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It's a Context Gap, Not a Competency Gap: Understanding the Transition from Capstone Design to Industry

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Daria Kotys-Schwartz is the Director of the Idea Forge—a flexible, cross-disciplinary design space at University of Colorado Boulder. She is also the Design Center Colorado Director of Undergraduate Programs and a Teaching Professor in the Department of Mechanical Engineering. She received B.S. and M.S degrees in mechanical engineering from The Ohio State University and a Ph.D. in mechanical engineering from the University of Colorado Boulder. Kotys-Schwartz has focused her research in engineering student learning, retention, and student identity development within the context of engineering design. She is currently investigating the impact of cultural norms in an engineering classroom context, performing comparative studies between engineering education and professional design practices, examining holistic approaches to student retention, and exploring informal learning in engineering education.

Prof. Robin Ott, Virginia Polytechnic Institute and State University

In 1995 Robin received a Bachelor's degree in Mechanical Engineering at Virginia Tech and has since gained 20 years industry experience. Early job experience included working as a design engineer for a

Naval Sea Systems Command contractor where she designed a Countermeasure Washdown System for the MHC-51 Coastal Minehunter ships. She also spent time as an Application Engineer at Parametric Technology Corporation, the creators of 3D CAD software PRO-Engineer. In 1999 she joined Kollmorgen, a motion control company based in Radford, where she held multiple roles of increasing responsibility during her nine years there. While at Kollmorgen Robin worked with Shingijutsu Global Consulting experts from Japan and earned black belts in the DBS kaizen areas of Standard Work and 5S and traveled globally to qualify suppliers in Asia and Europe. Most recently Robin worked as Senior Director of Project Management for a small bio-tech company, Intrexon, located in the VT Corporate Research Center and had the opportunity to introduce manufacturing principles into a highly specialized DNA production facility. Robin joined her alma mater's faculty in 2015, coordinating and teaching the Capstone Senior Design program in Mechanical Engineering. She has also completed her graduate certificate in Engineering Education, leading to the development of her research focus area in the student transition from capstone to work.

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Overview

This paper summarizes the principle findings from a multi-year, multi institution study of new graduates’ transitions from school to work. Reports of a competency gap between school and work for engineers abound, dating back at least to the Mann report in 1918.[1] Recent webinars and reports from ASEE, including the Transforming Undergraduate Education in Engineering (TUEE) reports [2, 3] and the Industry 4.0 Workforce Summit [4] continue to describe both the gaps and the changes needed in undergraduate education to better prepare today’s students to become tomorrow’s engineers.

While these and other reports often describe broad curricular changes needed to address the gap, historically capstone design courses have often been charged with supporting students’ transition to the workforce by providing authentic industry-oriented experiences. Beginning in the late 1980s, capstone courses provided a mechanism to respond to employers’ criticism about the lack of practical experience among new engineers. Now ubiquitous, these courses have a relatively common structure across disciplines and institutions [5, 6]. They are typically semester or year-long courses grounded in team projects; increasingly, these projects are linked to industry sponsorship and collaboration [6]. Capstone instructors see their courses as key sites for simulating real-world engineering work, helping students synthesize learning across courses and tackle ambiguous, open-ended design tasks [5] – goals that map to the kinds of “competencies” identified by the TUEE reports [2] and others as well as with accreditation requirements [7].

Despite significant research on the capstone courses themselves, including large-scale studies led by Davis [8-10], Howe [6, 11], and Paretti [12, 13], little work prior to the project described in this paper has systematically examined the extent to which capstone courses do (or do not) prepare students for work and support their transition across contexts. Researchers have explored the pathways and practices of working engineers [14, 15], as well as provided robust research studies on the gaps between school and work [16-18]. Yet the transition itself has remained underexplored.

To meet this critical need, the project described in this paper used a multi-case approach to understand **how and to what extent capstone design courses prepare students to effectively enter communities of practice in engineering workplaces.** Our study addressed 3 research questions:

RQ1: In what ways do individuals perceive themselves to be prepared or unprepared in their early work experiences?

RQ2: What skills, practices, and attitudes fostered through the capstone experience do individuals draw on or apply in their early work experiences?

RQ3: 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?

Given that detailed findings from this study have already appeared in multiple conference papers and journal articles addressing critical challenges, effective strategies, and areas of transfer as well as gaps for specific time periods (e.g. the first three months of work) and specific issues (e.g. self-directed learning, communication) [19-21], we provide brief summaries of prior findings and focus on synthesizing the overall project outcomes relative to our research questions.

