Bridging the Gaps Between Engineering Education and Practice

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INTRODUCTION

Increasingly, American engineers have had to contend with challenges including rapid technological innovation and the needs of changing workplaces (Duderstadt, 2008; National Academy of Engineering, 2008a; National Research Council, 2007). In response, industry, government, and the professional societies have called on educators to better prepare engineering students by emphasizing not only technical but professional competencies (Jamieson and Lohmann, 2009; Sheppard Macatangay, Colby, and Sullivan, 2008; Shuman, Besterfield-Sacre, and McGourty, 2005). There is even a consensus in the engineering community about what those competencies should be: communication skills, business skills, teamwork skills, creativity, lifelong learning skills, and problem solving skills (ABET, 2011; American Society for Civil Engineers, 2008; Boeing Company, 2009; National Academy of Engineering, 2004).

Yet, despite calls for reform, research has shown that engineering programs are often based on an outdated image of engineering practice that is misaligned with reality (Duderstadt, 2008; National Research Council, 20007; Sheppard et al., 2008; Vest, 2008). Although society has long looked to higher education to develop the nation's workforce (Sullivan and Rosin, 2008), employers, faculty, and even students have questioned whether engineering programs are meeting this goal. For example, in 2004 almost a quarter of employers reported that engineering graduates were less skilled in problem solving and less aware of organizational contexts and constraints than graduates ten years earlier. A third of the faculty who taught these students also reported that they were less able in math and science and had worse technical skills than their forerunners (Lattuca, Terenzini, and Volkwein, 2006). Other research has shown that many engineering students remain uncertain about what engineering is and what engineers do, even by the time they graduate (Matusovich, Streveler, and Miller, 2009).

The failure of engineering programs to adequately prepare students for practice is a problem in several respects. First, as more and more U.S. corporations opt to downsize and outsource, graduates looking for engineering work face pressure to stay relevant and adapt to new industry needs (Shuman et al., 2005). Second, graduates may need additional training to acquire missing competencies, which comes at a cost to their employers (Salzman, 2007). Finally, uncertainty about what engineering really involves and feelings of being ill-prepared may convince some graduates to abandon engineering altogether. Two years after graduation just over one-quarter (28%) of all engineering graduates from the classes of 2008 and 2009 were working in fields outside of engineering, including mathematics and computer science (National Science Foundation, 2015). Similarly, 20 percent of engineering seniors in 2007 reported that they were unsure about pursuing a career in engineering (Atman et al., 2010). Their uncertainty partially reflects a nationwide loss of interest in engineering, a belief that engineering careers are no longer secure, and the realization that other professions pay higher wages (Chubin, May, and Babco, 2008; Duderstadt, 2008; Lowell and Salzman, 2007; Shuman et al., 2005). Students' limited understanding of what engineering entails and the skills it requires may also turn them off to engineering careers (Lichtenstein et al, 2009; National Academy of Engineering, 2008b).

The studies described above support Trevelyan's (2007) claim that a better understanding of engineering practice is needed to inform students' career choices and improve their preparedness to work in this field. We believe that one of the best ways to accomplish this is to study engineering students and young engineers who have just entered the workforce to better comprehend the challenges they encounter and how they make sense of these challenges. This chapter uses interviews with engineering students and newly hired engineers to examine disjunctures between engineering education and professional practice. Based on our analysis we recommend ways of better connecting the two. These interviews come from two projects funded by the National Science Foundation (NSF), the Academic Pathways Study (Sheppard et al., 2009) and the more recent Engineering Pathways Study (Sheppard et al., 2011).

LITERATURE REVIEW

Although most studies of how to prepare engineering students more effectively for professional practice have focused on mastering competencies that educators and employers think are important (e.g., Bankel et al., 2003; Lattuca et al., 2006; Meier, Williams, and Humphreys, 2000), some researchers have approached the problem by exploring how young engineers' perceive the relevance of their education. Most of the latter have studied young engineers in the workplace; a few have studied engineering students currently in school.

Studies of Engineering Students

In our review of the current literature, we found just two investigations of how undergraduate students conceive of engineers and engineering. Dunsmore, Turns, and Yellin (2011) found that mechanical engineering students sharply contrasted their academic experience with professional practice. Students thought of work, but not school, as the "real world." However, their notion of reality was naïve. They identified teamwork and communication as "real world skills" that were crucial for success, but they nevertheless believed that such skills were less important than skills like the ability to design. Similarly, seniors surveyed in the

Academic Pathways Study also said communication and teamwork were important skills (Atman et al., 2010) but thought their school experiences were unrelated to engineering work (Sheppard et al., 2010). Moreover, even though fifty percent reported exposure to engineering through internships, jobs, company visits, and research experiences, they had no greater appreciation for the relevance of professional and interpersonal skills than did freshmen (Sheppard et al., 2010; Atman et al., 2010). These results suggest that while senior engineering students think that communication and teamwork are important, they may not understand how these skills are actually used in practice.

Studies of Practicing Engineers

Many more recent studies have asked practicing engineers how well their undergraduate education prepared them for their current work. Across these studies, working engineers report that knowing how to communicate and work with other people is paramount and that most of what they now do they learned on the job. Roughly half of MIT's mechanical engineering alumni from the classes of 1992-1996 reported using professional skills, interpersonal skills, and independent thinking skills almost daily in their work and that they had learned these skills on the job (Seering, 2009).[1] In contrast, the MIT alumni reported hardly ever using the theoretical knowledge they learned in college; for example, thermodynamics and fluid mechanics. Almost identical results were found in a mixed methods study of practicing engineers as part of the NSF-funded Aligning Educational Experiences with Ways of Knowing Engineering (AWAKEN) project. The respondents in this study considered communication, problem solving, ethics, lifelong learning, and business skills to be essential to their work (Anderson et al., 2009). Two-

[1] Seering (2009) operationalized professional skills as professional ethics and integrity, responsibility and accountability, professional behavior, proactively planning for one's career, and continuous learning; personal skills as initiative and willingness to take risks, perseverance and flexibility, creative thinking, and time and resource management; and independent thinking skills as skills in working independently, skills in setting project goals, ability to extract and evaluate relevant knowledge; and confidence in one's own skills and abilities.

thirds said that their schooling prepared them well for engineering practice and half said they still used skills they learned as undergraduates. But for many, “real” engineering consisted only of technical problem solving (Grohowski-Nicometo, Nathans-Kelly, and Anderson, 2009), and beyond the ability to think analytically, most said what they need to know at work they learned after graduating (Anderson et al., 2011). More recently, Passow (2012) found that engineers who graduated from a large, Midwestern university in the 1990s and 2000s also rated teamwork, communication, problem solving, and analytical skills as having been important in their professional experience. As a part of the Prototyping the Engineer of 2020 (P2P) study, Lattuca and colleagues (2014) discovered that engineering alumni from 31 institutions rated communication skills, teamwork skills, and professional skills as highly important to their current work. Of these three, teamwork was perceived as having been the most heavily emphasized in their undergraduate curricula.

American engineers are not unique in their perceptions of their education’s relevance. In a longitudinal study of early career professionals in the U.K., most engineers differentiated between learning in school, which emphasized theory, and learning in the workplace, which emphasized communication, teamwork, leadership, decision-making, reflection and awareness (Eraut, 2009). In another longitudinal study, Trevelyan and Tilli (2008) found engineers who graduated from the University of Western Australia (UWA) in 2006 spent, on average, 60 percent of their time interacting with other people at work. Ten percent said they wished they had been taught interpersonal skills at UWA, and interpersonal skills was the area in which engineers were most likely to report needing further training. Like American engineers, the Australians reported learning most of what they needed know on their own or from their coworkers (Trevelyan, 2008).

Finally, as part of the NSF-funded Academic Pathways Study, authors of the current report interviewed young engineers at a single organization, Car Company[2], to identify significant differences between their experiences at work and school. Korte, Sheppard, and Jordan (2008) found that the company's social and organizational context set the problems and processes on which the engineers worked. These problems were often more complex, ambiguous, and political than those the engineers had encountered in school. Additionally, how the engineers perceived and learned about engineering work depended to a large extent on their interactions with coworkers in their work groups (Korte, 2009; Korte, 2010).

