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Collaborative Research: From School to Work: Understanding the Transition from Capstone Design to Industry

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Ben Lutz is a PhD student in the Department of Engineering Education at Virginia Tech. His research interests include innovative pedagogies in engineering design, exploring student experiences within design settings, school-to-work transitions for new engineers, and efforts for inclusion and diversity within engineering. His current work explores how students describe their own learning in engineering design and how that learning supports transfer of learning from school into professional practice as well as exploring students' conceptions of diversity and its importance within engineering fields.

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Dr. Kochersberger has been an Associate Professor of Mechanical Engineering at Virginia Tech since 2011, teaching and leading new developments in the ME capstone senior design course as well as advising graduate student research in unmanned systems. He introduced an industry-sponsored model for capstone design with a favorable IP policy, established a student machine shop and introduced global humanitarian design projects as an option for students. Prior to Virginia Tech he was an Associate Professor at the Rochester Institute of Technology and developed a multidisciplinary design course that included students from Business, Arts and Sciences as well as Engineering.

Chris Gewirtz, Virginia Polytechnic Institute and State University

Graduate Student at Virginia Tech. The following ideas fall under the umbrella of my interests, humanitarian engineering, tolerance of uncertainty, engineering with community - instead of for industry, empathy, critical reflection, social justice, innovation.

Ms. Laura Mae Rosenbauer, Smith College

Laura Rosenbauer is an engineering major and landscape studies minor at Smith College. She is a research assistant on the national and international capstone survey efforts and the development of CDHub 2.0. She is also assisting with a new research collaboration to study the transition from capstone design to work. She was a summer intern at the Urban Water Innovation Network, where she studied the thermodynamic and hydrologic properties of pavements. She is interested in a career in civil engineering.

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Collaborative Research: From School to Work: Understanding the Transition from Capstone Design to Industry

1. Overview

This paper describes a new project exploring students' experiences as they leave their capstone (aka senior) design courses and enter engineering workplaces. The project is currently in its initial phase, with instrument development and pilot testing currently underway.

Multiple studies show significant gaps between school and work with respect to engineering practice [1-3]. That gap is clear, for example, in a recent American Society of Mechanical Engineering (ASME) survey that found weaknesses among new graduates in skills including practical experience, systems perspectives, project management, problem solving, and design [4, 5]. Equally important, industry supervisors identified such gaps more frequently than early career engineers or academic department heads [4], reinforcing Stevens et al.'s claim that "professional engineering work … may not align well with what often counts as engineering within the academy" [1, p. 132]. Such misalignment poses a serious challenge to the professional formation of engineers within the academy.

Capstone design courses are often positioned as key sites for bridging these gaps and supporting the holistic formation of engineers. These courses entered engineering curricula in the late 1980s in response to industry concerns about graduates' lack of practical experience. They have since become ubiquitous, with strong similarities in structure across settings [6, 7]. Most often structured as semester or year-long team projects in parallel with a formal course, capstone courses have increasingly shifted towards industry-sponsored projects [7]. Faculty see these courses as vehicles to help students synthesize prior coursework, engage in open-ended projects, and simulate real-world work experiences [6] – goals that are consistent with the needs identified by ASME and others as well as with accreditation requirements [8].

While capstone courses emphasize workplace preparation, few studies have systematically examined the effectiveness of this preparation in the context of students' transitions from school to work. At the same time, the gaps identified by industry and professional organizations point to the need for such research. Toward that end, scholars such as Korte [9], Trevelyan [2], and others have explored the career pathways and workplace practices of engineering graduates broadly. For example, Kotys-Schwartz and colleagues have identified differences between design practices in industry and design practices in capstone classrooms [10, 11]. Yet most research on capstone courses remains focused on structure, pedagogy, assessment, and course outcomes.

To meet this critical need, we draw on Wenger's [12] concept of *communities of practice* to study the experiences and perceptions of individuals as they move from capstone courses into workplaces. Using a multi-case approach, we seek to understand **how and to what extent capstone design courses prepare students to effectively enter communities of practice in engineering workplaces.** Our study addresses 4 research questions:

> **RQ1:** What skills, practices, and attitudes fostered through the capstone experience do individuals draw on or apply in their early work experiences?

RQ2: What differences do individuals identify between their capstone design and early work experiences, and how do those differences help or hinder their school-to-work transition?

RQ3: What specific pedagogical practices or aspects of the capstone course do students identify as helping or hindering their transition?

RQ4: In what ways do individuals perceive themselves to be underprepared in their early work experiences?

