International Journal of Engineering Education Vol. 35, No. 6(B), pp. 1993–2013, 2019
Printed in Great Britain
0949-149X/91 $3.00+0.00

Transitioning from Capstone Design Courses to Workplaces: A Study of New Engineers' First Three Months*

JULIE FORD
Mechanical Engineering, New Mexico Institute of Mining and Technology, 801 Leroy Place, Socorro, NM 87801, USA.
E-mail: julie.ford@nmt.edu

MARIE PARETTI
Engineering Education, Virginia Tech, 357 Goodwin Hall, 635 Prices Fork Road, Blacksburg,VA, 24061, USA. E-mail: mparetti@vt.edu

DARIA KOTYS-SCHWARTZ
Mechanical Engineering, University of Colorado Boulder, 2445 Kittredge Loop Drive, Boulder, CO 80309, USA.
E-mail: daria.kotys@colorado.edu

SUSANNAH HOWE
Picker Engineering Program, Smith College, 151 Ford Hall, Northampton, MA 01063, USA. E-mail: showe@smith.edu

CHRISTOPHER GEWIRTZ, JESSICA DETERS, TAHSIN MAHMUD CHOWDHURY and ROBIN OTT
Virginia Tech. E-mail: chrag@vt.edu, jdeters@vt.edu, tahsin@vt.edu, rso@vt.edu

NICHOLAS EMORY ALVAREZ
New Mexico Institute of Mining and Technology. E-mail: Nicholas.alvarez@student.nmt.edu

DANIEL KNIGHT and CRISTIAN HERNANDEZ
University of Colorado Boulder. E-mail: Daniel.knight@colorado.edu, Cristian.hernandez@colorado.edu

LAURA MAE ROSENBAUER, ANNE KARY and FRANCESCA GIARDINE
Smith College. E-mail: rosenbauerlaura@gmail.com, akary@smith.edu, fgiardine@smith.edu

This study investigates engineering students' transitions from academic to professional environments by examining the role capstone design courses play in preparing graduates for the workplace. To better understand how capstone design experiences contribute to graduates' professional preparation, we recruited participants from four different institutions as they completed multiple-semester project-based capstone design courses. We then followed them through their first three months of work using weekly quantitative surveys about participants' work activities and perceived preparedness, and weekly reflective journal responses about significant challenges experienced. To analyze the data, we used *a priori* and emergent codes to identify challenges, strategies, and areas of transfer from capstone to work, in combination with frequency analysis to identify patterns across the data set. The results indicate that participants' most significant challenges centered on self-directed learning and interpersonal communication, and that capstone courses played a key role in supporting professional preparation in these areas.

Keywords: learning transfer; professional preparation; capstone design; school-to-work transition

1. Introduction

Capstone design courses were created in the latter part of the twentieth century specifically to bridge the gap between theoretically oriented engineering curricula and the pragmatic realities of engineering workplaces [1]. In preparing engineering students for the workplace, capstone courses provide unique opportunities for students to develop their professional identities and learn critical workplace skills in the context of real-world, open-ended projects. While existing research explores what and how students learn within capstone courses, we know much less about how these courses affect students' transitions into the workplace—that is, whether the courses achieve their intent. The overarching goal of this study, then, is to better understand *how and to what extent capstone design courses do (and do not) prepare students for engineering workplaces*. Toward that goal, this study addresses two research questions:

1. What significant challenges do new engineers experience as they transition from academic engineering programs to professional engineering workplaces?
2. What strategies do these new engineers use to meet those challenges?

* Accepted 20 May 2019.

To answer these questions, we use data from a larger project that follows participants from three mechanical engineering programs and one engineering science program from the end of their capstone design courses through their first year of work. In this paper, we focus specifically on participants' first three months at work, as our data suggests that that these initial months represent a critical transition period. Preliminary results of this work were presented at the 2018 Capstone Design Conference [2] and the 2018 ASEE Annual Conference & Exposition [3]; this manuscript integrates and expands those preliminary analyses.

2. Prior school to work literature

Engineering education scholars have long identified significant differences between the closed-ended mathematical problem solving that dominates most technical courses in U.S. engineering programs and the open-ended socio-technical work that dominates practitioners' daily experiences in industry [2–5]. That is, the vast majority of engineering coursework in most U.S. institutions involves lecture-based courses focused on technical concepts (e.g., statics, fluids, thermodynamics), in which students learn through homework assignments focused on decontextualized, closed-ended problem sets with single correct answers [2, 3]. In practice, however, engineering work is characterized by complex team-based engagement in open-ended problems with often-competing constraints shaped as much by economic factors as technical ones [4, 6–8]. In looking specifically at design practices in school and at work, Lauff and colleagues identified significant differences in design approaches (linear versus non-linear), post-project product trajectory, and how these two groups organize around technical objects [9].

These persistent differences between school and work result in a skills gap between engineering graduates' capacities and industry expectations - a gap that has endured from the latter half of the twentieth century [1] through the 2010s. In a report from 2013, for example, the American Society of Mechanical Engineers [10, 11] cites gaps in new graduates' practical experience, systems perspectives, project management, problem solving, and design.

Capstone design courses emerged as one mechanism to address the school/work gap in response to industry concerns and corresponding shifts in accreditation requirements [1]; graduates from accredited engineering programs must have significant culminating design experience that integrates their prior coursework [12]. Regular surveys of capstone instructors beginning in the late 1990s highlight the ways in which the faculty teaching these courses focus on embedding technical engineering into real-world team design environments, with an emphasis on communication, collaboration, project management, and related professional skills [13–16]. The most recent survey, in 2015, highlighted the increasing prevalence of two-semester capstone sequences and industry- or client-sponsored projects [15].

Capstone courses, however, are expensive endeavors in terms of staffing, time, and logistics. Client partners often provide both funding and industry mentors for projects; the courses themselves may have not only a course coordinator, but in the case of larger courses, individual faculty advisors for each team. With typical team sizes of 4–6 students, students and faculty both invest significant time in designing and building products that meet real-world needs [1]. Moreover, descriptions of capstone design courses abound in conferences such as the ASEE Annual Conference & Exposition, and researchers have explored teaching and learning in this environment, including work on desired outcomes [17, 18], assessment practices [19–21], student motivation [22], faculty teaching practices [23–27], and student learning [28]. Such work further emphasizes the time that capstone faculty put into coaching and mentoring students through realistic open-ended projects. It also points to the significant learning that students themselves report not only in engineering design, but also in seeking out and learning new content, engaging with diverse team members, communicating with a range of stakeholders (including both faculty and industry clients), and developing confidence in their own abilities as "real engineers."

To date, however, little work has been done to understand the extent to which these resource-intensive courses achieve a key intended goal—preparing students for the transition to engineering work. While researchers have studied engineering courses and engineering workplaces independently, far less work has examined students' transitions from one to the other. Perhaps the most prominent among such studies is the Engineering Pathways Study (EPS), which built on the Academic Pathways Study to follow students through their undergraduate programs into their careers. EPS has provided important insights into the career pathways individuals follow as they navigate personal and professional goals [29–32].

Focusing more closely on the transition to work, Korte [33] examined newcomer engineers' socialization practices. His results emphasized social relationships, particularly in local work groups, as critical in supporting this transition. Brunhaver et al. extended Korte's original study to examine the ways in which employee education, help from both managers and coworkers, and camaraderie at work all could either help or hinder new engineers' transitions, depending on the nature of those factors [34]. In a similar vein, Lutz [34] examined what new engineers learn during their first few months on the job; his findings identified significant learning with respect to both performance proficiency (i.e., learning what the job itself entailed and how to do it) and sociocultural integration (i.e., coming to understand the company's goals and history, the office dynamics, the jargon, and related issues).

Looking more holistically at identity experiences as students shift from school to work, Huff et al. identified several critical themes related to the ways in which this transition enabled participants to embrace adult identities as practicing engineers, build personal identities outside of their work lives, and negotiate the tensions and contradictions between the demands of their personal and professional lives [35].

Collectively, these studies provide important windows into the early work experiences of new engineers and reinforce earlier studies on the gaps between these. While more work on these gaps is needed to continue to improve industry preparation in undergraduate education, we also need robust research to identify and understand what students *do* transfer—and thus what current educational practices effectively prepare students for engineering work. The present study addresses both goals by seeking to better understand both what challenges new engineers face and how they meet those challenges, with a focus on learning transfer from capstone design courses.

3. Methodology

As the authors have reported in detail elsewhere [2, 3, 36], this large multi-case study [37] uses a longitudinal design that combines intensive quantitative and qualitative survey data over participants' first twelve weeks of work with interviews at regular intervals throughout their first year of work. Participants were drawn from capstone programs at four different institutions.

3.1 Capstone sites studied

The geographically diverse research sites, summarized in Table 1, consist of three mechanical engineering programs, and one engineering science program. As one of the largest disciplines nationally and an archetypal design domain with a strong industry focus, mechanical engineering offers a useful study focus. The sites range in size from a small program graduating 35–45 students annually to larger programs with over 400 graduates per year. All programs include at least a full-year of senior design; one has a 4-semester sequence that begins in students' junior year. All include industry-sponsored projects, though most include faculty-sponsored and competition projects as well. Finally, all use a course coordinator coupled with individual faculty and/or industry mentors assigned to each team. Team sizes range, but the average across institutions is 4–7 students per team. Table 1 provides a summary of the capstone course logistics.

In addition to sharing many course logistics, the four research sites also maintain a similar philosophy regarding the essential features for a capstone design experience: a professional workplace environment, applied design projects, teamwork, a combination of formal and informal written and oral documentation, multifaceted advising (sponsor and faculty), student responsibility and autonomy, and an emphasis on professional practice. The course coordinators intentionally model workplace practices and actively coach students on critical workplace skills and attitudes. Moreover, the primary learning objectives for all four sites are similar (Appendix 1). The capstone experiences at these four sites also match current trends in capstone design education, especially in 2-semester (or longer) course duration, projects sourced primarily from industry/government and faculty, multiple distinct projects in a given class, and course deliverables that include reports, presentations, design reviews, and product demonstrations [15].