Contributions of the Current Study

Although the foregoing studies provide rich insights into the relation between engineering education and practice, they have limitations. First, more than half of the studies relied exclusively on surveys (Anderson et al., 2009; Atman et al, 2010; Lattuca et al., 2014; Passow, 2012; Seering, 2009; Sheppard et al., 2010; Trevelyan et al., 2008; Trevelyan, 2008). Although a survey's structured questions allow participants to voice their perspectives within the scope of defined response options, acquiring a deeper and more contextually sensitive understanding of young engineers' experiences at work requires a more qualitative approach. Second, with the exceptions of the Academic Pathways Study, the P2P study, and the AWAKEN project, the other studies sampled engineers graduating from or working in a handful of schools or organizations respectively. Third, and perhaps most importantly, each study captured only one side of the school-to-work transition. Either the researchers asked engineering students to anticipate what engineering practice would be like, or they asked engineering practitioners to reflect back on their academic preparation. Even the two longitudinal studies (Eraut, 2009;

[2] This name is a pseudonym.

Trevelyan, 2007; Trevelyan and Tilli, 2008) focused exclusively on recently graduated engineers.

In contrast, this chapter's study employs both structured *and* semi-structured interviews to elicit participants' own perspectives. The interviewees come from two samples, one retrospective and another longitudinal, and include both students and practicing engineers from multiple institutions and organizations at different points in their careers. By combining these data, we are able to demonstrate the changing nature of engineers' perspectives as they move from their engineering programs into the workforce. The next section describes the samples in detail.

METHODS

This chapter employs two samples to investigate the relationship between engineering education and practice. The *Workplace Sample* derives from the Workplace Cohort of the Academic Pathways Study (APS). Funded by the NSF, the APS was conducted between 2003 and 2007 under the auspices of the Center for the Advancement of Engineering Education (CAEE, see Sheppard et al., 2009).[3] Interested readers should consult Atman et al., (2010) for details of the study's design and an overview of the project's findings. Participants in the *Longitudinal Sample* were individuals who were first assessed as junior-year engineering students in the APS and again as early career professionals as part of the follow-on Engineering Pathways Study (EPS). More details about the EPS can be found in Sheppard et al., 2011.

Our objective is to identify and investigate major "gaps" in engineering education for preparing engineering students for practice. We use retrospective data from the Workplace

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[3] The other two elements are the Scholarship on Teaching Engineering and the Institute for Scholarship on Engineering Education. See http://www.engr.washington.edu/caee/ for more information.

Sample to identify how the knowledge and skills employed by young engineers diverged from what they learned in school. We combine the longitudinal data from the APS and the EPS to show how work altered the ideas about engineering that our participants held as undergraduates. Finally, we return to the Workplace Sample for further evidence of how young engineers' images of engineering had changed since leaving school. We define a young engineer as anyone who has earned at least a bachelor's degree in engineering in the past four years and who is currently employed in an engineering job. We also refer to these individuals as recently graduated engineers, early career engineers, and newly hired engineers.

The Workplace Sample

The Workplace Sample comprises newly hired engineers with whom we conducted semi-structured interviews in the winter of 2007. The interviews lasted for 45 to 90 minutes. Of particular interest were the 57 participants in their first full-time position since graduating. As recent graduates, these individuals could best offer opinions about the differences between their engineering education and new employment.

The participants were employed by four U.S. organizations: a global automobile manufacturer (Car Company), a large food company (Food Manufacturer), a smaller firm that made computer components (Computer Parts Company), and a state transportation agency (Transportation Department). The engineers at Car Company were mostly mechanical engineers. At Food Manufacturer the participants were chemical engineers, at Computer Parts Company they were mechanical and chemical engineers, and at Transportation Department they were civil engineers. Car Company and Computer Parts Company assigned young engineers directly to permanent positions that involved both technical and project management work.

Young engineers at Food Manufacturer and Transportation Department initially rotated through at least three departments before being assigned to a project management position.

Demographic information for the Workplace Sample is shown in Table 1. All participants had been working in their jobs for two months to three years, with an average duration of 11 months. Forty-five had held internships while in college. Of these, eighteen interned with their current employer. Nine participants had master's degrees, and the rest had bachelor's degrees. Sixteen of the fifty-seven worked at Car Company, 18 at Food Manufacturer, 16 at Computer Parts Company, and 7 at Transportation Department.

Insert Table 1 about here.

The primary goal of studying these 57 individuals was to identify what young, practicing engineers need to know and whether they had learned that knowledge in school or on the job. Among other questions, participants were asked to reflect on one or two problems or projects to which they had been assigned. For each problem or project, the interviewer asked:

- What knowledge and skills did you apply to work on the problem?
- Where and how did you learn the knowledge and skills?

Participants were also asked to reflect on their socialization experiences since joining their organization. In particular, the interviewer asked:

- How did you learn the way things work at this company?

- How did you learn what others expect of you on the job?

Finally, participants were asked about differences between their expectations as engineering students in school and their experiences on the job. Throughout the interviews, participants talked readily about knowledge and skills they used in both their assignments and their work in general, differences between school and work, how much they used their overall education, and how well their education prepared them for their jobs. Passages in the interviews that dealt with these topics, as well as the participants' answers to the questions above, provided data for the present analysis.

The Longitudinal Sample

The Longitudinal Sample comprises two sets of interviews from three institutions in the western United States: a technical public institution (TPub), a suburban private university (SPri), and a large public university (LPub). The first set of interviews was conducted under the Academic Pathways Study (APS) in 2006, when the participants were junior-year engineering students (Sheppard et al., 2009). The second set of interviews took place as part of the Engineering Pathways Study (EPS) in 2011, four years after the participants earned their engineering bachelor's degrees (Sheppard et al., 2011). The result is a longitudinal, or panel, design that allows us to compare how the same individuals thought about engineering as students with how they understood engineering after four years of work experience.

Although the APS and the EPS studies included both qualitative and quantitative data (i.e., both were mixed methods studies; see Creswell and Plano Clark, 2011), the current study employs only qualitative data from interviews. Nine participants comprised the Longitudinal Sample: five from Technical Public Institution, three from Large Public University, and one from Suburban Private University. These individuals were selected from a larger pool of APS/EPS participants because they participated in both interviews and were working in an engineering job at the time of the second interview. That these individuals represent only a subset of those who originally participated in the APS is a limitation; nevertheless, we see significant value in the ability of these interviews to provide us with clues about how engineers' perceptions change over time, which we corroborate with our Workplace Sample.

Insert Table 2 about here.

Table 2 displays demographic information for the nine participants in the Longitudinal Sample. Four of the nine were women, and four were members of an under-represented minority. Three were chemical engineering majors, two were computer-related majors, and the remainder ranged across other engineering disciplines. Four of the participants had held internships by their junior year. Four years after graduation, these individuals held a wide variety of positions with their employers. While none had earned additional degrees, one was enrolled in an engineering master's program.

Researchers interviewed the participants in person for approximately an hour when they were college juniors and on the phone for 30 to 60 minutes five years later. We focus here on participants' answers to three questions asked when they were juniors in the spring of 2006:

- Are there particular skills that you would say are important for an engineer to have?
- Of the skills you mentioned, which ones do you possess, and how did you develop them?
- In your own words, please define engineering.

We also focus on their answers to two questions posed during our follow-up interviews in the spring of 2011:

- What knowledge and skills do you see as most important to doing your job?
- How has your idea of an engineering job changed since you graduated?

Interview Analysis

Three sets of interviews were analyzed for this study: (1) interviews with the 57 engineers in the Workplace Sample, (2) interviews with the Longitudinal Sample one year before graduation, and (3) interviews with the Longitudinal Sample four years post-graduation. Prior to analysis, the interview recordings were transcribed verbatim and made anonymous. We then analyzed the interviews for each sample independently following a case study approach, with each participant representing a case (Creswell, 1998; Miles and Huberman, 1994; Stake, 2006; Yin, 2003). MAXQDA software was used to code the data.

Workplace Sample. We analyzed the interviews with our retrospective participants with dual purposes in mind: (1) to identify knowledge and skills they used on the job and where they learned them, and (2) to examine differences in their perceptions of school and work. As noted previously, the participants were asked about knowledge and skills they used in completing specific assignments, in learning about their organization, and in their work in general. Codes describing these knowledge and skills emerged inductively from the data analysis and stayed close to the participants' own language (Patton, 2002). After each transcript was coded in its entirety, we combined these mentions into 23 distinct categories such as content knowledge and communication skills. We further clustered the categories into three broad types: technical knowledge and skills, professional knowledge and skills, and organizational knowledge and skills.