2. Background

2.1 The Role of Capstone Courses in Engineering Curricula

For several decades capstone design courses have played a valuable role in engineering education [13, 14]. Positioned as the culmination of students' undergraduate engineering education, these courses are designed to synthesize prior technical coursework and promote practical application [6, 7, 15]. By emphasizing industrial applications and real-world projects, capstone courses seek to facilitate the transition from student towards professional. Projects range from work for government, industry, and non-profit organizations to competitions such as the Formula SAE competition. Their complexity requires students not only to integrate skills and knowledge from prior courses, but also to develop new technical knowledge, all in the context of challenges and constraints that classroom exercises cannot replicate. These courses engage students in the full design cycle, from brainstorming conceptual ideas through manufacturing and testing prototypes. At the same time, they intentionally foster professional skills such as project management, collaboration, communication, and self-directed learning [6, 7].

These courses also often represent major investments in terms of funding, infrastructure, and personnel [7]. Client projects may include donations from sponsoring industries; projects that involve building and testing require laboratory and machining facilities; and teams often have individual faculty and professional mentors, requiring substantial personnel time. Such intensive investment warrants a systematic examination of the effectiveness of these experiences in meeting intended goals.

2.2 Current Research on Capstone Courses

Centers such as the Center for Engineering Teaching and Learning (CELT) and Transferable Integrated Design Engineering Education (TIDEE), as well as individual researchers, have addressed a range of issues in capstone education, including students' design practices [16-20], design cognition [21-24], the role of reflective practice [25], course outcomes and assessment [26-30], course design [31-34], pedagogical practices [7, 14, 15, 35-39], faculty beliefs [40], and transfer from earlier courses [41, 42]. This research has explored not only systematic design processes but also professional skills and design thinking, decision-making, divergent and convergent questioning, system integration, and iteration. Researchers have studied approaches to ideation and creativity [43, 44] and linked the innovativeness of design solutions to specific practices. Others have studied the impact of gender on design experiences [45-47], uncovering ways in which team dynamics, campus culture, project structure, and faculty practices may marginalize women.

Holistically, this research has provided a rich base to help capstone educators design and implement courses that target necessary technical and professional skills. But little research to date has sought to follow students from capstone design into their first work experiences to assess the impact of this essential formation experience.

2.3 Current Research on School to Work

While design education research focuses on classroom practices and experiences, current research on engineering work provides a rich set of studies that highlight the contrast between industry and academic practices [1]. Work by Trevelyan [2], Buccarelli [21, 48], Anderson et al. [3], and others consistently highlights the complex, heterogenous, socio-technical nature of engineering work that contrasts sharply with the individual, isolated, closed-ended problem-solving that characterizes much of students' school experiences. Recent work by Kotys-Schwartz and colleagues, moreover, has specifically explored differences in design practices between capstone and industry via learning ethnographies [10, 11]. Results point to marked differences in spatiotemporal organization (when, where, and in what context design happens), and demonstrate that the idealized "design loop" taught to undergraduates does not capture the complexity of design in industry. Often class projects are simply a vehicle for hands-on learning without the organization structure (e.g., machine shop, test support, etc.) necessary for successful translation of ideas into products. Similarly, research by Atman and colleagues highlighted marked differences between experts and students on design tasks, with experts not only spending more time in general, but also distributing time more fully across design activities, gathering more information, and generally spending more time on problem scoping [49].

Several studies also examine the experiences of early-career engineers. Korte, for example, identified the importance of individuals' immediate work groups in supporting new engineers' transitions [9]. The Engineering Pathways Study [50] provides longitudinal research on participants, following them from the first years in engineering through their work experiences. Most of this research focuses on students' career choice pathways [51-55] and looks broadly at students' beliefs about themselves as they move through engineering programs and into careers. Work by Brunhaver et al. in particular echoes Korte's earlier findings in emphasizing the critical role played by coworkers and managers in helping participants transition successfully.

While such studies provide important insights, marked gaps remain regarding how and where students are (or are not) transferring educational experiences into workplaces. These gaps point to the need for longitudinal research to understand the effectiveness of capstone experiences in fostering professional formation that supports successful school-to-work transitions.