3.2 Recruitment

Beginning in late spring 2017, we recruited participants from each program; recruitment included in-person or videoconference visits to courses and team meetings, followed by an email inviting participants to complete a screening survey that captured basic demographic information and career plans (e.g., whether participants had secured post-graduation employment as well as company size and major industry of their future employer). The full data set for this study includes 29 females and 33 males (self-reported gender classifications) interviewed prior to graduation. Of those included in this analysis, 37 participants self-identified as white or Caucasian, 12 as Asian or Asian American, 6 as underrepresented minorities, 4 as other, and 3 did not disclose. With respect to sites, across the three large institutions, the data set includes 20, 18, and 14 participants, respectively, with an additional 11 participants from the smaller site.

3.3 Data collection

This study's full data set includes three forms of data collection for each participant: (1) background interviews conducted at the end of the capstone

Table 1. Capstone Course Logistics at Participating Research Sites

Capstone Features	**Site A**	**Site B**	**Site C**	**Site D**
Course Duration	2 semesters	4 semesters	2 semesters	2 semesters
Discipline	Mechanical Engineering	Mechanical Engineering	Engineering Science	Mechanical Engineering
Advising Structure	Course instructor oversees; faculty advisors mentor teams (instructor also advises some teams), client-based teams have industry liaisons	Course instructor oversees; faculty advisors mentor teams, client-based teams have industry liaisons	Course instructor oversees and advises all teams, client-based teams have industry liaisons	Course instructor oversees; faculty advisors mentor teams, client-based teams have industry liaisons
Number of Capstone Students	417 (20 in Study)	131 (18 in Study)	25 (11 in Study)	244 (13 in Study)
Number of Capstone Projects	51 (15 in Study)	20 (13 in Study)	7 (5 in Study)	29 (12 in Study)
Project Sources *(in capstone class and in Study (S))*	Industry: 16 (S = 7) Faculty: 19 (S = 5) Competition: 9 (S = 2) Humanitarian: 7 (S = 1)	Industry: 6 (S = 4) Government: 4 (S = 3) Faculty: 7 (S = 6) Competition: 2 (S = 0) Entrepreneurial: 1 (S = 0)	Industry: 6 (S = 4) Government: 1 (S = 1)	Industry: 24 (S = 10) Government: 2 (S = 1) Faculty: 1 (S = 0) Competition: 2 (S = 1)
Major Assignments	Reports (3) Presentations (4) Poster (1) Design Reviews (4) Product Demo (1) Expo (1)	Reports (6) Presentations (4) Poster (2) Design Reviews (2) Expo (2)	Reports (3) Presentations (3) Poster (1) Design Reviews (3)	Reports (5–8) Negotiated Reports (3) Presentations (6-9) Negotiated Presentations (3) Poster (1) Design Reviews (4) Expo (1)
Previous Design Experiences	First Year Design Course, Sophomore Design Course	First Year Design Course	First Year Design Course, Possible Electives with Design	First Year Design Course, Junior Design course, Sophomore and Junior Design Electives
Internship/Co-op Experience	Optional (Study = 95%)	Optional (Study = 94%)	Optional (Study = 91%)	Optional (Study = 92%)

course before participants began work, (2) twice-weekly surveys during participants' first twelve weeks, and (3) interviews after 3, 6, and 12 months of work. Participants received gift cards for completing interviews and surveys. Importantly, to increase retention through the full year of the study, we allowed individuals to skip data collection points and prorated payment accordingly; survey payments were prorated based on the number of surveys completed, while the interviews were paid individually. Unless a participant explicitly chose to discontinue participation, they received invitations for subsequent phases even if they had missed a previous data collection point. While this approach means that there are gaps in the data for each individual participant, it also yielded a relatively high retention rate: of the 59 participants who began work, 30 completed the 12-month interview at the conclusion of the study. In addition, response rates were generally high overall; during the first twelve weeks, on average, participants responded to nine of the twelve quantitative surveys and nine of the twelve reflective surveys (additional details on response rates are available in [3]).

Data analysis for this paper focuses on the weekly surveys during the first twelve weeks of work. Participants received two separate surveys each week: a Likert-type perceived preparedness quantitative survey sent each Tuesday via Qualtrics and a short open-ended reflective survey sent each Thursday via email. To triangulate and deepen our understanding of participants' challenges and strategies, we used the three-month interviews, which often provided more extended discussions of issues reported during the short weekly surveys.

The quantitative survey, informed by Experience Sampling Methodologies (ESM) [36, 38] asked participants to identify activities in which they had participated within the past week. The list of possible activities, as shown in Fig. 1, was selected based on common activities included in capstone design courses intended to replicate expected workplace practices; this list was then refined by the research team and a pilot survey phase to ensure coverage of

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
□ Computer-aided modeling
□ Meeting with clients
□ Project budgeting (business financials)
□ Other (please provide a short description)

Fig. 1. Short Quantitative Survey Items.

a wide range of workplace activities. For each activity participants checked, the survey asked a follow-up question about the degree to which participants felt prepared, using a 7-point scale with 7 being "Completely prepared" and 1 being "Completely unprepared." Because not every participant completed every survey, the data set includes a total of 540 quantitative survey responses.

The reflective survey contained six questions each week exploring participants' most significant challenge and the role their capstone experience played in preparing them for that experience. The prompts, as listed in Fig. 2, solicited in-depth descriptions of newcomers' salient challenges.

3.4 Data analysis

The quantitative survey data were analyzed descriptively to provide general trends in participants' work activities and perceived preparedness. Importantly, because participants were not required to complete every survey to remain in the study (as noted previously), we aggregated data by month rather than by week; we used data from all participants who provided quantitative survey responses during a given month. The results are reported descriptively because the size of the data set limits the usefulness and validity of any statistical comparisons. Perceived preparedness was analyzed in two ways: for each activity, we calculated (1) the overall average perceived preparedness over the first twelve weeks, and (2) the average of each participant's lowest perceived preparedness score for each activity. This dual approach helped us understand both how prepared participants felt in general, and where and how they felt least prepared.

The qualitative data, including both the reflective survey responses and the interviews, were analyzed using both *a priori* and emergent codes [39]. The *a priori* coding scheme was based on Lutz and Paretti's study of capstone design [28] which identified four categories of student-reported outcomes: engineering design, teamwork and communication, self-directed learning, and engineering identity. Based on our analysis, we modified "engineering design" to "technical work" to better capture the full range of activities our participants in engaged in, and we identified an new emergent category, "adulting," which refers to challenges pertaining to participants' negotiating work/life balance and navigating non-work-related tasks (e.g., buying insurance). Table 2 summarizes these coding categories. Within each category, we then developed emergent codes to better understand the nuances of participants' experiences; for example, challenges in Technical Work included emergent codes such as CAD software, software other than CAD, concept generation, and engineering calculations. The full codebook is provided in Appendix 2.

With respect to strategies, the coding process focused on generating emergent descriptive codes

1. What was your biggest challenge this week?
2. What made it so challenging?
3. How did you approach this challenge?
4. To what extent did you feel prepared for this challenge based on your capstone design experience? Based on other experiences?
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.

Fig. 2. Weekly Journal Prompts.

Table 2. Emerging Themes from Qualitative Data Analysis

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

from the data itself [39]. That is, our focus here was not to categorize the strategies or identify larger themes, but rather to describe how participants themselves reported meeting their workplace challenges. The only exception here was an explicit attention to the ways participants drew on their capstone design courses. "Drew on capstone" was an *a priori* code, and within that code, we applied the codes used for the significant challenges to explore in detail what aspects of participants' capstone experiences they considered relevant to their significant workplace challenges.

Several members of the research team were trained and normed on the codebook to ensure inter-rater reliability. The coding team reviewed commonly coded documents to compare results; discrepancies were negotiated to consensus and the code definitions were updated accordingly. The coding team also held regular meetings to ensure ongoing consistency. The final excerpts were also reviewed by all of the project leads to ensure consistency.

It is important to note that reflective responses and interviews were coded differently. Because a key goal in our analysis of the reflective responses was to identify the frequency of significant challenges and strategies during the first three months, any individual code was applied only once for each reflective response (i.e., each week); that is, if a participant wrote about a teamwork challenge in response to question 1, but then elaborated on that same challenge later in the response, the code for that challenge was applied only once for that week's reflective response. This approach allowed us to effectively track the frequency with which individual challenges or strategies occurred. Note, however, that within a given week, a participant may have described multiple intersecting challenges and/or strategies, and each challenge or strategy was coded. For example, learning to use a new piece of equipment would involve both a technical challenge (the equipment) and a self-directed learning challenge (learning new material).

In the interviews, however, the goal was to develop a more nuanced understanding of how participants experienced various challenges and strategies; as a result, codes were applied to segments throughout the interview. Thus, for example, if a participant described challenges communicating with her supervisor early in the interview, and then returned to that challenge at various points in the discussion, each point would be coded as a challenge in "interpersonal communication—manager"; this approach allowed us to use the interviews to enrich and expand the descriptions of each of the codes. As in the reflective responses, segments in the interview could also have overlapping codes whenever a given segment had dual themes (e.g., the respondent was referring to technical work that required self-directed learning).

3.5 Limitations

As with any study, while our approach to data collection yielded valuable qualitative descriptions of participants' experiences, the data are limited in multiple ways. First, as noted, participants are drawn from three mechanical engineering programs and one engineering science program, and findings may not be fully transferable across all engineering disciplines or programs. (A cross-site analysis is beyond the scope of this paper, but will be the subject of future work.) Second, participants in this study are self-selected and the pool may thus be biased toward students who are more inclined to be self-reflective and more interested in recording and learning from their experiences. They may also be participants who viewed their capstone experiences positively, though the interviews conducted prior to graduation indicated that not all participants had positive team or project experiences (even if they perceived high value in the capstone course). Third, participating in the study may itself have influenced participants' transition experiences; by asking our participants to reflect on their challenges and strategies, our data collection tools inherently changed their experiences. Fourth, as noted earlier, we allowed participants to stay in the study even if they missed individual surveys or interviews; while this resulted in gaps in the data for individual participants, overall participant response rates remained high, as did retention through the longitudinal study. Despite these limitations, the richness and complexity of this data set has yielded critical insights into new engineers' initial transitions from school to work.

