Student Perceptions of Capstone Learning Outcomes

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Capstone design courses are pivotal in engineering curricula, and understanding the resultant learning is critical to both researchers and practitioners. To effectively assess and measure learning, a useful first step is to develop meaningful outcomes. While current scholarship does provide tools for such assessments, most are derived through research with faculty, administrators, and various industry stakeholders. As a result, students' self-reported learning gains have been largely overlooked. Addressing this concern, the authors discuss the preliminary results of a qualitative study investigating student perceptions of capstone learning through semi-structured interviews. Reassuringly, findings are generally consistent with current outcomes, but participant discussions also highlight personal development that moves beyond acquisition of technical skills. That is, students' perceptions of their own learning in capstone reflects not only those outcomes currently desired by various stakeholders and accreditation bodies, but also those that might be more subtle and less tangible than those demonstrated via traditional assessment approaches.

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Introduction and Background

Many undergraduate engineering courses focus on technical content and theory-based knowledge, but capstone courses, positioned as the bridge from school to work, call on students to *apply* their technical and professional skills to complete a long-term project. These projects are typically sponsored by faculty and/or industry, with students serving as junior engineers under the guidance of more experienced project mentors. In many programs, the capstone course may be the only, or at least the most sustained, learning opportunity students have to integrate professional and technical skills in the context of authentic engineering work.

Given capstone's position as a bridge between school and work, understanding student learning is critical to continuous improvement. To effectively develop course objectives and design activities to support them, faculty need ways of talking about student outcomes. As a result, multiple scholars have characterized the skills that engineering graduates need to be competent in practice e.g.,[1, 2-6]. Although such resources are helpful in both understanding and developing engineers' skill sets, what the field lacks are robust discussions of learning from students themselves[7]. Capstone courses include reports, presentations, or products that offer important assessment points, but these artifacts may not fully capture less tangible student outcomes. To address this gap, we present a thematic analysis of interviews with capstone students themselves, to answer the question: *How do students in engineering capstone courses describe their learning gains?*

Methods

This paper presents a qualitative study of students' self-reported learning gains using data collected from a multi-case, multi-institution study. The case study approach allowed us to capture the dynamic, ill-structured nature of capstone courses[8]. Drawing on national surveys, capstone instructor interviews, and snowball sampling, three faculty with high levels of expertise were selected for intensive case studies. The sites included two large state institutions and one small private institution across the U.S. In terms of major, they included mechanical engineering, chemical engineering, and a multi-disciplinary program. All were two-semester courses with industry-sponsored projects.

The data presented here have been described in detail elsewhere[7]. Each case included observations of faculty/team interactions and interviews with faculty, as well as the student interview data used in this present analysis. In two of the three cases, students were interviewed at the end of the fall semester and again at the end of the spring semester; in the third case, students were only interviewed at the end of the spring semester, yielding 50 student interviews from 31 students; one third of the participants were women. The interview protocol probed students' interactions with their mentors and their perceived learning gains in the capstone course. All interviews were audio-recorded and transcribed verbatim. To characterize students' self-reported outcomes, we used open-coding following Strauss and Corbin[9]. Transcripts were coded by identifying distinct categories, grouping those categories into conceptuallyrelated clusters, and iteratively refining the categories to develop themes. Triangulation among multiple coders ensured trustworthiness.

Results

Five salient themes emerged regarding student learning: 1) Engineering Design Skills, 2) Teamwork Skills, 3) Connections to the “Real World,” 4), Self-Directed Learning Practices, and 5) Development of an Engineering Identity. No differences were observed across the three sites. The first three themes reflect the goals of most capstone faculty[10] and are supported by design education researchers broadly[2-4], while the latter two highlight personal development that moves beyond acquisition of skills. Importantly each broad theme represents a rich complex of individual skills, practices, and attitudes that merits further investigation.