Method

To study new graduates' transitions from capstone to work, we conducted a multi-case study [22] using a sequential explanatory mixed-method design [23]. Participants were recruited from four geographically and institutionally diverse institutions, across two different graduation years. Data collection included weekly qualitative and quantitative surveys during new engineers' first 12 weeks of work, followed by interviews after approximately three, six, and 12 months of work. We provide a brief overview of the methods here, with full details on the data collection procedures as well as a complete profile of the available data set available at [24].

Research Sites

The research sites included three mechanical engineering (ME) programs and one engineering science program, selected to provide both literal and theoretical replication as recommended by Yin [22]. ME was selected as the primary discipline both because it is one of the largest disciplines nationally [25] and because of its strong alignment with contemporary industry. The engineering science program offers a contrasting case that enabled us to explore the potential for disciplinary difference that might emerge across engineering subfields. All four programs offer capstone courses that are strongly industry-based; the courses are structured to mirror an industry work environment, with an emphasis on professional practices (communication, collaboration, project management and reporting) and behaviors. One site offers only industry-sponsored projects, while the others include a mix of industry-sponsored projects, national competition projects (e.g., Formula SAE), and faculty-sponsored projects. The 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. Finally, all use a course coordinator coupled with individual faculty and/or industry mentors for each team. Team sizes are generally 4-6 students. The sites are also geographically diverse (northeast, mid-Atlantic, mountain west, and southwest) and include both public and private institutions.

Sampling

Participants were recruited through a combination of in-person or video presentations from a member of the research team and emails sent through the capstone courses. Potential participants completed a screening survey. Our target was 20 participants per year from each ME program and 10 participants per year from the engineering science program based on recommended numbers for case studies, expected attrition, and the relative size of the programs. At some sites, where response rates were lower, we interviewed all respondents. Where possible, however, we sampled to provide variation based on intended employment, including company size and industry sector. Over two graduating years, 140 individuals participated in interviews prior to graduation. Note that each graduation year was considered a cohort; that is, participants from the first year of recruitment constitute Cohort 1; students from the second year of recruitment constitute Cohort 2. Of the 126 who started work or graduate school, 53 (42%) self-identified as female on the screening survey (which included non-binary options). Based on the initial screening survey, 81 participants identified as White or Caucasian; 21 participants reported identities from countries located in Asia; 10 participants chose not to answer. The remaining participants identified racial or ethnic affiliations typically considered underrepresented in engineering, including Latinx, Hispanic, African-American, and Black, as well as regional (e.g. Middle Eastern) or nation-specific identities.

Data Collection

All participants completed an initial screening survey that captured demographic data (name, gender, self-described race/ethnicity), background (previous internships, current capstone project), and employment plans (industry sector, company size). Subsequent data collection included the following data:

- Anticipatory interviews prior to graduation explored participants' learning in their capstone course and their expectations for work.
- Weekly quantitative surveys during participants' first 12 weeks of work identified relevant activities as well as participants' perceived preparedness for each activity.
- Weekly qualitative surveys during participants' first three months at work explored participants' most significant challenge or accomplishment during the week, along with salient details about that event.
- Interviews after 3, 6, and 12 months of work explored participants' experiences as new engineers, including job responsibilities, engineering identity, challenges, accomplishments, and transfer from capstone design to work.

Brief summaries of each instrument appear in the following sections; the complete instruments are available in [24].

Note that all data collection was performed by a member of the research team who was not the participants' capstone course instructor. In most cases, data collection was completed by graduate research assistants, though two members of the PI team did conduct some of the anticipatory interviews given the number of interviews that had to be conducted in a compressed time frame (i.e. interviews just prior to graduation at 4 different universities across the country with overlapping graduation dates).

<u>Weekly Quantitative Survey (Weeks 1-12 of employment)</u>

The weekly quantitative surveys were informed by *Experience Sampling Methodologies* (ESM), which seek to capture experiences in real time [26-28]. Each week, we asked participants to select which of the following activities they had participated in during the previous work 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
- Training
- Other (please provide a short description)

The list was developed based on common activities included in the industry-oriented capstone courses from which participants were recruited. For each activity they selected, participants were then asked to rate how prepared they felt for that activity using a 7-point scale, with 7 being “Fully prepared” and 1 being “Completely unprepared.”