4. Results

As noted in the previous section, our overall goal in this study is to better understand how and to what extent capstone design courses prepare students for engineering workplaces. Our findings address two research foci: the significant challenges that new engineers experience, and strategies they used to meet those challenges. To help illustrate the kinds of comments participants made within categories, we include excerpts from participants within this section. Quotations are identified by participant number; within quotations, bracketed ellipses indicate places where content has been removed for clarity or brevity, while unbracketed ellipses denote pauses in participants' speech. As noted in Table 1, most participants had internships, but we do not differentiate among demographic groups in the excerpts as our goal in this study is to provide a deep understanding of participants' challenges and strategies overall, not to compare experiences across any specific categories; such comparisons are planned for future work.

4.1 Challenges

To situate the significant challenges our participants reported in their first three months of work, we first identify what they reported actually doing in that time period, drawing on the weekly quantitative surveys. The results indicate that the most common activities across these first twelve weeks were team meetings, project planning, and engineering calculations. Fig. 3 shows the percentage of respondents who reported engaging in a given activity each month.

As Fig. 3 shows, our participants engaged in a wide range of activities that are typical of the tasks included in capstone design projects and reported across the literature on engineering work. Moreover, as expected from studies on how working engineers spend their time, the social dimensions (team meetings, planning, writing) are as or more prominent than the technical dimensions (e.g., CAD modeling, engineering calculations). Activities the participants marked as "Other" pertained mainly to training, a category not included on the quantitative survey. Within that category, the frequency drops substantially after the first month, which would align with initial onboarding practices typically present within the first few weeks of work. As to be expected, higher profile activities that depend upon knowledge of projects and understanding client relationships, such as writing reports and interacting with clients, showed increases over the span of participants' first three months on the job.

When we turn from activities to challenges, we find that our participants reported significant challenges across all five categories, with challenges related to Self-Directed Learning (reported by 49 of 53 participants) and Teamwork & Communication (reported by 48 of 53 participants) being most

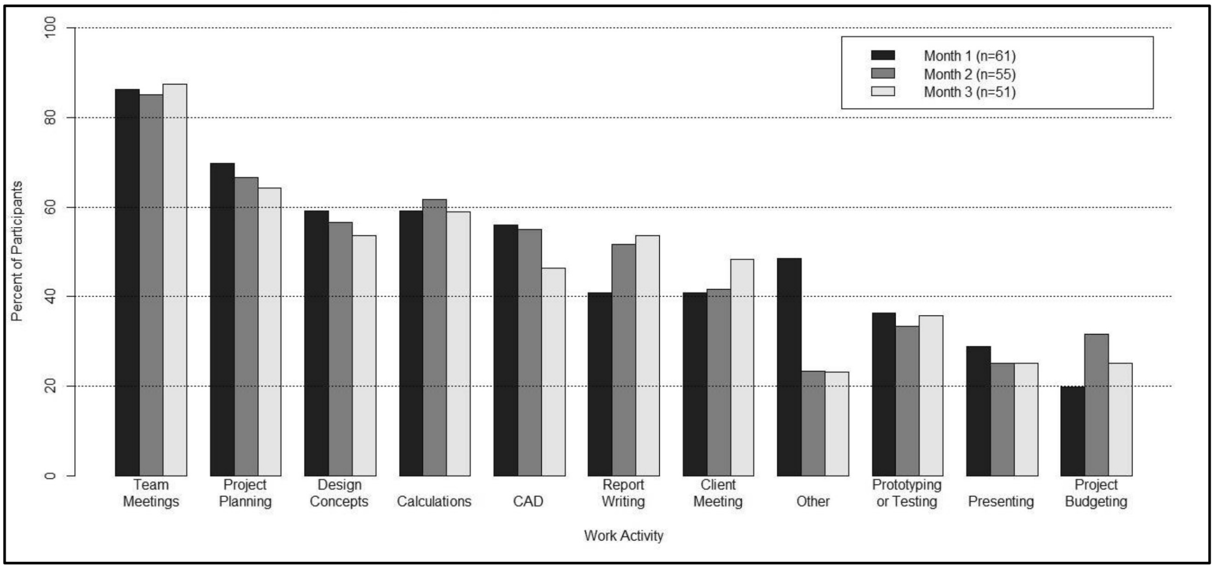

Fig. 3. Frequency of Work Activities in the First Three Months.

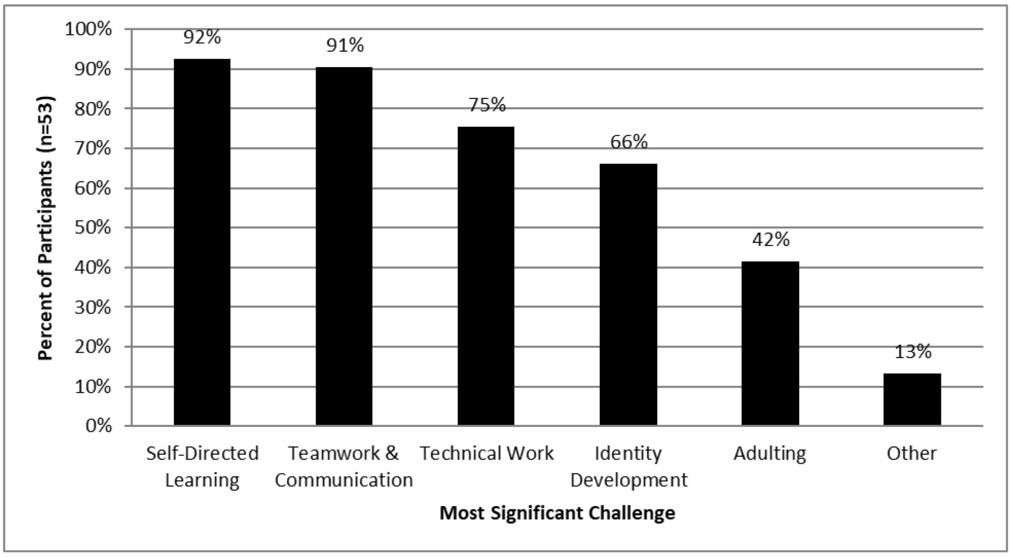

Fig. 4. Frequency of Significant Challenges Reported during the First Twelve Weeks of Work.

common. Fig. 4 shows the percentage of participants whose reflective survey responses included at least one significant challenge in a given category.

In addition to being the most common by participant—i.e., virtually all participants reported these challenges—, Self-Directed Learning and Teamwork & Communication were also the two most frequently reported categories—i.e., each participant typically cited in multiple weeks: of 962 coded challenges, 39% (357) were related to Self-Directed Learning and 27% (263) were related to Teamwork & Communication. The following subsections draw on both the reflective surveys and the interviews to provide detailed descriptions of each challenge category.

4.1.1 Self-directed learning

Self-Directed Learning, which encompasses managing and monitoring one's activities at work, was the most commonly reported category as participants described challenges associated with managing knowledge, time, and attention. The most prominent of these was managing knowledge, both in terms of not knowing how to do a given task—most often related to technical engineering work—and in terms of not knowing what resources were needed for the task or where those resources could be found. Multiple participants experienced challenges in terms of engaging in technical work they had not learned in school, as the following quotes illustrate:

> ". . . the job that I am doing is not directly related to a lot of my experience from my courses in college." [#1109]

> "The simulations used several plugins that required fairly detailed knowledge of electromagnetics, which is not really taught to [mechanical engineering] students outside of physics and a little bit in circuits classes." [#2166]

> "[Writing] the [standard operating procedure] was challenging because [my manager] asked me to write it for [specific equipment], which are pieces of equipment I don't know how to use, or much of anything about." [#4136]

> "This was tough because I had very little experience using [specific CAD package]." [#1111]

As these quotations suggest, participants lacked knowledge with respect to topics, pieces of equipment, software packages, company-specific techniques, and more. Lack of knowledge was, in fact, the most common code within Self-Directed Learning, reported 97 times in the reflective surveys across 37 participants. Often these challenges intersected with participants' needs to locate key information as they struggled to identify whom to ask or where to find relevant documentation, or were linked to joining an ongoing project for which the more experienced and knowledgeable members of the team may not have had time to bring the new engineer up to speed.

With respect to managing time, participants experienced challenges associated with tight deadlines and the pressure to finish projects under time constraints. For example, as one participant explained:

> "[. . .] it was the first time I've been a part of the final scramble before a design issue. There were a few days where we were all working kind of furiously to get the big parts of the design down and labeled, and I was getting a ton of emails about different tasks to try to complete before the issue. [. . .] I had my first experience having to stay late at the office for a deadline, which is something I have come to learn from the more experienced engineers here that I will get used to doing pretty often. The mechanical engineers in the [location] office

> working with us were also meeting and presenting to [client] today, so even today I was still being given tasks to do and presentation slides to prepare." [#3145]

A number of participants described similar experiences, but also noted the ways in which work deadlines differed from school. As one participant noted:

> "So at [University], all the timelines were hard dates; here they're all hard dates, but there's bigger consequences here if you go over time or if you have to request more time. The testing we do can be extremely expensive sometimes. We have some tests that cost $30,000 a day just to do [. . .]. If your testing runs over and it's costing your customer a lot more money, and [. . .] as engineers is our job is to try and keep costs down." [#2159]

Managing time at work is thus often more complex for new engineers not only because of the intensity of the deadlines, but also because of the associated consequences in terms of cost and business commitments.