Engineering Design Skills

Given that capstone courses focus on design, it is not surprising that students report gaining a range of design skills that illustrate their increased familiarity with engineering design as practiced in the workplace. These skills included canonical design process steps (e.g. identifying criteria, modeling, testing), technical project-specific skills, and project management skills. Discussions of engineering design steps reflect the broad consensus among design researchers[5] and involve problem definition, ideation, modeling, prototyping, testing, and documenting, and students consistently described more fully understanding with these processes, as in this description of design selection:

> *And so we better narrow it down to what we think will work and eliminate things that we don’t think will work, and doing that is a process in itself, but when it comes down to the actual details of what’s going to be a feasible design, that’s where I realized there’s a lot of information that goes into it. [Keith, Mountain West]*

This theme also includes project-specific technical content. For instance, to scope problems or generate potential solutions, students must often conduct research on relevant topics and develop new knowledge to make informed decisions. Thus, one student explained:

> *My mentor] gave me a better knowledge, really, on like the [technical] side, what all goes into [technology], the biology side of that… and I learned some things that, you know, I could take down the road with that, you know, I guess that'd probably be most of what [our mentor] contributed… [James, SouthEast]*

Finally, students frequently discussed the challenges associated with managing large projects and large teams, as illustrated by the following comment:

> *Biggest challenge was probably contacting people to get everything together. …we had to contact lots of different professors and organize times to use their lab or their tube bender or… whatever we needed to use, so really learning how to timely communicate with somebody and get things done. [Writing papers is] different than actually having to get something and take it somewhere and, so really making sure, you know, as soon as I hear back from I’ll tell my partner that the lab’s available so he can go in there at this time and then he’ll bring it to me at this time, organizing that. That’s one of the main things I learned, I guess. [Chris, SouthEast]*

Teamwork Skills

Like design, teamwork is a ubiquitous feature of capstone courses[10]. Not surprisingly, then, students reported acquiring multiple skills related to working in teams, including defining team roles to ensure accountability and leveraging different members’ skill sets to optimize performance. Students also discussed interpersonal communication skills gained through resolving conflicts, facilitating discussions, and empathizing with teammates. One student explained:

> *Well, obviously you’re going to be working in teams throughout your life…[our mentor] helped me kind of learn about how to deal with people just kind of, just by watching him, better ways to deal with different kinds of people… [T]his group’s almost unique, you know, we have like a person who’s a double-major in arts and engineering and we have the most typical of engineers, you know, like when they put an engineer in a movie that’s the kind of person he is. You know, I got a foreign exchange student, I got a hyperactive, emotional girl and the other one, she’s more or less like her friend, kind of on the artsy side of things, so I got a group of people that I will not usually work with and I was forced to work with them. [Charlie, Mountain West]*

Connections to the ‘‘Real World“

Capstone faculty also frequently reference a desire to engage students in “real world” practices[11]. Students, recognize that they are in one of their last college courses and that the capstone course is designed to prepare them for professional work; thus they make connections between the activities in capstone and those they anticipate in their future jobs. Comments in this theme moved beyond specific skills such as those noted above to address students’ overall sense of encountering “real world” expectations and challenges.

> *[Our mentor] says like 'this is not a project, this is a job.' Like and it you know were dedicating, some of us are doing 30 hours a week and this is a job. And it’s an unpaid job, but it’s a job. And like were*

making a real design for a real product and it's gotta work. And we have to deliver it by like we have a due date and um you know there's so much planning that goes into it. Like this is real, like I don't really consider it to be a class at all. Like whenever someone mentions senior design as a class like I get confused. I just consider it to be like you know I work in a lab, that's like a job that I have and like I work on [this project] like that's a job that I have. [Ashley, Mountain West]

Students made similar comments about project components. For example, several students described presentations as more than simply classroom exercises:

...when you get into the workforce or even into academia, you're not gonna be by yourself. So you need to learn to work with a team and communicate and you can't be little hermits. And you need to learn how to talk to people and you need to learn how to present things, and you need to know how to do all that stuff because you'll have to do it at some point no matter what you do. [Kim, NorthEast]

In addition to presenting information to mentors and peers, students also had to present to and sometimes negotiate with clients – another "real-world" skill consistently highlighted as they described navigating relationships among stakeholders:

There's 3 [mentors] and one coach so you know they all have different ideas about it, and what they want us to do, and what direction. So it's kind of trying to take it all and balance it, but also we want to do what our liaisons want since they're sponsoring but in a way that also gets you know the best project so… [Dylan, Mountain West]

Self-Directed Learning (SDL)