Weekly Qualitative Survey (Weeks 1-12 of employment)

In addition to the quantitative survey, participants also received a set qualitative questions via email designed to explore their most significant challenge or accomplishment that week, what made it a challenge or accomplishment, and how they believed their capstone experience did (or did not) prepare them for that experience. The journal prompt was informed by Wallin [26] and Lutz [27].

Interview Protocols

Interviews were semi-structured and lasted approximately one hour. While the protocols varied slightly at each data collection point, and included participant-specific prompts based on responses provided at previous data collection points, overall these interviews probed participants’ current work responsibilities, their challenges and accomplishments since the last data collection point, their perceptions of engineering and their own identity as engineers, and the role their capstone courses played in their transition from school to work.

Participant Retention

To maximize retention, the research team allowed participants to remain in the study even if they missed a data collection point, unless they explicitly indicated they wished to withdraw from the study. That is, if a participant was unable to complete a survey in week two, they still received the survey link in week three. Similarly, if they were unable to participate in the 6-month interview, they still received an invitation to the 12-month interview. All data collection points were compensated individually ($6.25 per survey response, $25 per interview). The complete list of available data by anonymous participant ID, including number of quantitative and qualitative survey responses provided as well as whether they participated in each interview, is available at [24].

Data Analysis

Methods used to analyze the quantitative data are available in the corresponding publications [19, 29-31].

Qualitative Code Book

To identify challenges our participants experienced, the qualitative data were analyzed using *a priori* and emergent codes [32], with the initial *a priori* codes drawn from Lutz and Paretti's study of learning in capstone design courses [12]. These *a priori* codes served as overarching categories, though definitions were tested and refined throughout the coding process and one new category emerged. The final category definitions are summarized in Table 1.

Table 1: Code Categories of Challenges in the Transition from School to Work

Category	**Definition: Activities associated with …**
Adulting	…being an independent adult, including balancing personal and professional aspects of life as well as specific challenges associated with life outside of work.
Engineering Identity	…seeing oneself as an employee and/or engineer
Self-Directed Learning	…managing and monitoring one's own activities at work, including time, attention, and knowledge
Teamwork & Communication	…working in teams or communicating clearly, including formal and informal communication as well as interpersonal relationships
Technical Work	… technical engineering work, including design, analysis, testing, software, and equipment

Within each category, we also developed emergent codes to capture a more detailed understanding of participants' experiences; this full codebook is available in [24].

Results

RQ1: *In what ways do individuals perceive themselves to be prepared or unprepared in their early work experiences?*

Overall, both quantitative surveys and qualitative data (surveys and interviews) indicate that participants perceive themselves to be moderately prepared for work [29]. As our published findings show, on a 7-point quantitative scale, with 7 being fully prepared, on average participants rated their perceived preparedness at 5.7 at the beginning of their employment, which rose to 6 at the end of the 12 weeks. Analysis underway explores this perceived preparedness in more detail to better understand what new engineers mean when they consider themselves prepared. Notably, preparedness does not equate to expertise. Instead, preliminary analysis highlights three emergent themes:

- Perhaps most obviously, participants felt prepared when they encountered a task that exactly matched prior work. Often this kind of preparedness centered on a specific tool (e.g. knowing how to use a particular CAD program or piece of laboratory equipment), and was most closely related to demonstrated competence.
- Participants also perceived themselves prepared when they encountered situations that were "familiar" or "similar" to their prior experiences. For example, they felt prepared to talk with a vendor at work if they had talked with a vendor during their capstone project.

- Finally, participants perceived themselves prepared when they had a strategy for approaching a challenge or an unfamiliar situation. For example, when their new job required them to learn a new technical domain, they felt prepared because they could explicitly call on strategies they had used successfully to learn technical details in their capstone projects.

Nonetheless, despite overall perceptions of preparedness, all participants identified significant challenges in their transition to work. While participants experienced challenges across all categories, those related to self-directed learning and teamwork and communication dominated (reported by greater than 90% of all participants), closely followed by challenges in technical work as participants came up to speed on the relevant industries, tools, and technical domains associated with their jobs. Notably, these challenges in technical work were typically also linked to challenges in self-directed learning as participants had to find ways to learn on their own (see [[19, 21] for additional details]. Figure 1 displays the percent of participants who cited each category as their most significant challenge at least once during their first twelve weeks of work.