3. Framework: Communities of Practice in School and Work

Several frameworks have been used to explore students' transitions to work, including social cognitive career theory [56], social exchange theory [9], activity theory [57], role identity [58], organizational socialization [59], and situated learning [57, 60]. Because of the emphasis on real-world contexts and workplace practices in capstone design, we frame our study of students' transition from capstone to work using situated learning [12, 61-64] and specifically, Wenger's concept of communities of practice [12]. As Johri et al. argue [63], situated perspectives, which emphasize the ways in which learning occurs in and is inextricably tied to particular contexts, offer a valuable but underutilized approach to engineering education research. Moreover, Korte's work on the socialization of new engineers stresses the role of relationships within workgroups [9], reinforcing the centrality of communities of practice in this transitional phase.

A community of practice (CoP), as Wenger defines it [12], is not simply any group of individuals, but rather a group engaged in a *joint enterprise* characterized by *mutual engagement* and a *shared repertoire*. The joint enterprise refers to the larger set of goals – goals that are negotiated among participants, shaped by the larger context, and supportive of mutual accountability. For example, the joint enterprise of a senior design team might include both creating a product that meets client needs and developing skills students can take to the workplace, or it might include simply surviving the class in order to graduate. Mutual engagement refers to the ways in which community members interact as they pursue that enterprise, reflecting a high degree of interdependence and ongoing interaction as individuals negotiate their work together. Finally, the shared repertoire refers to individual actions and practices as well as tools, concepts, stories, and language that individuals use to engage with each other. Importantly, none of these elements are static; instead, the nature of the enterprise, the forms of engagement, and the repertoire are continually renegotiated in practice among community members.

Within this framework, learning is not acquiring knowledge in one place (e.g. a classroom) and transferring it to another (e.g. a workplace). Instead, it is a process characterized by *legitimate peripheral participation* in a community of practice [12, 62-64]. That is, novices learn as they engage in authentic work characteristic of a given CoP, interacting with other members of the community and developing familiarity with the shared repertoire. While it might seem surprising to consider senior engineering students novices, Atman et al.'s work highlights critical differences in design cognition between seniors and experts [49], and studies such as the one conducted by ASME suggest that even at the end of the capstone experience, students continue to lack several critical skills. Novice participation in CoPs is typically "peripheral" in that their engagement may be limited in scope and/or may constitute simpler tasks demanding less knowledge and experience [61]. Moreover, implicitly or explicitly CoP underlies the way many capstone educators describe their courses as sites in which students undertake authentic engineering work that engages them with practices engineers, clients, vendors, users, and other stakeholders in the design process [15, 37].

At the same time, school and work remain markedly different environments [1, 10, 57, 65-67]. Given Wenger's emphasis on the situated nature of learning in CoPs [12], succeeding in an academic CoP, even one designed to mimic engineering workplaces, does not necessarily ensure that students can succeed in their new workplace CoPs. And as noted, little if any work to date has considered how effectively their capstone courses prepare them to do so. As a theoretical framework, then, CoP enables us to explore how students experience their transition to work by considering the joint enterprise(s) at play in their first workplace; their engagement with peers, managers, clients, and others; and the repertoires they draw on as they take on workplace tasks – and, importantly, how these facets build on their capstone work.

4. Method

In seeking to explore new graduates' transitions from capstone to work, we acknowledge the complexity of studying transfer and the difficulties of isolating the role of capstone design courses from other factors affecting workplace transitions. To address these difficulties, we have begun a multi-case study, following Yin [68] and using a sequential explanatory mixed-method design [69]. By gathering quantitative and qualitative data from graduates across 4 diverse institutions, the project will allow us to triangulate data sources and compare findings across contexts in ways that can illuminate commonalities. Each institution constitutes a case, and data analysis will include both within-case and cross-case analysis to identify common and divergent elements in students' transitions. We will follow two successive cohorts from each site to add robustness to the design and mitigates potential anomalies within a single cohort.

4.1 Research Sites

The research sites consist of three mechanical engineering programs, and one engineering science program. As one of the largest disciplines nationally and an archetypal design domain, ME offers a useful study focus. Following Yin's guidelines for multi-case studies [68], the cases provide literal replication via multiple ME programs and theoretical replication via both the engineering science program and the inclusion of two schools serving underrepresented populations.

The research sites range in size from a very small program graduating 20-30 students annually to a larger program with well over 350 graduates per year. All include at least a full-year of senior design; one has a 4-semester design sequence that begins in students' junior year. All include industry- sponsored projects, though most also include faculty-sponsored ones as options. Finally, all use a course coordinator coupled with individual faculty and/or industry mentors for each team. Team sizes are general 4-6 students. The sites are also geographically diverse (northeast, mid-Atlantic, mountain west, and southwest).