Long-terms projects such as those in capstone design require students to continue learning on their own across the project in ways that move beyond book chapters and exercises assigned by lecturers. Mentors are likely not experts in every area of a project, so students must develop the skills to find and utilize resources beyond the classroom. Rather than waiting to be given closed-ended assignments, students had to take initiative to acquire and use new information throughout their projects. Participants thus consistently described engaging in self-directed learning; as one student said,

Well we knew either way it was gonna be a radar project and we all knew that none of us had any background. So we were like… 'ok, so what do we know? ...And we decided that we would just go research as much as would could… So you know what, we have to learn radar basics, we have to understand what are all the big ideas in radar [sic] and can we start trying to understand some of these equations and some of the relationships. So we did a lot of work with that. [Allison, NorthEast]

An important dimension of this SDL is not only the ability to find information, but also a sense of responsibility for and ownership of the learning. Students noted a "personal attachment" to their work, "taking pride" in their accomplishments, and noting the taking initiative for their own futures in engineering. Below, a student discusses her motivation to educate policymakers at her school based on the knowledge she gained and the resultant problems she identified:

This is like a really good time in like [NorthEast] to sit down with like a bunch of different people who are pretty influential in like terms of how money gets spent about campus, and really like talk to them about like how green infrastructure like could come into their decision-making process and could be part of the discussion. Because right now, it's just like, no, like, we can't do it, it's expensive, we don't know how. And it's just like, it's never, never is really like fully thought about. [Alissa, NorthEast]

SDL here seemed to both reinforce the learning and give students a sense of ownership for their knowledge.

Development of Engineering Identity

Perhaps the most underexplored outcome in prior work, but one of the most prominent in our findings, is students' development of an engineering identity. Students' interactions and experiences in capstone help them see themselves as real engineers and develop confidence to move into unfamiliar work situations. By working alongside professionals and being treated as a colleague, students gained confidence in their abilities to perform in their future roles as practicing engineers. Part of identity development involves perceiving a congruence between the way a group (e.g., engineers) thinks and one's own way of thinking [12]. Through meaningful interactions with professionals and mentors, students gained an understanding of how engineering is practiced, but beyond that, these interactions served to reinforce their perceptions of themselves as engineers.

Like at some point during finals, I was like, I'm not a student anymore, like I work for [industry sponsor], I'm like, that's my job. Like people would laugh, but like that's how it felt for all of us. But I don't know [our mentor would], like, there was some, it was weird, he like trusted us, too… [Lauren, Mountain West]

These participants consistently described opportunities to engage in "real" engineering practice while remaining under the guidance and security of the university. Through these experiences, they both developed ideas about what it means to be an engineer and identified more strongly with the engineering profession. Additional study in this area is necessary, but early exploratory research has shown that “thinking like an engineer,” becoming part of a community, and beliefs of competence in practice are important contributors to this development [7].

Conclusions and Implications

A thematic analysis of student discussions of capstone revealed five themes relating to learning outcomes. Importantly, many of these themes aligned with findings from previous researchers[1-6]. But other themes suggest additional learning domains that, while perhaps not explicit, result from engagement in the capstone course. Specifically, students learn how to be self-directed and take ownership of their learning, develop an engineering identity, and make explicit connections between school and work. Equally important, through their successes and the encouragement of expert mentors, our participants consistently came to see themselves as professionals rather than students; they developed a sense of engineering identity that moved beyond what they knew and into what they were capable of doing and learning. As a result, their self-perceptions and confidence increased significantly through the course.

Given our understanding of mentoring practices in capstone and their impact on student learning[11], it would behoove faculty to consider these outcomes in both designing courses and interacting with students. Pembridge’s model of capstone mentoring highlights many concrete practices for faculty that support these outcomes[11]. For example, to establish *Connections to the “Real World,”* faculty can develop both projects and course environments that mirror professional practice – not only through assignments, but through the working relationships among the students and between students and faculty. To support *Self-Directed Learning*, faculty can help students by guiding students toward resources that might be helpful, modeling their own information-seeking practices, and scaffolding students’ initiative by asking questions that help students identify their own information needs. Designing projects in which students need to acquire and synthesize information from external sources can help develop the skills needed for effective engineering practice. Thus, if capstone faculty can impact students’ perceptions of the profession, its importance, and its norms and conventions, we should leverage that influence to design experiences that promote both technical *and* professional development.

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