistic nature of the design outcome (i.e.: whether the design could be used in a professional setting) should play an important role in students' engagement in design activities. That is, students engaged in a more 'realistic' project would show higher levels of engagement. However, our participants' narratives, such as Sallie's or Emilia's suggest that this isn't the case. Indeed, students did not express a preference for realistic design outcomes from project selection to engagement in design processes. For example, civil engineering students' capstone designs cannot be used in a professional setting because of licensing limitations.

This limitation to theoretical-only designs did not, however, lead to lower levels of engagement from civil engineering students compared to mechanical engineering students. Even within groups of mechanical engineering students, projects whose outcomes were theoretical design such as space exploration-related designs (eg; Tanya and Mia's design) did not result in lower engagement in design activities from students when compared to physical or prototype-oriented project outcomes. Which aspect of design outcomes, then, influenced engagement the most?

Amongst student's thorough descriptions of their experience with capstone design, one's agency over the design outcome proved to be an impactful and central topic, often having important implications for one's engagement with design activities. Indeed, students who perceived their design contribution as impactful to the project outcome typically showed high levels of design engagement throughout the project. Design experiences such as Seth's, Amelia's or Adrian's reflected the importance of design agency. For example, Adrian showed high levels of engagement throughout the project, and frequently proposed design changes to his sponsor: "One thing that's really nice about our sponsor is he's open to all and any ideas and he's really communicative and quick responding, so he's open to hearing my ideas.". Because his design ideas were often implemented, thus giving Adrian agency over the design outcome, he mentioned feeling like an integral part of the design process, which contributed to keeping him engaged.

On the other hand, students who perceived their contribution as of minimal impact on the project outcome often reported feeling isolated from the design process and tended to show low levels of engagement in the capstone course. As Jessie, a mechanical engineering student explained “I think our sponsor knows exactly what he wants and is just curious about what else we can come up with but then falls back to [his initial idea]. I don't know … maybe it's just capstone in academia, but when you work that hard on something and then it's just not used or considered… I don't know if I could do that for the rest of my life. I hope industry is not that way.”. Jessie reported feeling less and less engaged with the project as more of her team’s ideas were ignored by the sponsor. Similarly, the notion that agency over design led to higher levels of engagement was also confirmed by multiple cases (such as Isabella’s or Ana’s) in which, because of a change in project scope, students’ work became irrelevant to the project outcome which led to disengagement of previously involved students.

Building on this analysis, we can theorize that the process of engaging in design activity in capstone courses is related to students' identity formation as engineers. Specifically, by providing an impactful design contribution to a capstone project, students affirm their identity as professional engineers. This affirmation of one’s engineering identity from a perceived agency and impact on design outcome was suggested in multiple student reports of their capstone experiences. Students often reported feeling like professional engineers when their actions and ideas contributed to the design outcome. A lack of perceived agency and impact, however, often led students to consider capstone as a typical academic course and lower their engagement with design. These narratives suggest that students use open-ended engineering projects like capstone to affirm their identity as professional engineers, which in turn leads to high levels of reported engagement in design activities.

Discussion

Our analysis highlights a novel framework for understanding student engagement within capstone design courses. While traditional perspectives might predict that the realism of design outcomes would correlate with engagement levels [15], our findings challenge this notion. Indeed, the narratives from students across different engineering disciplines reveal that engagement is not necessarily tied to the practicality or realism of the design outcome.

Instead, our findings emphasize the critical role of agency over design outcomes. Students who saw their contributions as impactful on the project reported being more engaged throughout the design process. This sense of agency fostered a deeper connection to their work and reinforced their identity as emerging engineering professionals.

These observations suggest that engagement in capstone projects is influenced by the process of identity affirmation as engineers. Capstone courses, by their open-ended and iterative nature, provide students with a unique experience to transition from learners to practitioners. These findings coincide with theories of situated cognition [16], [17] and research in the context of capstone courses [18]. By providing an impactful contribution to such projects, students can strengthen their self-perception as capable, professional engineers [19], [20].

The implications of this are twofold. First, educators should consider strategies that enhance students' sense of agency throughout the capstone experience. This could involve structuring projects to ensure that all team members have clear, impactful roles and that their contributions are acknowledged and valued by project sponsors. Secondly, shifting the focus of capstone projects from being a realistic representation of engineering work to providing an identity-affirming experience could lead to higher levels of engagement with design activities and a more impactful experience for students.

By fostering environments where students feel empowered and integral to the design process, capstone courses can better fulfill their role in preparing students for the professional world. This approach not only enhances engagement but also nurtures the formation of a robust engineering identity, ultimately contributing to more confident and competent future engineers.

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