Finally, participants also identified challenges associated with managing attention and engagement. For many, these challenges centered on lack of work; as one explained, "I've found it difficult to manage the lack of work I've gotten this week. I'm yearning to feel as part of the team and really contribute to the company's progress, but haven't had a steady stream of work that has been asked of me." [#1108] In other cases, as they shifted from a fluid student schedule to a standard industry workday, participants struggled with work that was tedious; they described challenges such as "staying focused when reading 500 page documents everyday" [#1122] or "staying focused and motivated during my 9 hour work day." [#3150]

4.1.2 Teamwork & communication

As noted in Fig. 4, almost all participants also experienced significant challenges working in teams and communicating with a range of individuals. In some cases, these challenges were associated with formal situations such as reports, presentations, client meetings, or structured team meetings, but more often, the challenges centered on informal interactions with coworkers and managers. In part, these challenges were linked to participants' status as newcomers, as in the following comment:

> "For me, in [capstone design] I felt like I could talk to the team openly about [a conflict]. We would have team meetings where I felt more comfortable to just talk about it. Whereas now, I don't feel comfortable doing that because I'm also new and I . . . At [University], I knew people. They were my friends and it was totally different to talk about it openly. Whereas here, it's like I just started and I don't want to create unnecessary tension." [#3146]

As this excerpt illustrates, participants throughout their first three months often struggled to learn to interact with more established members of their team or company. Some of these challenges centered on problems that participants were hesitant to address. Others involved the process of simply getting work done. One participant, for example, described the challenge of holding co-workers accountable for work:

> "I think [my biggest challenge is] probably interacting with the different people. I mean, I am honestly still kind of afraid to talk to my boss. He's still a little bit intimidating to me. And especially with the project management stuff, meeting all the new people and, you know, almost taking like a box figure with the project management stuff. Not officially a box; that's probably not the best word for it, but having to go up to people and be like, 'Hey, I need this by this time, can you get it to me now?' type of thing. So I think just general people interaction with professionals has been a little more difficult for me." [#1122]

In other cases, the challenges participants describe reflect the demographic shift involved in moving from a college environment surrounded by people of similar age and educational backgrounds to a more diverse workplace. One participant, for example, highlighted the need to communicate across disciplinary boundaries:

> "We had a few times where there was actual networking opportunities [within] our [Company] team. I don't know if other teams had more opportunities, but it's huge for the job right now. Just having that ability to deal with a network of people and kind of building that group of people where you can look for resources from other people, or maybe you can be a resource to somebody, and just, again, getting to know how to just communicate with a lot of people from a lot of different disciplines. That would've been one thing I would've loved to learn." [#4131]

In other cases, participants described learning to communicate across age and experience levels:

> "Another one would be that, when I was in capstone, I was managing a team of college students, ranging from the age of 21 to 24. It was very different managing that team, whereas at work, it's managing analysts who are between the ages of 25 and 55. You get that different kind of exposure to just the different age groups that could be in the real world." [#4135]

Still other participants described learning to work with unionized workers, vendors, technicians, and team members across a variety of day-to-day contexts. One participant summed it up as follows:

> "[The challenge is] keeping track of all of the different relationships between myself and the guys on the shop floor, and kind of managing those relationships as well as myself and the other engineers in my group, and then as well as myself and the customer, the ultimate customer. And I know it's very broad, but I think that sort of dynamic has been the most challenging

> thing for me. But I think that goes back to the idea of being a professional, and that's probably the most foreign thing to me." [#1120]

As these excerpts suggest, as participants transition from school to work, they have to negotiate a far more complex and diverse set of relationships in their professional lives. Communication and teamwork are among the most complex—the most "foreign"—aspects of their transition.

4.1.3 Technical work

As might be expected from the lack of knowledge described under Self-Directed Learning, participants also reported significant challenges associated with the technical aspects of their work. These challenges included pragmatic tasks such as learning new software (such as CAD packages and a full range of other products), performing calculations and analysis, and learning new equipment, as well as what might be classified as more conceptual tasks such as generating or refining design concepts and managing ambiguity. For example, one participant highlighted the challenges associated with integrating and refining design concepts as a significant challenge:

> "I think the most challenging part . . . I think probably bringing together design concepts from all of the influencers. We are a subsidiary of a company, but we're also another one of their subsidiaries, and so they're headquartered in [country] and they have an R&D group up there, and of course they also have a lot of opinions about what should and shouldn't be included on things, as well as our team does. I think getting down to the brass tacks of what needs to be on something, and kind of getting everybody on the same page and moving forward and not backtracking [is a big challenge]." [#1113]

As this excerpt illustrates, such technical challenges are also often linked to Teamwork & Communication challenges—here "getting everybody on the same page" and dealing with diverse opinions.

In other cases, the technical challenges were much more pragmatic, linked to the workings of a particular piece of equipment or software. One participant, for example, described traveling with their boss for a demonstration at a customer site:

> "My boss had actually gone down the week before with the unit and couldn't get [the equipment] to work. I drove down on Sunday with [a new] one] and set it up Monday. We were doing a demo on Tuesday. By the time the demo came around, everything was okay, but Monday, there were parts that were in the wrong place. There was a gas leak in part of the gas train. Getting help at the facility was really difficult. Everything that could've gone wrong did." [#1105]

Also prominent were technical challenges associated with learning new software packages. Participants' reflective journals detailed their struggles in "learning to navigate [Company's] internal systems for creating and tracking parts and jobs," [#2418] "learning how to use all of the specific programs for the different aspects of my job," [#2485] "learning Microsoft PowerPoint professional," [#1314] "working with outdated software to perform simulations that exceeded the normal scope of what was taught at [University] with this software," [#4682] and a range of similar experiences. In some cases, these challenges were with CAD packages, but more often they were with myriad company-specific software tools integral to the work at hand.

Notably, while a majority of our participants reported significant challenges in their technical work during their first three months, these challenges were far less pervasive and prominent than those associated with Self-Directed Learning and Teamwork & Communication in that they were reported as the most significant challenge only once or twice for a given participant.

4.1.4 Identity

Challenges in Identity Development are those associated with how participants perceived themselves as engineers and/or employees, including learning their roles, feeling a part of the group, feeling competent, and thinking like an engineer. Approximately two-thirds of participants reported challenges associated with their identity as engineers; not surprisingly, among the codes in this category, "feeling competent" was the most common challenge. In some cases, participants' perceptions of competence were linked to the demographic shift described earlier. One participant described it as follows:

> "I don't really have anyone around my age to compare myself with. I feel like if I came in with the whole class of new hires just out of college, I could compare notes and be like. "Oh you know compared to this guy, I'm way ahead of him, but this guy knows a lot more than me" and something. The two owners of my company are both like 50 years old. . . They have been working in robotics for like 30 years. The electrical engineer I work with is like 40 and he has like two PhDs and stuff. The other designers are like 30. One guy is my age, but he didn't go to college." [#4137]

As this participant notes, many new graduates move from a school context in which all of their colleagues are at roughly the same level of experience into environments where they are the only or one of a few new hires, and their lack of knowledge and experience is immediately apparent.

This perceived lack of competence was also linked to both lack of knowledge and a strong desire to contribute to the company in many cases; as one participant explained:

> "I wanna figure out how I can make myself an

important asset to [Company], instead of just being someone who can do anything that's asked of me. It's just hard for me to figure out how to do that when I'm still trying to figure out everything else and understand a project. But the appraisal season is coming up. I have my appraisal with my supervisor next week. We have to have an impact plan for how we want to progress ourselves in the upcoming year. I think just something that I'm trying to focus on is how to make myself an important piece of the mechanical team. [Co-worker 3] is really good at [specific program] modeling. [Co-worker 4] is really good at doing the controls. I want to become some sort of asset like that. I can master one piece and I can help other people with it. But it's just hard for me, because I don't know all the moving pieces of projects yet. It's hard for me to know what is needed.'' [#3145]

Many participants were acutely aware of what was expected of them and, even as they may have reported feeling generally prepared in their weekly quantitative responses, struggled with their inability to contribute productively given how much they needed to learn. Often this perception represents a marked shift from their experiences in school, as the following comment suggests:

> ''I have to . . . I don't know, I just really was hoping that I would be doing more hard engineering. Because I felt like I needed something there; I felt that there wouldn't be that steep learning curve [at work] and I could use knowledge I'd already gained. I wouldn't have to go through and still feel like I'm in school almost. The first day they handed me a textbook and said, 'Yeah you need to read this.' I went, 'okay.' But just feeling like I'm lost again. Just not expecting to feel that way after I got out of school. I was shocked to my system and I had to get over with.'' [#2171]

As illustrated by the experiences in Self-Directed Learning, almost all of our participants quickly recognized that they lacked key knowledge and skills needed for their current job, and this lack of knowledge challenged their identities as competent engineers. At the same time, as the excerpt above suggests, many participants also quickly learned ''to get over it'' and came to recognize that while they were still learning, they were also capable of developing the needed competencies.

4.1.5 Adulting

The four categories described previously focus on students' experiences at work, and align with the *a priori* categories that formed the primary lens for our analysis of the data. The final category of challenges, Adulting, reflects participants' experiences associated with being an independent adult working full time. These challenges include a range of non-work personal tasks such as buying a car or choosing health insurance, as well as challenges in balancing their professional and personal lives. At times, these Adulting challenges eclipse the challenges experienced on the job. Approximately a third of participants discussed such challenges in their reflective journals (22 of 53) and 3-month interviews; like Technical Work, however, such experiences typically occurred only once or twice during the first three months.

Like the shift in demographic context, new engineers also experienced a significant shift in the structure of their time. In response to the question about advice for new graduates, one participant put it this way:

> ''I think I'm also probably just getting a little bit burned out. So I think that's probably another thing I would give advice to is take care of yourself and if you feel burnt out, make sure that you prioritize yourself as well. Yeah. I haven't, at least the past month, I haven't been doing things that were helpful for me. I used to go to the gym a lot more frequently as a stress reliever, and the last month I haven't been able to do that. So I haven't been really necessarily taking care of myself because of my job. So I guess prioritizing yourself, too. Making sure that work life balance is in balance and not one thing taking over another.'' [#3147]

In several cases, work/life balance challenges result from travel, as in the following example:

> ''The other thing, I think, that a lot of people, I think, that is challenging at work is, the travel aspect of it. 'Cause they book our flights at, relatively, good times; like late afternoon, so you can go get a half day of work in, and then go travel the rest of the day. Sometimes, travel is very unexpected, and sometimes you get a six hour delay in Detroit, and you have to sit in the airport, and just wait for your flight to come. I guess that's another challenging part. Just the little things about, like just [inaudible], and not being able to sleep in your own bed, and that kind of thing. Thinking that you're, 'Okay, well I have to travel for work.' It's kind of like work is making this challenging for me. You know?'' [#4135]

And finally, as noted above, Adulting challenges include life tasks that participants do not encounter in school. As one explained, he was ''not prepared to be an adult—many benefits and 401k things that I wish I had known in school.'' [#1106].

4.2 Strategies

While participants experienced a range of significant challenges during their first twelve-weeks of work, they also reported both feeling generally prepared for their work environments and having a full range of strategies to help them address those challenges.