We refer to knowledge as understanding or awareness of concepts, principles, and information related to a specific domain, and skill as the ability to apply domain knowledge in a particular context. For instance, an engineer might have technical knowledge of how a machine works, but she would use her technical skills to troubleshoot it. By technical knowledge and skills, we mean competencies needed to accomplish specific engineering, mathematical, scientific, or computer-related tasks, such as technical problem solving, analysis, and design. In contrast, professional knowledge and skills are non-technical competencies "that relate … to the profession of engineering" and to interaction with people more generally (Jarosz and Busch-Vishniac, 2006, p.243). Sometimes referred to as "soft" (as opposed to hard) or "social" skills, professional knowledge and skills are commonly known to include teamwork, communication, and leadership skills (ABET, 2012; Knight, 2012: Shuman et al., 2005). Finally, we define organizational knowledge and skills as information about one's organization, work group, and job role which enables one to better navigate their work (Korte et al., 2008; Korte, 2009, 2010).

After coding was complete, we quantified the data using frequency counts and tables. Quantifying data helps describe the sample population and identify patterns (Sandelowski, Voils, and Knafl, 2009). For each skill and area of knowledge, we counted the percentage of participants who reported using it, the percentage of participants who reported learning it in school, and the percentage of participants who reported learning it on the job. Definitions for each skills and area of knowledge are provided in the appendix. We present the quantitative data, in addition to quotes, in the findings section. We coded differences in the Workplace

Sample's perceptions of school and work in the same way that we coded knowledge and skills, but we present these results in a more qualitative fashion.

Longitudinal Sample. The two sets of interviews with our longitudinal participants were coded for (1) the knowledge and skills they considered important to doing engineering work and (2) their ideas about what engineering entails. Taken together, the interviews show how engineers' perceptions change as they move from learning about engineering as students to actually practicing engineering as recent new hires. The longitudinal interviews were analyzed using the same inductive coding strategy that was used for the Workplace Sample; thus, the knowledge and skills that emerged differ slightly since they are grounded in the language our informants used. Furthermore, because the Longitudinal Sample spans two sets of interviews, coordination across sets was required to create a consistent coding scheme. For example, variations on problem solving skills were mentioned both when participants were juniors and when they were four years beyond their bachelor's degrees, and so these mentions were combined under a single category. Other skills and areas of knowledge were only mentioned when participants were *either* juniors *or* young engineers and, thus, are represented by their own categories. Each skill and area of knowledge is shown in the findings section and defined in the appendix. We also present qualitative results related to participants' changing perceptions of engineering work.

Summary of Samples

In this chapter, we use two samples to highlight the knowledge and skills that engineers need for practice. Besides employing different study designs, the Workplace and Longitudinal Samples complement each other in three ways. Taken together, they illustrate how engineers' views change from their junior year in college to their first few years of work. They also span five years of data collection, allowing us to determine the stability of needed engineering knowledge and skills over time. Finally, they encompass multiple institutions and organizations, enabling generalizability to a range of fields and industries. The specifics of each sample are summarized in Table 3.

Insert Table 3 about here.

FINDINGS

The two samples explored in this chapter provide insights into "gaps" between engineering education and practice. The Workplace Sample, comprised of young engineers who had been working for 0-3 years in their first jobs after graduation, help us compare knowledge and skills engineers use at work with those learned in school. The Longitudinal Sample, comprised of early career engineers first as college juniors and then as practitioners four years out, let us see how engineers' views of the work they do change with time. Both samples also help to understand why engineers perceive differences between their jobs and education, and why they value some aspects of their work more highly than other aspects.

Knowledge and skills in engineering practice (The Workplace Sample)

The recently graduated engineers in the Workplace Sample identified the knowledge and skills that they applied on the job. Table 4 shows the number of participants who mentioned using technical knowledge and skills, professional knowledge and skills, and organizational knowledge and skills, as well as whether each of these was learned in school or on the job.[4] As the table shows, virtually every participant reported using technical (98%) and professional (96%) knowledge and skills in their work. The engineers learned technical knowledge and skills

[4] The appendix contains definitions of each skill and area of knowledge.

in school (93%) and in the workplace (86%). Where they learned professional knowledge and skills, however, differed. Just over half reported learning a professional skill or area of knowledge in school. Yet every engineer who mentioned professional knowledge and skills claimed to have mastered at least one of them at work. Additionally, only two-thirds reported relying on knowledge about their organization to do their work, and this knowledge was also learned almost entirely on the job (56%, compared to 16% who reported learning this knowledge in school).

Insert Table 4 about here.

Technical knowledge and skills. Although participants claimed to have acquired technical knowledge and skills from school as well as work, school was the more frequently mentioned source. The best demonstration of this can be seen in Table 4 under content knowledge. Nearly three-quarters of the interviewees reported using content knowledge in their jobs, and sixty percent traced this knowledge back to courses ranging from basic physics and calculus to more advanced engineering topics. Which advanced courses the participants viewed as relevant varied by discipline, as well as by the companies for which they worked. For example, mechanical engineers at Car Company spoke of using what they learned in their engine courses, while their electrical engineering colleagues at Car Company relied more on their training in circuits. Compared to knowledge learned at school, instances of content knowledge learned at work were less prevalent, reported by only 16 percent of participants, and typically revolved around the engineer's particular job (e.g., traffic signal guidelines at Transportation Department, the mechanical behavior of specific materials at Computer Parts Company).

Similarly, school was more important for learning how to solve problems and how to model and analyze data, with more than twice the number of participants reporting learning these skills in school than at work. With regards to problem-solving, they did not credit their learning to any particular course or combination of courses. Instead they felt their entire engineering education contributed to their ability to solve problems:

> There's definitely not a class on that [problem solving] by any means. It's more as you go through problems for homework and you work with your team members in labs, you just learn how to approach problems and come up with a solution. I wouldn't say it's something that people teach you at school. It's just something you pick up along the way. (Food Manufacturer, Chemical Engineering major, 17 months on the job) [5]

With regards to learning software applications, participants reported that school and the workplace were more or less equally important. In fact, some engineers ended up deepening their knowledge of applications that they had first encountered in a course. Nearly half of the engineers who learned to use a new software application on the job told us they had learned to use a simpler version in school which made their learning curve less steep:

> I've used different programs up at school. It just so happens that, in this job as a process engineer, we don't deal with those ones as much, but other ones. But just having the experience of using those programs, I was able to jump right into these

[5] To assist the reader in interpreting our qualitative data, passages from interviews end with the organization where the participant worked or where he or she went to school, their undergraduate major, and the amount of time they had been either on the job or in/out of school.

new ones and get a feel for them. (Computer Parts Company, Mechanical Engineering major, nine months on the job)

In sharp contrast to the technical knowledge and skills discussed above, young engineers overwhelmingly reported learning about specific equipment and processes pertaining to their work on the job rather than at school. This result is expected, given the diversity of jobs that engineers take and the limitations of current engineering curricula to train for them all. The few participants who did attribute their knowledge of a process to school cited learning about it in a particular course or an internship experience.

Participants mentioned a variety of other technical skills, but with far less frequency: rapid iteration skills, programming skills, design skills, testing skills, systems thinking skills, and hands-on skills. With the exception of testing skills, the young engineers told us they had learned these skills primarily or exclusively at school.

Professional knowledge and skills. The workplace is generally where young engineers said they learned professional knowledge and skills. Substantially more interviewees reported learning professional knowledge and skills on the job than in school, and most equated learning to be professional with acquiring communication skills, working with other people, and developing information finding skills. While we present these skills as separate categories, there was a high degree of relatedness among them.