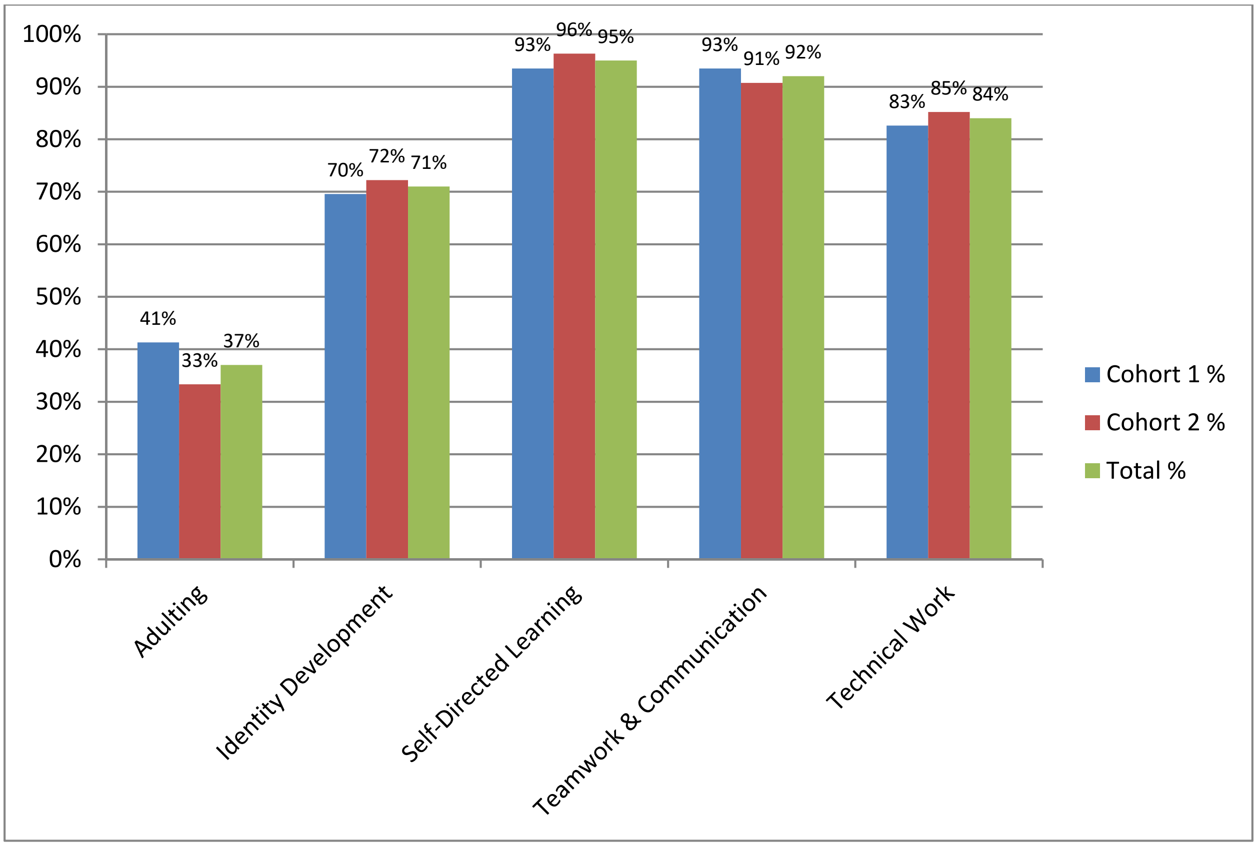

Figure 1: Challenges Participants Experience in Their First Twelve Weeks of Work. (Data reflect the percent of participants reporting a challenge in each category at least once during the first twelve weeks).

Note that frequency counts of code occurrences (i.e. the number of times each code appears) show a similar pattern, with 33% of participants' most significant challenge each week related to teamwork and communication, 30% related to self-directed learning, and 21% related to technical work.

As detailed in a previous publication, challenges related to self-directed learning typically focused on managing knowledge and managing time [21]. Managing knowledge refers to the ways in which participants needed to seek out information needed to do their jobs, while managing time focused on the ways in which participants had to learn, on one hand, how to balance competing priorities and high-pressure deadlines and, on the other, manage situations in which, as new employees, they did not have enough work to keep them busy.

Challenges associated with communication and teamwork typically centered on interpersonal communication as participants needed to negotiate relationships and understand the communication norms and preferences of their coworkers and managers [20].