With respect to preparedness, participants reported their perceived preparedness for each of the identified activities on a 7-point scale with 7 being ''Completely prepared'' and 1 being ''Completely unprepared.'' Although there were some tasks for which participants felt less prepared, overall participants' perception of preparedness indicates that capstone design courses and the

Table 3. Average Perceived Preparedness for Activities Reportedly Engaged in during the First Twelve Weeks of Work

Activity*	Average Perceived Preparation	Average Minimum Preparation
Presentations (n = 26)	6.1	5.7
Report Writing (n = 39)	6.1	5.4
Team Meetings (n = 56)	6.0	5.0
Engineering Calculations (n = 43)	5.9	5.2
Prototyping/Testing (n = 29)	5.9	5.0
Client Meeting (n = 36)	5.7	5.1
Design Concepts (n = 41)	5.6	4.8
CAD Modeling (n = 38)	5.6	4.8
Project Planning (n = 50)	5.5	4.7
Other (n = 36)	5.5	4.9
Budgeting (n = 23)	5.1	4.3

* n = number of participants reporting the activity and thus included in the average.

engineering curriculum broadly do build students' confidence in their technical and professional abilities. Table 3 reports the average perceived preparedness score across the twelve weeks for all participants reporting an activity, as well as the average of the lowest score reported by each participant for each activity.

Given that 4 was "Neither prepared nor unprepared" and 5 was "Slightly prepared," the data here suggest that in general, participants rarely found themselves wholly unprepared for their work experiences, although often their sense of preparation may have been only slight or moderate.

Notably, these data reflect only participants' perceptions of their preparedness, which may not correspond to manager or supervisor perceptions. However, the data do capture perceptions over a substantial time period in which these new engineers negotiated numerous challenges, received feedback from supervisors about their performance, and—perhaps in part because of the reflective practices promoted by the study itself—engaged in thoughtful self-evaluation of their work in the context of the expectations and practices of their coworkers. Thus their self-perceptions, particularly when considered across the full twelve weeks, are contextualized within the expectations of their workplaces.

This strong level of self-reported preparedness is echoed in participants' ways of approaching their most significant challenges. Our participants encountered a range of complex challenges in their first three months of work, but the reflective journals and interviews indicated that they also had an array of strategies to address those challenges. Fig. 5 summarizes these strategies, again displaying the percent of participants who reported employing a given strategy at least once during their first twelve weeks.

As described earlier, the codes for strategies emerged from the data itself, with the exception of "Drawing on capstone." Since the reflective survey specifically prompted participants to reflect on whether and how their capstone design course helped prepare them for the challenge, it is not surprising that "Drawing on capstone" was a common code, and the question itself may have acted as a metacognitive prompt that increased participants' tendency to draw on their capstone courses in addressing challenges.

The most common strategy across participants, as shown in Fig. 5, was talking with people. Throughout both the reflective journals and the interviews, participants recount instances of observing and asking for help from coworkers, supervisors, technicians, and other colleagues as a means to address their lack of knowledge and to learn more about their role and the organization as a whole. While participants also sought resources such as websites, internal company documentation, manuals, and other informational material, interacting with other employees—whether formally assigned mentors or simply other colleagues—was the dominant approach to addressing the full range of significant challenges. Comments such as the following were frequent across the data set:

> "I reached out to our parts room supervisor and asked what he knew about the processes." [#1118]

> "I talked to more experienced engineers about modifications I could make to the design to improve it. I used some of their suggestions for my new design." [#1123]

> "I asked questions of the other people working on the task." [#2166]

> "I just started to talk to people. And I lowered the threshold at which I get help." [#4127]

Participants also highlighted ways in which these interactions supported not just immediate knowledge acquisition, but also relationship building and engagement. As one explained:

> "Talking to different engineers and asking questions has been the biggest way for me to learn, because I can ask the same question to four people and get four different answers, and that ultimately helped me gain the knowledge as well as the perspective from four different people. But I think at the end of the day it [also] helps me to keep from not being bored, so if I'm working on something and I kind of get it but I could probably figure it out on my own, it's a whole lot easier for me to just go find a person who I know knows and talk to them and maybe chat for a little bit." [#1120]

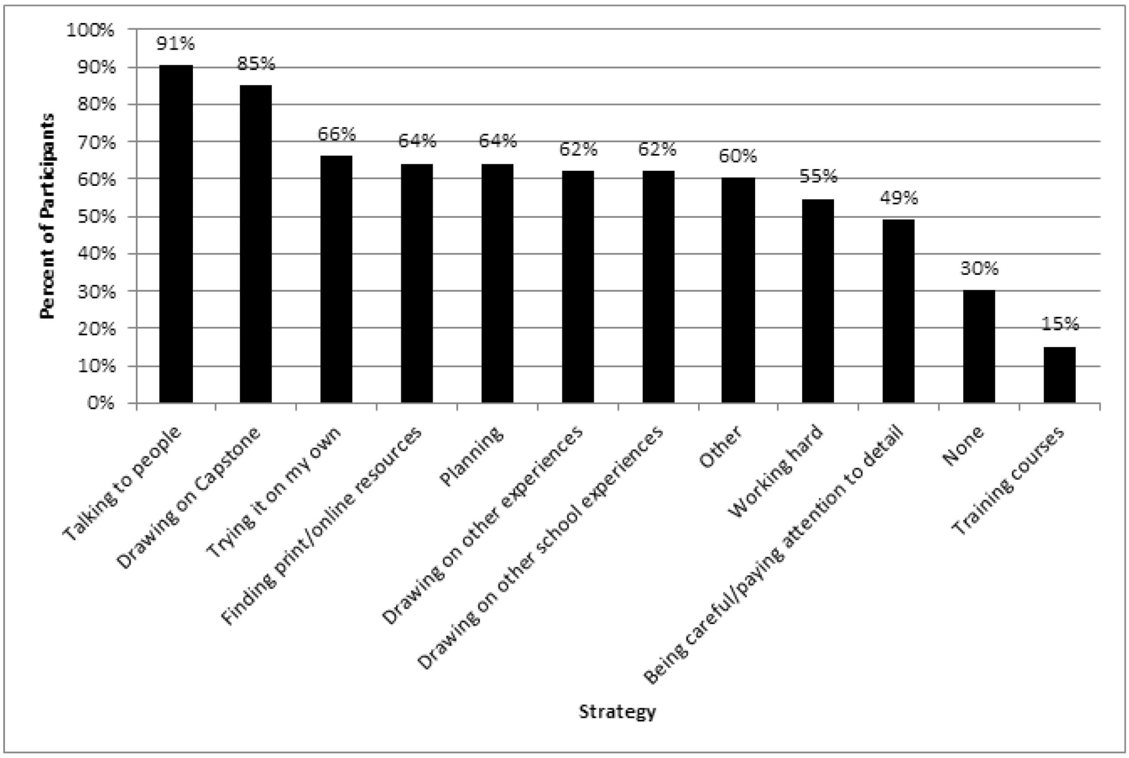

Fig. 5. Frequency of Strategies Used to Address Challenges as Reported in Reflective Journals.

These interactions also helped new engineers build confidence in their work more broadly, as suggested in the following comment:

> "I reviewed [my work] with my senior engineer three or four times, and each revision I understood what I knew was unclear was wrong, and then I got a little bit better. Then [Date], we ended up releasing it. That was good because I saw where I started from and why I had a crappy one before. Then four iterations later I saw what was acceptable, what was good, what was better than good." [#1111]

Such interactions were pervasive across new engineers' experiences and formed a central tool participants used to address the challenges they experienced in their transition to professional work.

While talking to people in their current environment was the dominant strategy, most participants also drew on their capstone design courses to help address workplace challenges. To illustrate where and how capstone experiences were relevant, Fig. 6 displays the percent of participants who reported drawing on their capstone courses to address challenges by category.

While participants drew on capstone in ways related to each of the challenges, Self-Directed Learning was by far the most prominent area of transfer, not only in absolute terms (i.e., total number of participants), but also relative to the number of participants experiencing a given challenge. That is, 49 participants reported challenges relative to Self-Directed Learning, and 45 drew on capstone experiences in this area; in contrast, 40 participants reported challenges in Technical Work, but only 24 drew on capstone in this area. Such patterns would be expected given that a primary goal of capstone design courses and instructors is to provide students with real-world scenarios that push them to apply their knowledge to unfamiliar, open-ended problems. One participant, in response to an interview question about similarities between their capstone experience and their work experience, framed it this way:

> "I guess the general . . . just being able to absorb new information very quickly; that's been the biggest similarity [to capstone], I think, and being able to retain that information and apply it to different systems. Just the general trying to figure out the next step before . . . [My capstone professor] would always tell us to instead of waiting for your [industry] liaisons, just jump into it, and then ask them what to do differently and how to improve the process and to essentially guide us into the right direction after we've attempted it. I think that's been a big part of the job as well, just because there are only like three leads, and there are like 20 of us, so it's hard for them to be everywhere all at once. It's like moving onto the next step: if I have a question, to ask it, but also if I can't ask someone, just to try to figure it out, think through it logically and just go through that process. I guess that's been the biggest similarity." [#3155]

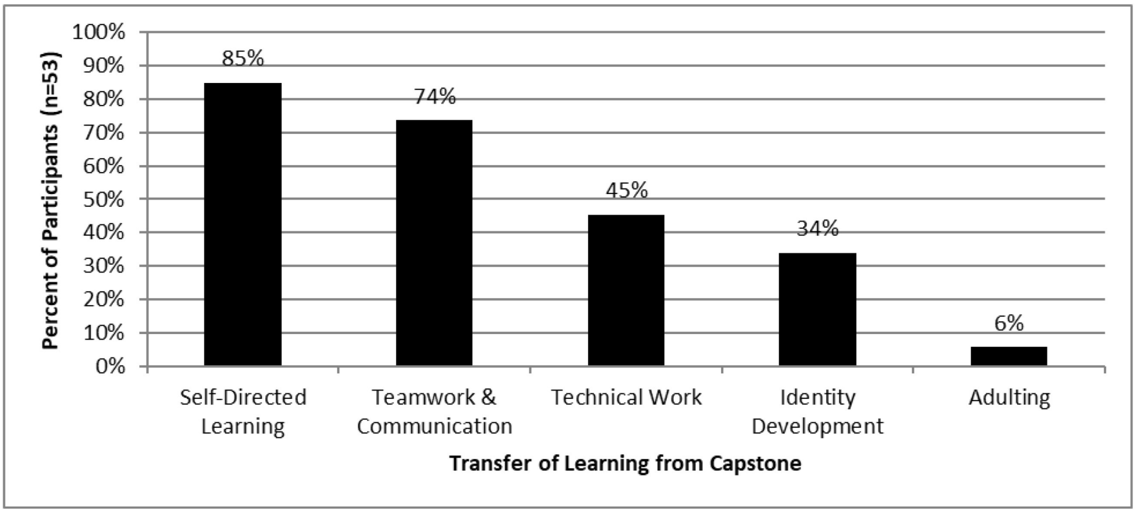

Fig. 6. Frequency of Drawing on Capstone Design Experiences to Address Challenges.