Effective communication (both oral and written) was the most commonly used professional skill, cited by 65 percent of the engineers, and while a quarter reported learning this skill in school, more than twice as many (58%) told us they learned it on the job. For participants, learning to communicate effectively encompassed not only delivering better reports and presentations, but learning how to communicate with people who were not engineers, for example, marketing, purchasing, sales, and client personnel. Perhaps because three of the four employers were manufacturers, many participants reported needing to communicate with – and sometimes even manage – workers on the production floor, including foremen, machine operators, and maintenance workers. Others found they needed to communicate with contractors, suppliers, and customers. Learning to work with members of such groups was an eye opening experience for many. In these experiences, young engineers discovered the importance of expressing themselves clearly and of listening carefully:

> I learned a lot about making assumptions when it came to managing contractors. In one situation I had assumed that this contractor was capable of doing [a project], and it was a situation where basically that project didn't get done and had to be postponed. So what I learned was the more information you can give them, the more successful you'll be. (Food Manufacturer, Chemical Engineering major, eight months on the job)

> I learned that the people out on the floor are kind of the eyes and ears of the operation. They observe firsthand what's happening. So you better get to know them well and listen to what they have to say. Earning their respect is also important because if they don't think that you know what's going on, then they're going to have a hard time discussing their problems with you. (Computer Parts Company, Mechanical Engineering major, seven months on the job)

Working with other people was another important professional skill that young engineers claimed to have learned mostly on the job. Many considered having good interpersonal skills to mean getting to know coworkers and supervisors personally, establishing relationships with them, networking to gain visibility and identify key resources, and being able to convince collaborators of their ideas.

> I've learned where people's strengths are. Some people are really detail-oriented, so if I have a detailed-oriented question, I'll go to them. Some people are better communicators. And there are people that know their stuff but when they try and explain it to you, I'm just like, "You're not even understanding my question." So I've sort of flagged those people in my mind. (Computer Parts Company, Chemical Engineering major, eight months on the job)

> [I learned] that you've really got to network and get to know people on a personal level and earn their respect and respect them. It's really different around here because no one has to do anything. If you want people to go outside of the box to help you, you've got to [get to] know them. (Car Company, Mechanical Engineering major, 12 months on the job)

On the job, young engineers also acquired tips on good group work practices. Such tips included following up emails with face-to-face or phone conversations, requesting that deliverables be sent by a certain date, and checking on the status of deliverables at regular intervals. Several mentioned learning to keep others updated on the status of their own deliverables, since it prevented conflict and made it easier to locate help when problems occurred:

> I learned that you've always got to check up on people and make sure that they have it [their deliverable] done in a week or so of what they said. You want to rely that they're going to do what they say they're going to do but you really can't. So you've always got to double check behind someone to make sure that he's doing exactly what they asked. (Car Company, Mechanical Engineering major, four months on the job)

> I guess it's best to keep everyone in the loop always. Send out mass emails to try to keep everyone in the loop, so then there isn't questioning. Everyone knows where you're at with it, and then if they have an idea, they can throw it out and you can try that idea too. (Computer Parts Company, Mechanical Engineering major, seven months on the job)

Young engineers also reported having to learn information-finding skills on the job. For a few, information finding meant becoming familiar with using their organization's databases, but, as Korte (2009) documented, many more discovered that their coworkers were the most significant source of information. Some interviewees spoke of specific strategies for seeking help, such as first building camaraderie with their coworkers and then making sure not to monopolize their coworkers' time.

Other professional knowledge and skills young engineers used in their work included project management skills, time management skills, leadership skills, documentation skills, context knowledge, and a work ethic. Participants learned all but project management skills primarily or exclusively in the workplace.

Organizational knowledge and skills. Two-thirds of the participants reported applying knowledge about their organization in their technical work. As one might expect for engineers first entering employment, most reported learning this knowledge on the job (56%). The 16 percent of participants who acquired this knowledge as students did so during their internship and co-op experiences.

Among all who mentioned knowledge about their organization, over 40 percent equated this knowledge with routine or bureaucratic procedures. That is to say, they spoke of specific policies and procedures that they had learned (for example, how to write test protocols or submit work orders). By contrast, only sixteen percent talked about the organization's background or culture. Just over a quarter said they had developed an understanding of the hierarchy or division of labor, including how different departments worked together and what role the various departments played in the bigger picture.

It is noteworthy that only a quarter of participants who had held internships mentioned what they had learned about their organizations or life in their organizations during that time. In fact, even after becoming employees, few explicitly acknowledged using knowledge about their organization in their technical work. In most cases, it was not until the interviewer asked them about how things worked in their organization that they spoke about this topic. As such, it is possible that knowledge about one's organization may be less salient than are technical or professional knowledge and skills. Conceivably the young engineers may have been aware of their organizations and how they operated but did not believe they consciously applied that knowledge in their work. Furthermore, because we asked the participants about knowledge and skills they used while doing specific tasks, this may have focused their responses away from what they learned in other contexts such as meetings, conversations with coworkers, and even co-ops and internships. Interestingly, not all who reported learning about how organizations work in an internship had interned with their current employer. This suggests that lessons from working in one professional engineering environment may transfer to others.

In sum, engineers reported early in their careers employing a variety of technical, professional, and organizational knowledge and skills. Technical work required knowledge of specific content, tasks, and processes, as well as general problem solving skills. Professional work involved communicating with many different groups of people, as well as interpersonal and information-finding skills. Organizational work included understanding the culture, values, and operating procedures of their organization. Although these young engineers had developed strong technical backgrounds in school, which they expanded and refined at work, they learned most of their professional knowledge and skills, as well as their organizational knowledge and skills, at work. Additionally, although they might have gained some professional and organizational knowledge and skills through their internship or co-op experiences, most could not explicitly connect this to their technical work. The findings suggest that engineering graduates may need better instruction in the professional and organizational aspects of their work.

Changing views of engineering practice (The Longitudinal Sample)

Comparing the knowledge and skills that engineers thought were important when they were college juniors with those they thought were important after four years on the job provides a sense of how engineers' perceptions change as they move from being students to being practitioners. Table 5 shows the number of Longitudinal Sample participants who mentioned various technical and professional skills or areas of knowledge at both points in time.[6]

Insert Table 5 about here.

As Table 5 illustrates, the participants' impressions of the general importance of professional knowledge and skills remained relatively constant over time, but the relative importance of technical knowledge and skills declined considerably with 20 fewer mentions after working for four years. Specifically, these engineers were less likely to mention math, logic, science, problem solving, and visualization skills as being crucial for their work. They were just as likely to mention content knowledge and software skills, and like engineers in the Workplace Sample, could provide specific examples of knowledge and applications once in a job. The pattern suggests that engineering students may mistakenly overemphasize the relevance of broad technical knowledge and skills to engineering practice.

This supposition is supported by responses that interviewees gave when asked to define engineering as students. Seven described engineering as problem solving, and three explicitly emphasized that engineering entailed the application of math and science.

> Engineering is the applied use of science and technology to solve problems.
> (Paul[7], Technical Public Institution, Engineering Physics major, junior year)

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[6] As noted in the methods, the knowledge and skills listed in Table 53 differ slightly from those found in Table 24 because we coded and labeled skills based on the language informants used. Definitions of the knowledge and skills in both tables can be found in the appendix.
[7] Names are pseudonyms assigned to participants during the APS.

> Engineering is the art of figuring out interesting problems that need to be figured out using math and science. (Otis, Suburban Private University, Computer Science major, junior year)

> Engineering is just coming up with solutions to problems using math and science. (John, Technical Public Institution, Petroleum Engineering major, junior year)

Furthermore, when asked as students where they learned the knowledge and skills they considered important, the participants told us they learned math and science in the classes they had been taking since elementary school. A few mentioned teachers that had encouraged them to pursue engineering because of their abilities in science and math. Thus, the students' images of engineering revolved around technical knowledge and skills because engineering was linked to math and science in school.

> My childhood was pretty exposed to gaining those types of skills. My father was an accountant so his math background helped a lot. As far as grade school, I always had teachers that were supportive with math and science in general. So I was kind of encouraged in that area. (Justin, Large Public University, Computer Engineering major, junior year)

Interestingly, the students were less likely to claim that they had mastered non-technical knowledge and skills. When students did say they learned non-technical knowledge and skills, the learning was linked to experiences outside of school, such as extracurricular activities and sports, rather than to internships, although some had had such experiences.