RQ2: *What skills, practices, and attitudes fostered through the capstone experience do individuals draw on or apply in their early work experiences?*

Even as participants experience significant challenges in their transition to work, however, they also report significant transfer from their industry-oriented capstone courses to their industry workplaces, as reflected in their perceptions of preparedness as well as the detailed interview data around transfer. Importantly, this transfer aligns closely with the two prominent categories of challenges: self-directed learning and teamwork and communication [19].

In terms of self-directed learning, for example, participants highlighted the ways in which they had to continually master new technical knowledge for their capstone project as critical in their ability to navigate the technical learning they had to undertake in their new industries [21]. Moreover, the ability to reach out to experts (vendors, clients, researchers) they developed in their capstone projects served them well in workplaces where the knowledge they needed most often resided with other individuals rather than on the internet or in a textbook [20, 21].

With respect to teamwork and communication, participants noted their preparation in specific genres during the capstone class (e.g. reports, project documentation, meeting minutes) as well as specific scenarios (meeting with clients, providing regular updates to supervisors) as key sites of transfer [20]. Moreover, they transferred general practices around adapting communication to meet the needs of their audiences, working on diverse teams and adapting to individual personalities, and communicating with multiple audiences at different levels around a given project.

Notably, transfer was more limited around specific technical skills because in general, participants entered industries that not only represented technical domains that differed from their specific capstone projects, but also required them to delve into technical issues they had not learned in any school course. Instead, what they transferred were the strategies for this learning – again, particularly rooted in seeking out experts and gathering knowledge from vendors, technicians, and other individuals directly or indirectly related to their work.

RQ3: *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?*

While the participants in this study did report significant transfer between their industry-oriented capstone courses and their new workplaces, they also highlighted a range of areas where transfer did not – and perhaps cannot – happen. Overall, we argue, these gaps are related to the specific contexts of their work. For example, some gaps center on specific technical knowledge – equipment, jargon, procedures, or practices of their new industry (see, for example [21]). In other cases, they concern differences in the social context. Participants often enter workplaces where they are the youngest member of the team, for example, or where many of their colleagues are at different life stages, and thus forming relationships presents a new set of challenges [20]. Similarly, while participants may understand the general practice of adapting their communication to their audience and have a general understanding of how to communicate with, for example, a manager, they still need to learn the expected norms and practices within their specific workplace – for example, who prefers a phone call versus an email, and how much or how little detail this manager or this client prefers [20].

Even within the self-directed learning space, where participants have strategies they can call on for learning new material, they often lacked strategies for dealing with boredom at work or maintaining attention on tedious tasks for hours on end [21]. Where the structure and schedule of most universities allows them to break up their days with classes, studying, social time, and recreation, most workplaces constrain them to a limited set of working hours when all other members of their team are present.

Conclusion

The data from this project deepens our understanding of the challenges new engineers experience as they transition from school to work – challenges often related to the significant context shift as they move from structured classrooms with same-aged peers that focus on teaching and learning to workplaces that are diverse in terms of age, job function, experience and that focus on company productivity. In these new contexts, knowledge resides within individuals and within internal organizational documentation rather than in textbooks and on the internet. Negotiating these new contexts and relationships takes time and persistent attention, as our participants repeatedly highlighted.

Nonetheless, the data also shows that the industry-oriented capstone courses these participants experienced provided a strong grounding to support them through the transition. The opportunity to work with diverse groups of colleagues on authentic projects; to interact with clients, vendors, and industry mentors; to report to faculty who adopted roles as supervisors or managers as well as learning facilitators; and to see projects through full design cycles provided both familiarity with the kinds of situations students experienced at work and strategies for overcoming challenges and negotiating contexts.

As with any study, of course, the findings here are limited by their contexts. Participants were drawn primarily from a single discipline, though to date no differences have emerged when comparing the mechanical engineering graduates to the engineering science graduates. Perhaps even more importantly, the study itself acted as an intervention: we repeatedly asked participants to reflect not only on their challenges and accomplishments, but on the ways in which their capstone experiences facilitated their transition. While they also reported differences between school and work, research on reflection broadly suggests that repeatedly prompting students to consider how their capstone experiences supported their transition inevitably foregrounded that support and may have enabled them to more readily transfer knowledge and practice from one context to another. More work remains, then, to better understand how we can continue to develop students' strategies for transferring their learning and adapting it to their new workplaces. Industry-oriented capstone courses are an essential starting point.

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