Capstone experiences played a similarly prominent role in helping participants address challenges related to Teamwork and Communication; 48 participants reported challenges in this area, and 39 reported drawing on capstone design. Areas of transfer ranged from the overall practice of working in teams and managing projects to interacting with clients and supervisors professionally to negotiating conflicts, as the following examples suggest:

> "I felt very prepared for [this challenge]. Having to convince someone smarter and older than you about something you have researched more thoroughly than them could be the motto of the [university] capstone course." [#4136]
>
> "Based on my capstone experience, I felt fairly prepared because I didn't know anyone on the team originally but still had to learn to work with them." [#1109]
>
> "As far as the design course I took goes that really helped me in terms of communication and understanding the nuances of professional courtesies and etiquette especially when it comes to Skype calls or video conferencing." [#4128]

Across our participants, capstone courses provided experiences that help them learn to interact with a range of colleagues in a variety of contexts.

As indicated in Fig. 6, participants also transferred knowledge about Technical Work and perceptions of competence (Identity Development), but at much lower rates, as would be expected given that most our participants moved into positions that differed from their capstone experiences and shifted from being seniors at the end of their college careers to be being brand new engineers among teams of far more experienced individuals.

5. Discussion

Our findings relative to the activities and significant challenges participants report during their first three months of work align with and extend findings from prior research on both engineering work and student transitions. Consistent with findings from Bucciarelli [6], Anderson et al. [8], Stevens et al. [4], and others, our participants engaged in what might be considered the traditional "technical" engineering work of CAD modeling and calculations within larger socio-cultural team-based contexts: team meetings, informal interactions with coworkers at all levels, and meetings with clients surrounded and in some cases dominated the technical work. And as Korte [33], Brunhaver et al. [40]], and Lutz [34] all noted, much of the newcomer transition experience is grounded in social interactions. Among our participants, interactions with managers and coworkers represented some of the most significant challenges they experienced in moving from school to work, but also represented a primary strategy for addressing challenges and learning on the job. The findings reported here demonstrate both the pervasiveness and the complexity of negotiating these interactions.

In addition to confirming and deepening earlier findings for a new generation of engineers, however, this study also points to the critical role that the project-based, industry-oriented capstone courses at the heart of this study played in preparing students for the transition to work. As noted earlier, studies of capstone faculty nationally highlight the importance this group places on creating course environments that simulate authentic industry experiences [16, 23, 24]. Capstone faculty nationally provide projects that push students not only to integrate prior knowledge but also to learn new skills; simultaneously, they role model the professional behaviors and attitudes essential to professional work and create course structures that seek to foster those behaviors and attitudes in students [41]. The courses from which our participants are drawn exemplify these practices, and the value of this approach is evident in both the challenges students face and the extent to which they perceived their capstone experiences as effective preparation for those challenges.

Perhaps most notable in this context is the prominence of self-directed learning. Our participants consistently faced projects, equipment, and software that were unfamiliar, and encountered concepts that they had not learned in school. A substantial percentage of their significant challenges in the first three months involved learning complex new information. This heavy demand for lifelong learning—despite its recent removal from accreditation criteria as an essential student outcome [12]—aligns closely with the emphasis in capstone design courses on open-ended design projects that push students outside their comfort zone to acquire and apply new knowledge and skills. Importantly, beyond presenting students with challenging open-ended projects, the capstone courses our participants experienced also focused strongly on mentoring students through that learning process. Consistent with larger national trends in which faculty report helping students learn how to learn (rather than providing answers) [23, 24, 41], participants in this study noted the ways their capstone mentors prepared them for this self-directed learning through coaching and modeling effective learning behaviors. These findings—the prominence of self-directed learning challenges and the role that capstone design plays in preparing students to face those challenges—underscore the need to scope capstone projects that mirror the open-ended, multifaceted problems characteristic of engineering workplaces [4]. At the same time, the findings also reinforce the importance of developing capstone faculty's ability to effectively mentor students through such projects—a type of guidance Adams et al. refer to as "integrated knowing" [27] that represents the unique pedagogical content knowledge of design educators.

The reported challenges and strategies also point to the importance of professional communication and teamwork practices in the capstone course, and extend the scope of what those skills entail. Beyond formal report writing, presentations, and structured team meetings, both the challenges and the strategies described by our participants relied heavily on interpersonal communication and interactions with a highly diverse group of people—diverse in terms of ages, education levels, and project roles. Each of the capstone courses in this study, like other such courses nationally [15], focus on teamwork and communication, including formal and informal interactions as well as conflict management, professional demeanor, and related skills. These teamwork and communication practices formed a significant source of preparation and transfer for the participants in this study, and highlight the need to conceptualize the capstone course in terms that reach well beyond "design" as a narrowly technical process.

While capstone courses can provide opportunities for students not only to expand their capacities in self-directed learning, teamwork and communication, and technical work, but also to build their identities as engineers, there are important dimensions of the transition from school to work that capstone design courses cannot replicate. For example, while capstone courses can begin to prepare students for the kinds of team dynamics they will experience at work, that preparation is limited in that, given the context of a university course, students typically only interact with a fairly narrow band of individuals. Capstone teams may be diverse in terms of gender, race, or ethnicity, but are rarely diverse in terms of experience levels, education levels, or age. Yet these are key differences between school and work that pose challenges as individuals transition from one environment to the other. Industry-oriented projects, where students do have the chance to engage with more experienced engineers, can offer some diversity in terms of age, as can opportunities for students to engage professionally with technicians, lab managers, and others in fabrication environments. But even in the best circumstances, such interactions are necessarily limited and students' dominant interactions in most universities are with equal peers and with faculty; exceptions, of course, would be programs with high populations of non-traditional adult students. This gap points to the need for companies to consider how best to transition new engineers into a more diverse work environment. Capstone courses can promote attitudes, but can rarely provide representative experiential learning in this space.

Similarly, while capstone projects can simulate some workplace challenges in terms of time pressures and competing demands, they cannot fully replicate the financial and business consequences found in industry or the time constraints of a workplace in which their professional colleagues work during business hours and head home to families and personal lives after work. Participants in this study noted differences such as being able to devote as much time as needed to school tasks, while work tasks must often be billed under budget constraints (particularly, for example, in consulting work). Similarly, they noted that while their student teammates were able to get together and work late into the night, in many cases their new work colleagues headed home at the close of the business day.

Finally, consistent with Huff et al.'s work on new engineers' professional identity trajectories [35, 42], capstone design courses—and even engineering curricula broadly—cannot prepare students for the broader challenges of emerging adulthood as they seek to separate and balance their developing personal lives with their professional commitments. Experiences such as buying insurance, setting up households, and learning to schedule personal tasks such as exercising and socializing after-hours influence how students experience the transition to work, but again, are well beyond the scope of capstone courses, and in fact, generally beyond the contemporary residential university. Traditional undergraduate students simply have fewer adult responsibilities and have the freedom to intermingle work and personal activities much more flexibly than post-graduation professionals.

6. Conclusions

This paper describes results from a study investigating engineering students' transitions from academic to professional environments and the role that capstone design courses play in preparing graduates for the workplace. After recruiting participants from four different institutions as they completed their capstone design experiences, we followed them through their first three months of work through weekly surveys about work activities and perceived preparedness and weekly reflective journal responses about significant challenges. We were especially interested in the following two research questions: (1) What significant challenges do new engineers experience as they transition from academic programs to professional engineering workplaces?, and (2) What strategies do new engineers use to meet those challenges?

The results of the quantitative and qualitative data analysis indicate that participants engaged in a wide range of tasks during their first twelve weeks of work, often with social dimension tasks occurring as frequently or more often than technical dimension tasks. Within the various tasks, self-directed learning and interpersonal communication were the most commonly reported challenges, followed by technical work, identity development, and adulting. Participants reported feeling generally prepared for the tasks and having a full range of strategies—including talking to people and drawing on capstone—to address the challenges they faced. In particular, participants drew on their capstone experiences for all types of challenges, especially those related to self-directed learning.

Capstone courses have the potential to play a large role in successfully preparing new graduates for the tasks and challenges they are likely to encounter in their professional work environments, yet we do recognize the hazards of treating the capstone course as a catch-all for covering professional skills and topics deemed desirable for graduates. It is important to remember that school provides baseline knowledge, but engineers will enter workplaces with steep learning curves where they will perform activities they did not learn in school. No matter what the structure of a capstone course, some things simply cannot be replicated, such as age diversity, the cost of time, and workday demands. Beyond the impossibilities of replicating irreplaceable circumstances, capstone courses already suffer from being overloaded with demands of teaching multiple technical as well as organizational and communication skills; to add more would likely stretch the capacity of existing resources and dilute the depth of topics covered. Organizations hiring engineering graduates must share a role in facilitating successful school-to-work transitions by enculturating new employees and providing them with the training and resources necessary to be able to draw upon their educational preparation, including the experiences from the capstone course. Ideally, new engineers' academic grounding and industry onboarding experiences act in concert to result in productive, effective, and satisfying work.

7. Future work

While the findings presented here represent a major contribution to our understanding of the role of capstone design courses in new engineers' transitions from school to work, more work remains. Notably, data collection for the present study is currently underway with a second cohort of students from the four study sites. This expanded data set will allow us to check for cohort effects and provide a larger data set that will better support statistical analysis. We can also then analyze the full data set to explore not only patterns beyond the first three months, but also examine the impact of variables such as study site, company size, employment sector, and gender. Notably, a comparison between the mechanical engineering and engineering science programs can also help illuminate the extent to which challenges are discipline-specific. The full data set also offers opportunities to build on work by Huff et al. [35, 42] in engineering identity to better understand how individuals experience identity trajectories as they move from students to practicing engineers. With this full data set, we look forward to providing recommendations that can shape future pedagogical decisions as well as help inform industry onboarding practices.