> Being social is easy for me. I'm involved in a whole bunch of different things on campus that allows me to get out there and meet new people. That's how I developed that one [social skills]. (Emily, Large Public University, Civil and Environmental Engineering major, junior year)

The findings also suggest that even though participants ascribed some importance to professional knowledge and skills when they were students, they were not attuned to those most needed in practice. As students, the engineers thought teamwork skills, context knowledge, and creativity skills were most important. Other knowledge and skills such as communication and working with people were deemed more valuable four years later. Mentions of these two skills more than doubled after the graduates had worked. The meaning of these skills also changed, from very general communication and teamwork skills as juniors to interacting with people within and outside their work group as working engineers. This change is consistent with the previously discussed evidence from the Workplace Sample in which young engineers spoke of needing to work with different groups of people, but not necessarily in teams. This could be another case of students aligning their beliefs of what is important to engineering practice with what they experienced in the classroom. Or, to put it differently, engineering programs may overemphasize teamwork skills, while underemphasizing communication skills, especially the ability to communicate with people from different positions, disciplines, and even walks of life. As in the Workplace Sample, after working for four years, participants talked about the need to communicate with different groups of people, including other engineers, operators, managers, and clients.

> I work with a lot of different groups of people, and I communicate with a lot of different types of people, and the way that I communicate with my operators is very different than the way that I communicate with the engineers that I work with, just because of their level of education and understanding of certain things. (Karen, Technical Public Institution, Chemical Engineering major, four years post-graduation)

> I have to communicate recommendations and changes to a wide variety of people, from people with engineering experience in my own group to operators who have a high school education to operating management. So being able to communicate to a wide array of people is very important. (Laura, Technical Public Institution, Chemical Engineering major, four years post-graduation)

Nevertheless, despite the foregoing similarities, participants in the Workplace Sample and the Longitudinal Sample had somewhat different opinions of the knowledge and skills that engineers require. For instance, participants in the Longitudinal Sample did not mention specific job tasks and processes, information finding skills, or knowledge about their organizations. Perhaps this difference merely reflects the fact that the two studies framed the issue differently; engineers in the Workplace Sample were asked about task-specific knowledge and skills (skills used to work on a particular project or problem), while engineers in the Longitudinal Sample were asked about meta-skills important to their work in general. Alternately, participants in the Workplace Sample spoke about knowledge and skills they had used in the first couple years at work, while longitudinal participants spoke about knowledge and skills at two very different points in their career. It could be that the two groups of engineers actually thought different knowledge and skills were important because participants in the Longitudinal Sample had been working longer than participants in the Workplace Sample. As engineers work longer, they might move into less technical roles with broader scope. Some knowledge and skills may become less important to engineers' work, causing these aspects of the work to recede into the background.

Particularly curious is that no engineer in the Longitudinal Sample specifically identified project management skills as important, either as students or after four years on the job. Yet, when asked whether their idea of an engineering job had changed since they graduated, six of the nine participants said that they had not realized their work would include project management-including such tasks as dealing with people, attending meetings, writing documents, and creating schedules and budgets. Given the high frequency with which some interviewees needed to perform these tasks, it is unclear why they did not identify project management skills as important. One possible reason is that they did not perceive project management to be "real engineering" a finding corroborated by the Workplace Sample. With regards to how their idea of an engineering job had changed, two longitudinal participants replied:

> There are parts of the job that I don't think make use of my engineering skills but I think are necessary for the role that I'm in, things like writing procedures. I don't think that's necessarily what I would call an engineering task, but

sometimes it's necessary just because I'm the one with the knowledge required to write that procedure. (Karen, Technical Public Institution, Chemical Engineering major, four years post-graduation)

I think a lot of it [work] can be time management and dealing with people. But as far as *strict engineering* like what we were taught in school -- calculations and stuff like that -- it's a lot of fun but it doesn't take up the majority of my day. (Italics added, John, Technical Public Institution, Petroleum Engineering major, four years post-graduation)

Analysis of our interviews with the Longitudinal Sample suggests that students may have unrealistic or distorted views of engineering. As students our participants saw engineering education and practice as primarily technical, and their perceptions of the professional aspects of engineering were overly narrow. Moreover, some of their misconceptions remained with them into the workplace, influencing their views of their jobs. To the degree that students either choose or do not choose engineering as a profession because of these views, the profession has a problem. Moreover, those who choose engineering may not be taking advantage of opportunities at school that would make them better engineers at work.

Changing expectations for engineering practice (The Workplace Sample, revisited)

With the changes in how our longitudinal participants perceived engineering in mind, we return to the Workplace Sample for further comparison of students' expectations for professional practice and the realities they faced as new hires. We asked the 57 engineers in the Workplace Sample to tell us how engineering practice differed from the expectations they had when they were in school. Some claimed there were no differences and that their classes, extracurricular activities and internships had well prepared them for work. A few even considered school and work to be similar, since both required using the same tools and concepts to solve problems:

> I would say [school is similar] in that you're given a problem and left to go from there. You've got to figure out what exactly you need to do, how you're going to go about doing it, and then get the results and look at them and figure out if they are good. I feel like that's similar to the work here. (Car Company, Mechanical Engineering major, 15 months on the job)

> It's easier to answer how they're [school and work] the same, actually. I don't use the equations for almost anything anymore, but I understand the concepts and I use those all the time. (Computer Parts Company, Mechanical Engineering major, eight months on the job)

More prevalent, however, were discussions about differences. We have covered many of these in prior writings; for example, engineers' work emphasizes application while school emphasizes theory, problems at work have greater scale and complexity, and at work, engineers need to seek out information actively on their own (Korte et al., 2008; Brunhaver et al., 2010). Particularly telling is that young engineers quickly learned that professional practice requires more social interaction it does technical work, and that it is more cross-disciplinary than school led them to appreciate.

Of the 29 participants who said that engineering work was more social than technical, 16 admitted having been surprised by this. Prior to starting their jobs they expected to do primarily technical work. For some, this meant spending considerable time doing design or analysis. Others expected to use the equations and theories that they had learned in school. But once on the job our interviewees reported spending more time than they expected managing people, helping to troubleshoot equipment, and working on the production floor. For those who had expected to work alone, the reality was difficult to accept:

> Yeah, that [doing more technical work] was my expectation and that's why I chose to be a civil engineer. I just want to do technical work and don't [want to] deal with people and management. (Transportation Department, Civil Engineering major, 12 months on the job)

> I think there's a lot of disillusion once you leave engineering school, because when you're there, you're taking all these tests, you're doing all these math problems, and you're delving deep into theories and equations and formulas, and I haven't touched any of that stuff in the year and half that I've been here. (Food Manufacturer, Chemical Engineering major, 17 months on the job)

Some of the young engineers had theories as to why their work was so different. One believed that his or her organization had already solved all of the hard problems and now only needed engineers to verify the results.

> Engineering here seems less technical at times because the company is established and the processes have been established. There's already been a lot of testing. So we have learned everything. I'm dealing a lot more with tests now, verifying I guess what the computer programs are getting out. (Computer Parts Company, Mechanical Engineering major, nine months on the job)

Another believed that his or her organization outsourced their technical work to save time and money.

> What I learned was that we typically, at least at this plant, don't do so much [design]. We are resource limited, so rather than spend our time trying to figure things out, you know, "I need a two-inch pipe," we farm that out to an outside vendor. (Food Manufacturer, Chemical Engineering major, 17 months on the job)

Still others thought the amount of technical work varied widely by position, and that even though they were not doing as much technical work, some of their coworkers could be. Besides, no matter how technical the job, engineering work would always involve some social interaction.

> There's technical [work] and project management, but in the particular role I'm in now, it's more project management than it is technical. And you'll find that within [organization], it depends on the position that you're in. (Transportation Department, Civil Engineering major, 36 months on the job)

> Yeah, there are some places you can go technical. But there is nothing that's centrally technical. There has to be communication, you have to work with people. I think that's the major thing I learned when I started at [organization]. (Transportation Department, Civil Engineering major, 12 months on the job)

Sixteen participants said engineering work required them to reach beyond the discipline they studied in school. Four of the sixteen were not surprised. Even in school they had expected to be primarily general problem solvers and only secondarily, disciplinary experts.

