This large multi-case study 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.

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. Participants were recruited in two cohorts from all four sites, one cohort in 2017 and a second in 2018. The table provides some of the descriptive statistics of the sites in 2017 (for the first cohort), which can reasonably be extrapolated to the second cohort.

<table>
<thead>
<tr>
<th>Capstone Features</th>
<th>Site A</th>
<th>Site B</th>
<th>Site C</th>
<th>Site D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Course Duration</td>
<td>2 semesters</td>
<td>4 semesters</td>
<td>2 semesters</td>
<td>2 semesters</td>
</tr>
<tr>
<td>Discipline</td>
<td>Mechanical Engineering</td>
<td>Mechanical Engineering</td>
<td>Engineering Science</td>
<td>Mechanical Engineering</td>
</tr>
<tr>
<td>Advising Structure</td>
<td>Course instructor oversees; faculty advisors mentor teams (instructor also advises some teams), client-based teams have industry liaisons</td>
<td>Course instructor oversees; faculty advisors mentor teams, client-based teams have industry liaisons</td>
<td>Course instructor oversees and advises all teams, client-based teams have industry liaisons</td>
<td>Course instructor oversees; faculty advisors mentor teams, client-based teams have industry liaisons</td>
</tr>
<tr>
<td>Previous Design Experiences</td>
<td>First Year Design Course, Sophomore Design Course</td>
<td>First Year Design Course</td>
<td>First Year Design Course, Possible Electives with Design</td>
<td>First Year Design Course, Junior Design course, Sophomore and Junior Design Electives</td>
</tr>
</tbody>
</table>
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.

**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 recruitment process was repeated in late spring of 2018.

A total of 135 recent graduates were recruited to the study (62 from cohort 1, and 73 from cohort 2) and performed interviews before starting work, although there was attrition at each step of data collection. Of those recruited, 117 completed at least one survey, reflective journal, or additional interview after starting work, the other 18 were considered “discontinued.” Table 2 below reports some of the demographics of these 117 participants.

<table>
<thead>
<tr>
<th>Internship/Co-op Experience</th>
<th>Optional</th>
<th>Optional</th>
<th>Optional</th>
<th>Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Capstone Students in 2017</td>
<td>417</td>
<td>131</td>
<td>25</td>
<td>244</td>
</tr>
<tr>
<td>Number of Capstone Projects in 2017</td>
<td>51</td>
<td>20</td>
<td>7</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 2: Participant Demographics

<table>
<thead>
<tr>
<th>Gender</th>
<th>Men: 65</th>
<th>Women: 52</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Work Or Co-Op Experience</td>
<td>Yes: 102</td>
<td>No: 15</td>
</tr>
<tr>
<td>Cohort</td>
<td>Cohort 1: 58</td>
<td>Cohort 2: 59</td>
</tr>
<tr>
<td>Site</td>
<td>Site A: 39</td>
<td>Site B: 27 Site C: 24</td>
</tr>
</tbody>
</table>
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 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 118 participants who continued with the study, 75 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 survey.

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) [2, 3] asked participants to identify activities in which they had participated within the past week. The list of possible activities, as shown in Figure 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 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 1063 quantitative survey responses.

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)

Figure 1: Short Quantitative Survey Items

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 Figure 2, solicited in-depth descriptions of newcomers’ salient challenges.

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?
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 [4]. The a priori coding scheme was based on Lutz and Paretti’s study of capstone design [1] 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 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.

Table 3: Emerging Themes from Qualitative Data Analysis

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

With respect to strategies, the coding process focused on generating emergent descriptive codes from the data itself [4]. 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).

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.

References
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