Acknowledgments—This material is based upon work supported by the National Science Foundation under Grant Number 1607811. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

1. A. J. Dutson, R. H. Todd, S. P. Magleby and C. D. Sorensen, A Review of Literature on Teaching Engineering Design Through Project-Oriented Capstone Courses, *Journal of Engineering Education*, **86**(1), pp. 17–28, January 1997.
2. D. H. Jonassen, Engineers as Problem Solvers, in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds. Cambridge, UK: Cambridge Univ. Press, 2014.
3. S. M. Lord and J. C. Chen, Curriculum Design in the Middle Years, in *Cambridge Handbook of Engineering Education Research*, A. Johri and B. M. Olds, Eds. Cambridge, UK: Cambridge Univ. Press, pp. 181–200, 2014.
4. R. Stevens, A. Johri and K. O'Connor, Professional Engineering Work, in *Cambridge handbook of engineering education research*, A. Johri and B. M. Olds, Eds. Cambridge, UK: Cambridge University Press, pp. 119–137, 2014.
5. G. L. Downey, The Engineering Cultures Syllabus as Formation Narrative: Critical Participation in Engineering Education Through Problem Definition, *University of St. Thomas Law Journal*, **5**(1), pp. 428–456, 2008.
6. L. L. Bucciarelli, Design Knowing and Learning: A Socially Mediated Activity, in *Design Knowing and Learning: Cognition in Design Education*, W. C. Newstetter, C. Eastman, and M. McCraken, Eds. Oxford: Elsevier Science Ltd, pp. 297–313, 2001.
7. L. L. Bucciarelli, *Designing Engineers*. Cambridge: The MIT Press, 1994.
8. K. J. B. Anderson, S. S. Courter, T. McGlamery, T. M. Nathans-Kelly and C. G. Nicometo, Understanding engineering work and identity: a cross-case analysis of engineers within six firms, *Engineering Studies*, **2**(3), pp. 153–174, 2010/12/01 2010.
9. C. A. Lauff, J. Weidler-Lewis, K. O'Connor, D. Kotys-Schwartz, and M. E. Rentschler, Undergraduate to Professional Engineering Design: A Disconnected Trajectory?, in *American Society for Engineering Education Zone IV Conference*, Long Beach, CA, 2014.
10. American Society of Mechanical Engineers, *V2030 Research—Drivers, Data, Action and Advocacy*, American Society of Mechanical Engineers, New York, NY2013.
11. American Society of Mechanical Engineers Center for Education, *Vision 2030: Creating the Future of Mechanical Engineering Education*, American Society of Mechanical Engineers, New York, NY2011.
12. ABET Engineering Accreditation Commission, *2018–2019 Criteria for Accrediting Engineering Programs*, ABET, Baltimore, MD2017, Available: www.abet.org/wp-content/uploads/2018/02/E001-18-19-EAC-Criteria-11-29-17.pdf, Accessed on: 24 January 2019.
13. R. H. Todd, S. P. Magleby, C. D. Sorensen, B. R. Swan and D. K. Anthony, A survey of capstone engineering courses in North America, *Journal of Engineering Education*, **84**(2), pp. 165–174, April 1995.
14. S. Howe, Where are we now? Statistics on capstone courses nationwide, *Advances in Engineering Education*, **2**(1), pp. 1–27, 2010.
15. S. Howe, L. Rosenbauer, and S. Poulos, The 2015 capstone design survey results: current practices and changes over time, *International Journal of Engineering Education*, **33**(5), pp. 1393–1421, 2017.
16. J. J. Pembridge and M. C. Paretti, The current state of capstone design pedagogy, in *American Society in Engineering Education Annual Conference and Exhibition*, Louisville, KY, 2010.
17. D. Davis, S. Beyerlein, P. Thompson, K. Gentili, and L. McKenzie, How Universal are Capstone Design Course Outcomes, presented at the *American Society for Engineering Education Annual Conference and Exposition*, Nashville, TN, 22–25 June, 2003.
18. D. C. Davis, S. W. Beyerlein and I. T. Davis, Development and Use of an Engineer Profile, in *American Society for Engineering Education Annual Conference and Exposition* Portland, OR, p. Session 3155, 2005.
19. S. Beyerlein, D. Davis, M. S. Trevisan, P. Thompson and O. Harrison, Assessment Framework for Capstone Design Courses, in *American Society for Engineering Education Annual Conference and Exposition*, Chicago, IL, p. Session 1444, 2006.
20. D. Davis, S. Beyerlein, O. Harrison, P. Thompson, M. S. Trevisan and B. Mount, A Conceptual Model for Capstone Engineering Design Performance and Assessment, in *American Society for Engineering Education Annual Conference and Exposition*, Chicago, IL, p. Session 1237, 2006.
21. D. C. Davis, K. Gentili, M. S. Trevisan, R. K. Christianson and J. F. McCauley, Measuring Learning Outcomes for Engineering Design Education, in *American Society for Engineering Education Annual Conference and Exposition*, St. Louis, MO, p. 7 pp, 2000.
22. B. D. Jones, C. M. Epler, M. Parastou, L. M. Bryant and M. C. Paretti, The Effects of a Collaborative Problem-Based Learning Experience on Students' Motivation in Engineering Capstone Courses, *Interdisciplinary Journal of Problem-based Learning*, **7**(2), 2013.
23. J. J. Pembridge, *Mentoring in engineering capstone design courses: Beliefs and practices across disciplines*, Ph.D. Doctoral Dissertation, Engineering Education, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2011.
24. J. J. Pembridge and M. C. Paretti, An examination of mentoring functions in the capstone course, in *American Society in Engineering Education Annual Conference and Exhibition*, Vancouver, BC, Canada, 2011.
25. C. D. Pérez, A. J. Elizondo, F. J. García-Izquierdo and J. J. O. Larrea, Supervision typology in computer science engineering capstone projects, *Journal of Engineering Education*, **101**(4), pp. 679–697, 2012.
26. M. V. Manuel, A. F. McKenna and G. B. Olson, Hierarchical model for coaching technical design teams, *International Journal of Engineering Education*, Article **24**(2), pp. 260–265, 2008.
27. R. S. Adams, T. Forin, M. Chua, and D. Radcliffe, Characterizing the work of coaching during design reviews, *Design Studies*, **45**, pp. 30–67, 2016.
28. B. D. Lutz and M. C. Paretti, Exploring student perceptions of capstone design outcomes, *International Journal of Engineering Education*, **33**(5), 2017.
29. C. A. Carrico, K. E. Winters, S. R. Brunhaver and H. M. Matusovich, The pathways taken by early career professionals and the factors that contribute to pathway choices, in *119th ASEE Annual Conference and Exposition, June 10, 2012—June 13, 2012*, San Antonio, TX, United states, 2012: American Society for Engineering Education.
30. K. E. Winters and H. M. Matusovich, Career goals and actions of early career engineering graduates, *International Journal of Engineering Education*, **31**(5), pp. 1226–1238, 2015.
31. S. R. Brunhaver, S. K. Gilmartin, M. M. Grau, S. Sheppard and H. L. Chen, Not all the same: A look at early career engineers employed in different sub-occupations, in *120th ASEE Annual Conference and Exposition, June 23, 2013—June 26, 2013*, Atlanta, GA, United states, 2013: American Society for Engineering Education.
32. S. R. Brunhaver, H. M. Matusovich, R. A. Streveler and S. D. Sheppard, Understanding engineering students' professional pathways: a longitudinal mixed-methods study, in

ASEE Annual Conference & Exposition, New Orleans, LA, 2016, p. 10 pp: American Society for Engineering Education.
33. R. F. Korte, How newcomers learn the social norms of an organization: A case study of the socialization of newly hired engineers, *Human Resource Development Quarterly*, **20**(3), pp. 285–306, 2009.
34. B. Lutz, *Into the Workplace: Exploring the Learning Experiences of Recent Engineering Graduates during the School-to-Work Transition*, PhD, Engineering Education, Virginia Tech, Blacksburg, VA, 2017.
35. J. L. Huff, J. A. Smith, B. K. Jesiek, C. B. Zoltowski and W. C. Oakes, Identity in Engineering Adulthood: An Interpretative Phenomenological Analysis of Early-Career Engineers in the United States as They Transition to the Workplace, *Emerging Adulthood*, p. 2167696818780444, 2018.
36. S. Zirkel, J. A. Garcia, and M. C. Murphy, Experience-Sampling Research Methods and Their Potential for Education Research, *Educational Researcher*, **44**(1), pp. 7–16, 2015.
37. R. K. Yin, *Case Study Research: Design and Methods*, 5th ed. Thousand Oaks: Sage Publications, 2014.J.
38. M. Hektner, J. A. Schmidt and M. Csikszentmihalyi, *Experience Sampling Method: Measuring the Quality of Everyday Life*, Thousand Oaks, CA: Sage, 2006.
39. M. B. Miles, A. M. Huberman and J. Saldaña, *Qualitative data analysis: A methods sourcebook*, 3rd ed. Thousand Oaks, CA: Sage, 2014.
40. S. R. Brunhaver, R. Korte, M. Lande and S. Sheppard, Supports and barriers that recent engineering graduates experience in the workplace, in *2010 ASEE Annual Conference and Exposition, June 20, 2010–June 23, 2010*, Louisville, KY, United states, 2010: American Society for Engineering Education.
41. J. J. Pembridge and M. C. Paretti, Characterizing Capstone Design Teaching: A Functional Taxonomy, *Journal of Engineering Education* Accepted February 2019, forthcoming.
42. J. L. Huff, Psychological journeys of engineering identity from school to the workplace: How students become engineers among other forms of self, 3669254 Ph.D., Purdue University, Ann Arbor, 2014.

Appendix 1: Capstone Design Learning Objectives from Four Sites

Site A:

- Design mechanical and/or thermal systems using engineering, science, and mathematical methodologies. The design process includes the following steps: problem recognition and definition, concept generation and selection, design communication and review, and project management.
- Understand the following: team dynamics, ethical responsibilities of the engineer, generation and protection of intellectual property, professionalism in behavior and dress, and design documentation.

Site B:

- Gain a thorough overview of the design procedure that is followed by today's mechanical engineers.
- Obtain an understanding of design principles and practices that should assist them in making informed design decisions and in solving complex problems.
- Develop the framework for understanding how various mechanical engineering technologies are used in the design process.