> I was studying to be an electrical engineer, but [I learned] I was going to be an engineer first, and then an electrical engineer. Engineering has to do with solving problems, making requirements, stuff like that. I learned that that's how engineering was going to be, and I've come to the conclusion that, yes, that's how it is. (Car Company, Electrical Engineering major, five months on the job)

The other twelve were surprised when their employer made them responsible for projects outside their expertise. At Car Company a few mechanical engineers found themselves doing electrical or computer engineering-related work. Similarly, chemical engineers at Food Manufacturer and Computer Parts Company became involved in mechanical and civil engineering-related work. Some of our interviewees found the differences between their work and the discipline they studied to be nuanced. Others, like the chemical engineers at Food Manufacturer and Computer Parts Company, were not working with any of the processes or equipment they had learned in school and felt like they had been thrown into a completely different field:

> I would have never guessed that I'd be making circuits. I never thought about how the chemical engineering process can be applied in that type of scenario. This company does not have actual chemical engineering processes. I wasn't really expecting [that] big a contrast. (Computer Parts Company, Chemical Engineering major, six months on the job)

Overall the reflections of the engineers in the Workplace Sample suggest that engineering work is much more variable *and* complex than most engineering curricula convey. The picture is consistent with the other data we have discussed. A young engineers' work is less about using theories or equations, for example, than about project management and working with other people. Furthermore, engineering practice is not confined to a single area of expertise. Instead, it requires young engineers to pick up new knowledge and skills on the job. Given the reported gap between work and education, it seems reasonable to suggest that engineering programs and engineering practice be reconfigured to achieve closer alignment between school and work. We elaborate on this idea next.

DISCUSSION

In this section, we summarize important findings and situate them amid the current literature. We also provide implications and recommendations for several stakeholders, including engineering educators, employers, and researchers.

Summary

Our interviews with early career engineers in the Workplace and Longitudinal Samples point to two distinct but interrelated sides of engineering practice: the technical and professional sides. In addition to doing technical work, young engineers are responsible for non-technical tasks that require significant social interaction, such as managing projects and coordinating the work of other people. Employers also expect young engineers to be able to work outside the specific discipline in which they trained and to work with people who were not engineers. Thus, successful practice requires integrating several kinds of knowledge and skills, from the technical to professional and organizational.

Despite these realities, our findings also show that engineering students emerge from their programs with relatively narrow views of professional practice. Although students may ascribe some importance to non-technical skills, they mainly conceive of engineering as technical problem solving involving the direct application of theory and equations they learned in classes. We can begin to understand why students have these conceptions by looking at their teachers and college professors. The majority of respondents in a recent survey of K-12 educators associated engineering with math, science, and making and fixing things (Yaşar et al., 2006). Furthermore, Pawley (2009) showed that engineering faculty described their profession in much the same way. Given that students learn and internalize these messages as early as elementary school (Capobianco et al., 2011; Cunningham, Lachapelle, and Lindgren-Streicher, 2005; Oware, Capobianco, and Diefes-Dux, 2007), it is not surprising that they persist beyond formal schooling.

To be sure, as the data indicate, the technical knowledge and skills that students learn in school are indeed important to engineering practice. Furthermore, most young engineers continue to refine and expand their knowledge and skills after starting work. This later learning, however, focuses primarily on the doing of a specific job. Once on the job, the importance of technical knowledge and skills appears to decline. Many engineers in the Workplace Sample even noted the lower importance of these competencies from the start.

But as technical knowledge and skills become less central or less sufficient for doing engineering work, the importance of professional knowledge and skills increases. Even when students are exposed to the professional side of engineering work in school, they may not fully grasp what this work looks like on the ground. This seems particularly true for communication and teamwork. Although some students think that communication skills are important to engineering, it is only after they start working that they begin to speak explicitly about the value of formal (technical reports and oral presentations) and informal (e.g., interacting with others via phone and email) communication on the job. Similarly, students readily talk about the importance of working in teams, but ironically none of our young, employed engineers described teamwork in the manner typically found in engineering programs (Colbeck, Campbell, and Bjorkland, 2000). Instead, they spoke of needing to work and communicate with different groups of people, including other engineers, operators, managers, clients, and suppliers. This discrepancy is systemic of a larger issue in engineering education. Despite a recent focus on multidisciplinary teamwork (ABET, 2011; National Academy of Engineering, 2004), faculty lack the time, resources, and incentives to create such experiences within the current disciplinary structure (Jamieson and Lohmann, 2009; McNair et al., 2011). Thus, most group work is often done within students' own disciplines, and while faculty members are encouraged to assign roles to simulate diversity (Johnson and Johnson, 1994), few have experience or training in managing groups (Colbeck et al., 2000).

The data show that once on the job, young engineers' appreciation of professional knowledge and skills become more nuanced, and he or she becomes better at articulating this understanding to others. Yet, engineers are apt to consider less technical work, such as project management, to be different than "real engineering" and not directly related to their degrees. Going forward, outsourcing and automation will likely make project management a common position for engineering graduates. Since students expect synergy between "what is learned in [the] classroom and what is needed in the field for successful practice" (Steering Committee of the National Engineering Education Research Colloquies, 2006, p.259), we must consider the implications of this trend on how engineers value their education.

Finally, two-thirds of the engineers in the Workplace Sample mentioned knowledge they had learned about their organizations in order to do their jobs. However, most participants failed to see connections between this knowledge and their technical work on their own. Furthermore, although many had held undergraduate internship or co-op experiences, few could transfer lessons they had learned then to their current work situations now. These findings substantiate employers' low ratings of engineering graduates in the area of organizational contexts and constraints (see introduction; Lattuca et al., 2006). It is also puzzling that none of the participants in the Longitudinal Sample mentioned knowledge about their organization as important, especially since knowing how an organization operates and how to successfully negotiate hierarchies, divisions of labor, and status structures are critical for success in almost any organization. Further research on the importance of knowledge about one's organization is required. We suspect, however, that young engineers fail to mention organizational policies and processes because they do not see them as a form of knowledge unless explicitly cued to do so.

Our findings are consistent with and extend prior studies of engineering education. Bucciarelli and Kuhn (1997) argued that formal education prepares engineers to succeed in the "object world" (p.211) but overlooks the process-oriented, context-laden social world. Based on a study of engineers in a large high-tech company, Perlow and Bailyn (1997) not only concurred with Bucciarelli and Kuhn's assessment but added that engineers typically perceive "real engineering" to pertain only to the object world. Through semi-structured interviews with a broad sample of engineers, Trevelyan (2009; 2010) found that most engineering curricula focus solely to the technical aspects of engineering even though engineering is both a technical and social discipline. Similarly, Sheppard et al. (2008) described engineering as interactive and complex work that encompasses many domains beyond the technical. Sheppard et al. also found such an image of engineering contrasted sharply with the narrow way that most engineering education is currently framed.

Earlier studies have shown that employers find engineering graduates, even those who are highly competent technically, to be unprepared to practice. Salzman (2007) reported that because managers find technical skills to be common, they cannot use them to distinguish between job candidates. Managers seek young engineers who possess non-technical skills, especially communication skills and the ability to work across "borders," both disciplinary and organizational. Yet, these skills are often the most difficult for the managers to find in new engineers (Salzman and Lynn, 2010; Lattuca et al., 2006).

Like our own, these studies point to deficiencies in the current model of engineering education that constrains it from producing engineers with knowledge and skills required for being effective in the workforce. In particular, professional and organizational knowledge and skills need to be elevated to the same level of importance as technical knowledge and skills.

Complicating such a change is the fact that most engineering programs are burdened by an already overcrowded curriculum, which makes adding content a challenge (Jamieson and Lohmann, 2009; Salzman and Lynn, 2010, Trevelyan, 2007). Moreover, because engineers need to be able to apply engineering concepts and use engineering tools to solve ever evolving problems, cutting edge technical training must remain a central component of engineering education. Accordingly, educators and policymakers must redesign engineering pedagogy, assessment, and accreditation in ways that integrate technical, professional, and organizational knowledge and skills to achieve tighter connections with practice (Froyd and Ohland, 2005; Litzinger et al., 2011; Sheppard et al., 2008). Based on these recommendations, we next consider implications across four domains: engineering education, engineering practice, future research, and educational strategy.