4.2 Sampling

Beginning in late spring 2017, we will recruit 20 participants from each ME program and 10 participants from the general engineering program. Participants will be selected using purposive sampling; sampling criteria includes demographics (sex, race/ethnicity), employer size, and employment sector; based on responses, we may also choose to include participants who may not have yet finalized a position. With respect to demographics, sampling will seek balance to enable us to capture the experiences of both majority and underrepresented populations since underrepresented individuals may face unique challenges in entering both school and work communities of practice [47, 70-75]. With respect to employer size, we will also seek a balance among large (e.g. multinational), medium (e.g. single-site, hundreds-low thousands of employees), and small (e.g. under a hundred employees) employers, with a target of at least 6 participants in each category per institution each year. With respect to employment sectors, because ME graduates enter a wide range of workplaces, we will seek logical groupings based on participants' actual employment; that is, we will identify a set of domains (e.g. consumer products, automotive/aerospace) that will enable us to study different employment sectors but maintain a minimum of 6 participants per domain per site each year. Factors such as employer location may also be considered in the sampling based on survey responses.

4.3 Data Collection

The proposed project will involve 3 forms of data collection:

- Capstone surveys and interviews, administered at the beginning and end of the capstone course will provide relevant background about participants, their experiences in the capstone course, and their perceived levels of preparedness for work.
- Weekly surveys during participants' first three months at work will capture details of participants' experiences during this key transitional period.
- Interviews after 3, 6, and 12 months of work will yield rich detail about how participants experience their transitions.

Data collection will follow a sequential-explanatory approach in which data collected in each phase will inform subsequent phases, and qualitative data will help explain quantitative results. The team has developed two preliminary instruments that are currently in pilot testing: a short, quantitative survey, and a longer set of open-ended reflective journal prompts.

<u>Short survey</u>

The short quantitative survey design was informed by *Experience Sampling Methodologies* (ESM), in which the purpose of the instrument is to capture experiences as they happen in real time for participants [44, 76, 77]. We asked participants once a week at regular intervals to report on activities in which they had participated within the past week. Activities were selected based on common notions of engineering design activities and refined by the research team to ensure coverage of a wide range of workplace activities. Figure 1 identifies items included in the short survey:

Please check all of the activities you've been involved with over the past week

- ☐ Team meetings within your unit or project team
- ☐ Project planning
- ☐ Writing reports
- ☐ Making formal presentations
- ☐ Performing engineering calculations
- ☐ Generating or refining design concepts
- ☐ Prototyping and testing designs
- ☐ Modeling
- ☐ Meeting with clients
- ☐ Other (please provide a short description)

Figure 1: Short Survey Items

Because this work is in the pilot phase, we have also included an option for participants to discuss activities that were not covered in the survey items but which they nonetheless perceived as important in describing their school-to-work transfer. For each activity participants check, we then ask a follow up question about the degree to which they felt prepared, using a 7-point sliding scale with 7 being "Fully prepared" and 1 being "Completely unprepared."

Weekly Journal Prompt

In addition to the weekly quantitative survey, participants will also receive a set of 7 reflective journal questions each week exploring participants' most significant challenge or accomplish that week and how they believe their capstone experience did (or did not) prepare them for that experience. The journal prompt was informed by Wallin[78]and Lutz[79]. Figure 2 provides the prompts used to solicit a thick, rich description of newcomers' salient challenges.

1. What was your biggest challenge or accomplishment at work this week?
2. What made this challenge or accomplishment significant?
3. How did you approach it?
4. In what ways (if any) do you feel your capstone experiences prepared you for this? Are there other experiences that prepared you for this?
5. Is there anything you think your education might have done that would have better prepared you?
6. Are there any other workplace activities this week that you felt particularly well or poorly prepared for? If so, please explain.
7. Is there anything else you'd like to share this week as you think about transfer of learning?

Figure 2: Weekly Journal Prompts

As with the short survey, the last item is included as part of the pilot study in order to refine our questions and items in future iterations of data collection or survey distribution.

4.4 Pilot Data Collection

To allow us to pilot our weekly data collection tools prior to recruiting our first cohort in the Spring of 2017, the research team recruited 4 participants from Site 1 who graduated in December 2016. Participants were interviewed at their local campus by two members of the research team, and weekly data collection is set to begin in February 2017.

Conclusion

The study results will directly help capstone course faculty more effectively support the professional preparation of engineers. By identifying both ways in which capstone courses support professional formation and gaps in formation, the project will inform the structure, assignments, and pedagogies of capstone design. Such enhancements will, in turn, facilitate students' transition to work and help graduates acclimate to the culture and expectations of the workplace more rapidly and effectively.

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