Site C:

- Design an appropriate solution to a real-world engineering design problem.
- Understand, apply, and manage the engineering design process.
- Communicate effectively through oral, written, and visual means.
- Work effectively as a member of a diverse team.
- Exercise professional responsibility, ethical reasoning, and contextual awareness.
- Evaluate academic experience and professional training in light of future career and educational goals.

Site D:

- Develop an understanding of the necessary professional skills needed to succeed in industry.
- Understand how to collaboratively work in a team toward a common design.
- Become proficient at written technical communications.
- Become proficient at oral technical communications.
- Become proficient at managing long term projects.
- Become proficient at integrating technical skills to successfully complete a project.
- Develop the knowledge and ability to use skills in heat transfer, fluid mechanics, circuits, etc. to perform engineering analysis.
- Generate alternative design concepts and evaluate using design requirements.
- Apply engineering design skills to create CAD models and drawings to build professional prototypes.
- Use results of engineering analysis to make decisions (engineering and business) in a methodical manner
- Fabricate and test physical prototypes to help make decisions.

Appendix 2: Full Codebook

Code	Subcode	Definition
Adulting	Challenges associated with being an adult in the world rather than a student, being independent, including . . .	
	Non-work Personal Tasks	Balancing personal and professional aspects of life (e.g., having enough time for personal things, being tired at work because of personal activities)
	Work/Life Balance	Anything associated with life outside work (buying a car, opening a bank account, relationships, family, etc.)
Technical Work	Challenges associated with engineering design and technical work, including . . .	
	Ambiguity/Uncertainty in Design	. . . uncertainty in the design process itself—e.g., not knowing which design decision to make or which approach to take
	CAD Modeling	. . . modeling something using CAD or learning CAD software
	Engineering Calculations	. . . performing engineering calculations
	Engineering Design- Other	. . . any other aspect of technical engineering work
	Equipment	. . . learning or working with new equipment
	Generating/Refining Design Concepts	. . . creating or developing design concepts or plans
	Problem/Requirement Definition	. . . defining the design problem itself, understanding requirements or specs
	Project Budgeting	. . . developing or sticking to a project budget, cost estimating
	Prototype/Testing	. . . creating prototypes or testing designs
	Software (non-CAD)	. . . using or learning software other than CAD
	Engineering Design-Other	. . . any other aspect of engineering design or technical work broadly
Identity Development	Challenges associated with seeing oneself as an employee and/or an engineer, including . . .	
	Feeling competent	. . . feeling hesitant or uncertain about one's skills, abilities, and knowledge
	Feeling part of the group	. . . feeling connected to or integrated with others at work; sense of belonging; fitting in
	Identity-Other	. . . any other challenge associated with how the participant perceives themselves in the work environment
	Learning role	. . . knowing what one's role is and/or how one fits into the team or company
	Thinking like an engineer	. . . knowing how to make engineering decisions or justify ideas
Self-Directed Learning	Challenges associated with managing and monitoring one's own time and activities, including . . .	
	Finding Resources	. . . knowing what resources are needed for a task and/or where to find them
	Finding Work/Keeping busy	. . . finding things to do at work (e.g., during slow times or between projects)
	Lack of knowledge	. . . not having the information, skills, background, etc. to take on tasks; not knowing enough
	SDL- Other	. . . not having the information, skills, background, etc. to take on tasks; not knowing enough
	Time Management	. . . balancing time among different work tasks
	Time Pressure	. . . dealing with short/tight deadlines and/or a fast pace at work
	Work Ethic	. . . maintaining a commitment to work e.g., long work days, staying engaged, doing routine or boring tasks

Teamwork & Communication	Challenges associated with working in teams or communicating clearly, including	
	Client Meeting	. . . meeting with customers, clients, or other external stakeholders
	Formal Presentation	. . . developing or giving a formal presentation
	Informal Presentation	. . . developing or giving an informal presentation (e.g., to coworkers or supervisors)
	Informal Writing	. . . writing something other than a formal report
	Interpersonal—General	. . . communicating or interacting with others in the workplace (e.g., colleagues)
	Interpersonal—Manager/ Supervisor	. . . communicating or interacting with a manager, supervisor, or others higher up in the organization
	Project Planning/Logistics	. . . organizing work among members of a team
	T&C—Other	. . . any other aspect of communication and teamwork
	Team Meeting	. . . conducting or participating in a meeting
	Writing Reports	. . . writing formal documents such as reports
Other	Challenges not captured by other codes	

Julie Dyke Ford is Professor of Technical Communication (housed in the Mechanical Engineering department) at New Mexico Tech where she coordinates and teaches in the junior/senior design clinic as well as teaches graduate-level engineering communication courses. Her research involves engineering communication, technical communication pedagogy, and knowledge transfer. She has published and presented widely including work in the Journal of Engineering Education, the Journal of STEM Education: Innovations and Research, IEEE Transactions on Professional Communication, the Journal of Technical Writing and Communication, Technical Communication and Technical Communication Quarterly. Julie has a PhD in Rhetoric and Professional Communication from New Mexico State University, an MA in English with Technical Writing Emphasis from the University of North Carolina at Charlotte, and a BA in English from Elon University.

Marie C. Paretti is a Professor of Engineering Education at Virginia Tech, where she co-directs the Virginia Tech Engineering Communications Center (VTECC). Her research focuses on communication in engineering design, interdisciplinary communication and collaboration, design education, and gender in engineering. She was awarded a CAREER grant from the National Science Foundation to study expert teaching in capstone design courses, and is co-PI on numerous NSF grants exploring communication, design, and identity in engineering. Drawing on theories of situated learning and identity development, her work includes studies on the teaching and learning of communication, effective teaching practices in design education, the effects of differing design pedagogies on retention and motivation, the dynamics of cross-disciplinary collaboration in both academic and industry design environments, and gender and identity in engineering.

Daria A. 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 Senior Instructor in the Department of Mechanical Engineering. She received BS and MS degrees in mechanical engineering from The Ohio State University and a PhD 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.

Susannah Howe is the Design Clinic Director in the Picker Engineering Program at Smith College, where she coordinates and teaches the capstone engineering design course. Her current research focuses on innovations in engineering design education, particularly at the capstone level. She is invested in building the capstone design community; she is a leader in the biannual Capstone Design Conferences and the Capstone Design Hub initiative. She is also involved with efforts to foster design learning in middle school students and to support entrepreneurship at primarily undergraduate institutions. Her background is in civil engineering with a focus on structural materials. She holds a BSE degree from Princeton, and MEng and PhD degrees from Cornell.

Chris Gewirtz is a PhD student in Engineering Education at Virginia Tech. His research interests revolve around how culture, history and identity influence assumptions made by engineers in their design practice, and how to change assumptions to form innovative and socially conscious engineers. He is particularly interested in humanitarian engineering design, where many traditional engineering assumptions fall apart.

Jessica Deters is a PhD student at Virginia Tech in the Department of Engineering Education. She holds a BS in Applied Mathematics & Statistics and a minor in the McBride Honors Program in Public Affairs from the Colorado School of Mines. Jessica is engaging in projects that emphasize the sociotechnical nature of engineering with a focus on social justice and diversity. She aims to educate the next generation of engineers to understand and value the social, political, economic, environmental, and human implications of their designs.

Tahsin Chowdhury is a PhD student at Virginia Tech in the department of Engineering Education. Tahsin holds a BSc degree in Electrical and Electronics Engineering from IUT, Dhaka and has worked as a lean manufacturing professional at a Fortune 500 company. He is actively engaged in different projects at the department involving teamwork, communication and capstone design with a focus on industry and engineering practice.

Robin Ott received a Bachelor's degree in Mechanical Engineering at Virginia Tech in 1995 and has since gained 20 years industry experience including working as a design engineer for a Naval Sea Systems Command contractor and work an Application Engineer at Parametric Technology Corporation, the creators of 3D CAD software PRO-Engineer. In 1999 she joined Kollmorgen, where she held multiple roles of increasing responsibility during her nine years there. Most recently Robin worked as Senior Director of Project Management for a small bio-tech company. Since joining the faculty at her Alma Mater in 2015, Robin has been coordinating and teaching the Capstone Senior Design program in Mechanical Engineering while pursuing graduate work in Engineering Education.

Nicholas Emory Alvarez is pursuing his Masters in Mechanical Engineering at New Mexico Tech. His area of interest is fluid science, and his research involves the study of cloud-based computational fluid dynamics (CFD). He has worked on drill site layout and environmental protection for petroleum companies as a Project Engineer, prior to his Masters at New Mexico Tech. He has also worked as an ESL (English as a Second Language) instructor in South Korean Elementary schools. He is currently assisting research efforts to study students' transition from School to Work.

Daniel W. Knight is the Program Assessment and Research Associate at Design Center (DC) Colorado in CU's Department of Mechanical Engineering at the College of Engineering and Applied Science. He holds a BA in psychology from Louisiana State University, an MS degree in industrial/organizational psychology and a PhD degree in education, both from the University of Tennessee. Dr. Knight's research interests are in the areas of retention, program evaluation and teamwork practices in engineering education. His current duties include assessment, team development and education research for DC Colorado's hands-on initiatives.

Cristian Hernandez is currently a junior at the University of Colorado Boulder with a major in Civil Engineering. He served as a research assistant and assisted with tasks including organizing the case reports for participant interviews. He was a summer intern for Waner Construction and is going to be a field intern for Turner Construction in summer 2019.

Laura Mae Rosenbauer graduated in May 2018 with an engineering major and landscape studies minor at Smith College. She served as a research assistant on the national and international capstone survey efforts and the development of CDHub 2.0. She also assisted with multiple tasks including data coding for the transition from capstone design to work study. She is currently working as a design engineer at Eriksson Engineering Associates in Chicago.

Anne Kary is a junior at Smith College majoring in Engineering and Mathematics, originally from Claremont, CA. Her interests largely lie in Aerospace Engineering and Engineering Education. She is interested in studying aerospace propulsion systems in graduate school. In her spare time, she dances and plays ice hockey for Smith.

Francesca Giardine is a junior Engineering and Mathematics double major at Smith College. She is particularly interested in both mechanical engineering and computational modeling, and would like to pursue graduate studies in these fields. Outside of academics, she enjoys reading and hiking.