Implications for Engineering Education

Implications for academia. To develop competent and productive graduates, the narrow technical education that most engineering schools now offer must expand to emphasize the professional and organizational content as well--not only in the classroom but in co-curricular and extracurricular activities as well. Many engineering students hold the unrealistic view that engineering is synonymous with technical problem solving. Particularly worrisome is that this view persists even after they have completed design projects (such as senior capstone) in upper division courses. Given how resistant to change the image of engineering as solely technical seems to be, bridges must be intentionally built to help students connect their early experiences in math and science to later engineering experiences and, ultimately, to professional practice. Providing opportunities to learn about real engineering work at every stage of an undergraduate career is crucial, and perhaps should even be part of K-12 education.

One way to accomplish this goal would be through cognitive apprenticeships (Collins, Brown, and Holum, 1991; Sheppard et al., 2008), in which students are exposed to professional practice through a series of carefully staged and monitored steps. In this approach, educators first model expert practice; then, they scaffold students' efforts to imitate their performance providing feedback where needed. The process is repeated over time, moving from simple lab and design exercises in the students' freshman year to closer "approximations of practice" (Grossman et al., 2005) by their senior year. Other ways to expose students to real engineering include pedagogies specifically designed to help students make sense of and develop the abilities for practice. Some traditional examples include design tasks and laboratory work (Litzinger et. al, 2011; Sheppard et al., 2009). More recently, educators and researchers have experimented with other methods such as portfolios (Dunsmore et al., 2011; Eliot and Turns, 2011) and think-aloud protocols (Douglas et al., 2012). Given their emphasis on the social, these latter examples may be especially effective for teaching professional and organizational knowledge and skills.

The most important professional knowledge and skills that students need to master are the ability to work with others, to communicate effectively, and to independently seek information. Because engineering graduates must be able to work with a wide variety of people including non-engineers, collaborative and cooperative learning, which emphasize small group work, are particularly promising (Johnson, Johnson, and Smith, 1998; Prince, 2004; Smith et al., 2005). However, such experiences must do more than focus on working in groups, the groups must be demographically and disciplinarily heterogeneous so that students learn how to work with people who are different from themselves (Colbeck et al., 2000; McNair et al., 2011). Similarly, students should be required to take courses in other departments to prepare for multidisciplinary products and projects in the workplace. For their part, engineering programs and schools must lend faculty the necessary support to make this happen (Jamieson and Lohmann, 2009; McNair et al., 2011).

Engineering students also need to learn to communicate their ideas to a variety of audiences and in many modes. For this objective, project-based learning may be particularly useful (Dym et al., 2008). Especially when implemented in teams, projects allow students to practice formal communication via technical reports and oral presentations as well as informal communication through email, memoranda, group meetings, and so on. Projects also expose students to other professional knowledge and skills including the management of tasks, schedules, and people. Finally, engineering graduates must be able to direct their own learning when they recognize they do not know something. Problem-based learning requires students to formulate their own problems and then find information for solving the problems (Prince, 2004; Woods, 1994).

Students also need to begin becoming savvy about organizations while in school. Given the wide range of paths that students eventually pursue, a curriculum cannot address every organization's history, culture, policies, and procedures. It is possible, however, to expose students to a variety of organizations through field trips, case studies, and in-class speakers. Homework and project assignments can be designed to emphasize contexts and constraints which mimic those that students might encounter in their workplaces. At very minimum, engineering students should be encouraged if not required to take courses in organizational behavior and other related topics. Even technical engineering courses could include a stronger emphasis on the organizational and contextual influences that affect the practice of engineering. The goal is for students to develop an understanding of how organizational dynamics influence jobs and how their organizations operate formally, informally, and politically.

Engineering students should also be given opportunities to learn about professional practice outside the classroom, ideally as part of the required curriculum. Venues for doing so would include research experiences, study abroad, involvement in professional societies, internships, co-ops, and other forms of employment. Internships and co-op experiences are particularly valuable because they provide first-hand insight into what engineers really do and how they use the knowledge and skills they learned in school. They also provide a head start on developing a professional network. Students who participate in internships and co-ops are better prepared for the workplace and, thus, more employable (Haag, Guilbeau, and Goble, 2006). Internships and co-ops may also help students more knowledgably choose an engineering discipline or even whether they want to pursue an engineering career (Raelin et al., 2006). To optimize co-curricular and extracurricular activities, engineering programs must actively help students reflect on and integrate these experiences into their understanding of engineering practice. As our analysis suggests, this step may be especially important for making explicit the implicit organizational knowledge that students learn from work-related experiences.

Of course, incorporating such changes into a four-year engineering curriculum will not be easy. Some academicians, organizations, and even some students have called for either extending the engineering bachelor's degree to five years or making the master's degree the first professional engineering degree to attain a more equal balance of theory and practice (National Academy of Engineering, 2005; Grose, 2012). Revising engineering curricula will certainly require creativity, dedication, and careful coordination at all levels within the university. It may also require considering how to streamline the engineering degree, perhaps by re-designing traditional courses to more closely align with practice or by building consensus on what conceptual and theoretical knowledge is more relevant for practice.

Implications for other stakeholders. Other stakeholders can also help tighten the connection between schooling and work, and the foremost of these are employers themselves (Korte, 2009; Sheppard et al., 2008). Locally, firms can partner with engineering schools to assist in redesigning programs and developing ways for students and practitioners to interact inside and outside of the classroom. Practicing engineers might deliver guest lectures, coach students, provide program feedback, and serve as adjunct faculty. Firms and trade associations can sponsor fieldtrips, design projects, internships and co-ops. They can also sponsor educational innovation and scholarship both in the university and industry (Jamieson and Lohmann, 2009).

National research, accrediting, and professional organizations already play a vital role in advocating for educational reform. They promote and reward engineering programs and faculty dedicated to experimenting with innovative pedagogies. They also endorse best practices through assessment and accreditation criteria. These parties should continue to provide resources for developing and sharing prototypes and ideas that engineering schools can deploy to become more practice-oriented (Sheppard et al., 2008).

Finally, reforming engineering education needs to extend into elementary and secondary schools for it is here that students begin constructing their images of engineering. Findings from our study and others suggests that, much like collegiate engineering programs, K-12 education tends to emphasize the importance of math and science to engineering. Others have argued that primary and secondary schools are neither teaching the right knowledge and skills nor sending the right messages to students about engineering (National Academy of Engineering and National Research Council, 2009; Anderson et al., 2011; Capobianco et al., 2011). For example, it is not uncommon for K-12 students to believe that engineering is sedentary work that involves little interaction with people (National Academy of Engineering, 2008b). Connections between pre-college engineering education and engineering practice need to be made more explicit. In addition to teaching both technical and professional skills, K-12 educators need to expose students to images of how engineers use their skills. K-12 educators must increase their familiarity with and address stereotypes that they have about engineering as well.

Implications for Engineering Practice

Just as engineering education should aim to help students make tighter connections between education and professional practice, so too should industry help young engineers adjust more effectively to the transition from school to work. Particularly helpful would be information at the point of hiring about the kind of work a student will be doing. During the first few months of a new employee's job, discussions of the employer's culture, history, policies, and procedures should be contextualized so that new recruits can envision how these factors will influence their work. Young engineers would benefit if managers and coworkers served as mentors and helped them see how the knowledge and skills that they learned in school apply to their jobs, particularly if they will primarily be doing project management (Korte, 2009, 2010). Studies have shown that similar coaching and mentoring enhances internships and co-op experiences by giving students greater exposure to diverse people and organizational settings and transforming them into more realistic job previews (Parsons, Caylor, and Simmons, 2005; Raelin et al., 2006).

To achieve these objectives, employers will require a better understanding of the work that they hire young engineers to do, so that they can set their own expectations appropriately. In many firms, a bachelor's degree has become a requirement for practice. Yet, it is possible that some engineering jobs can be adequately filled by workers with an associate's degree. Employers should ask themselves whether they are properly utilizing their young engineers and whether these individuals are capable of doing more complex and creative work. If the latter is true, then the young engineers' roles and responsibilities need to be adjusted so that they feel that they are contributing to the organization and pursuing meaningful work. Ultimately, employers must collaborate more closely and meaningfully with engineering educators and researchers so that engineering curricula can be improved.

Perhaps most troubling for the profession is the possibility that students may be turning away from engineering careers because they have a limited understanding of what engineering is or because they do not see how it makes use of the knowledge and skills they value (Atman et al., 2010; Lichtenstein et al., 2009). Of course, how a better understanding of professional practice might influence students' career decisions is hardly certain. For students who are confident in their communication and interpersonal skills, realizing that engineering involves a significant amount of social interaction may make engineering more attractive. Students without this confidence may find engineering less attractive. It is also possible that more realistic images of engineering would attract different individuals and change the make-up of the engineering workforce in ways that we cannot anticipate. When asked how her idea of an engineering job had changed since she graduated, one of our interviewees remarked, "I'm just seeing more of the opportunities I didn't even know existed when I was in school" (Karen, Technical Public Institution, Chemical Engineering, four years post-graduation). Her remark makes us wonder how many more students would choose engineering careers if they were also familiar with these opportunities. At the moment, we sorely need further research on how engineering students' concepts of the nature of engineering work affect their career decisions.

Implications for Future Research

Our findings suggest that, over the first four years of employment or practice, the importance of general technical knowledge and skills in engineers' work wanes while the importance of professional and organizational knowledge and skills rises. As we previously noted, we do not know whether this shift represents a change in engineers' work responsibilities or just a change in their perceptions. However, we suspect it is both. Additional research into how the importance of technical, professional, and organizational knowledge and skills changes, and why, could help sharpen our current understanding of professional practice at different stages in an engineers' career.

Further study of engineering students' and young engineers' conceptions of engineering is also needed, to more completely characterize the relationship between engineering education and work. In particular, more research is needed into how the nature of engineering work varies depending on the type of organization or project. Larger datasets can help, for example, determine the influence of organizational size or industry sector, or of engineering discipline and institution type. Our longitudinal study may also be expanded to capture how engineers' views change over a longer period of time.

This study presents valuable insights into the nuances of engineers' changing conceptions of professional practice. Through these means, we have identified organizational knowledge as an important competency for young engineers, one that is typically overlooked in contemporary engineering curricula. Thus, we recommend continued investigation into these issues, capturing the perspectives of engineering leaders and educators as well.

Implications for Educational Strategy

We end this chapter with a call to industry and the university, to re-examine the roles that each should play in preparing graduates for the workforce. While our study has focused on the gaps between engineering education and practice, other literature has identified similar gaps in nursing, medicine, business, law, accounting, and teaching (Colby et al., 2011; Cooke, Irby, and O'Brien, 2010; Jones, 2002; Sullivan et al., 2007). Like engineering, programs in these professions struggle with the integration of professional knowledge and skills with technical content. In addition, common criticisms in these other professional programs indicate that their graduates are not job-ready. Too often, lack of preparation is seen as a deficit in the university or a matter for public policy. Instead there needs to be greater understanding of the divergence between education and job skills and the causes behind it.

Among the possibilities are a decline in the quality of higher education, changing job demands, and heightened employer expectations. But according to Cappelli (2007), the real reason is that employers are no longer willing to provide the internal training needed to develop the skills of their new hires. Rather than provide support and training, they seek new hires who can "step immediately into the job and start doing the work" (Center for Education. 2008, p.67). Cappelli also remarked that today's employers expect educators and policy makers to take on the responsibility for training that they have shouldered in the past. While controversial (Center for Education, 2008), these comments set the stage for a discussion between the university and industry.

In particular, these two "communities" need to figure out what their expectations for graduates are and what their respective roles and responsibilities will be. It may be that the university is the better place to train young professionals, and that a major overhaul is needed to make this possible. Or, employers might need to do more – to provide more training, support, and mentorship, and to invest more in education – if they expect graduates to join their organizations with a desired level of competence. Again, the responsibility is shared. There must be more collaboration between education and professional practice, with industry and the university designing professional curricula and training.

Students (i.e., tomorrow's graduates and employees) should also be involved in talks about educational strategy. Direct knowledge of industry and university expectations will enable students to take greater ownership of their learning. With the rise of extracurricular and off-campus activities (e.g., service learning, study abroad), distance learning, and open-source materials, students have more opportunities than ever to expand their knowledge and skills and keep current. Yet, judging from the few participants who mentioned self-directed learning, it appears that most engineers in our study never received guidance or opportunities to do this. In fact, even after working in their jobs for up to three years, some engineers in the Workplace Sample spoke of not understanding how their work fit into the organization or not knowing what they needed to know (Brunhaver et al., 2010; Korte et al., 2008). By making known the knowledge and skills required for practice, employers and institutions can help students take charge of their futures. Students who adopt an active learning approach will in turn be better prepared for a modern and ever-changing workforce.

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APPENDIX. DEFINITIONS OF KNOWLEDGE AND SKILLS MENTIONED BY THE WORKPLACE AND LONGITUDINAL SAMPLES

Knowledge and skills	Sample	Definition
business knowledge	Longitudinal	Awareness of the organization's business needs
communication skills	Workplace, Longitudinal	Ability to express oneself effectively, in written/oral reports and when working with different groups of people
content knowledge	Workplace, Longitudinal	Understanding of technical content, including engineering, science, and math
context knowledge	Workplace, Longitudinal	Awareness of contextual issues affecting engineering solutions, e.g., safety, finances
creativity skills	Longitudinal	Ability to develop original ideas or solutions
design skills	Workplace	Ability to generate and develop concepts for a system, component, or process
documentation skills	Workplace, Longitudinal	Ability to take good notes and keep track of records
equipment/processes knowledge	Workplace	Understanding of equipment and processes needed to do a job
hands-on skills	Workplace	Ability to make or build an object using tools/processes
information finding skills	Workplace	Ability to locate resources and information
leadership skills	Workplace	Ability to provide direction for a team or project
logic skills	Longitudinal	Ability to draw conclusions using reasoning
math skills	Longitudinal	Ability to apply math knowledge and methods
modeling and analysis skills	Workplace	Ability to model, analyze, and interpret data
organizational culture/ background knowledge	Workplace	Understanding of the organization's culture and background
organizational hierarchy knowledge	Workplace	Understanding of the organization's labor hierarchy
organizational policies/ procedures knowledge	Workplace	Understanding of the organization's policies and procedures
problem solving skills	Workplace, Longitudinal	Ability to define and solve engineering problems
programming skills	Workplace	Ability to write and troubleshoot software code, e.g., in C or C++
project management skills	Workplace	Ability to plan, organize, and manage project resources
rapid iteration skills	Workplace	Ability to try out different solutions in a rapid manner
self-directed learning skills	Longitudinal	Ability to acquire new knowledge and skills on one's own
self-motivation skills	Longitudinal	Ability to focus one's energy and effort towards doing one's work, without influence from other people
science skills	Longitudinal	Ability to apply science knowledge and methods
social skills (general)	Longitudinal	General skills required to interact with others on the job
software skills	Workplace, Longitudinal	Ability to use software applications, e.g., CAD
systems thinking skills	Workplace	Ability to visualize the relationships among a system's parts, as opposed to just the parts themselves

teamwork skills	Longitudinal	Ability to function on teams
technical skills (general)	Longitudinal	General skills required to do the technical aspects of a job
testing skills	Workplace	Ability to plan, conduct, and collect data from tests
time management skills	Workplace	Ability to manage one’s time and meet deliverables in a timely manner
visualization skills	Longitudinal	Ability to mentally picture an object or process
work ethic	Workplace	Willingness to keep working until the task is finished
working with people	Workplace, Longitudinal	Ability to get along and work with other people

Table 1. *Demographic information for participants in the Workplace Sample (n=57)*

	Count	Average time since hire (months)	Number who reported internship: At any company	Number who reported internship: At current company	Number who reported earning master's degree
All Participants	***57***	***11.3***	***45***	***18***	***9***
Food Manufacturer	18	13.7	15	3	1
Car Company	16	11.4	14	8	7
Computer Parts Company	16	7.0	9	0	1
Transportation Department	7	15.4	7	7	0

Table 2. *Demographic information for participants in the Longitudinal Sample (n=9)*

Pseudo-nym	Insti-tution	Sex	URM	Major reported in junior year	Reported internships in junior year	Occupation reported at follow-up
Emily	LPub	Female	Yes	Civil and environmental engineering	Yes	Structural engineer
Jesse	LPub	Male	No	Mechanical engineering	No	General engineer
John	TPub	Male	No	Petroleum engineering	Yes	Operations engineer
Justin	LPub	Male	No	Computer engineering	No	Software engineer
Karen	TPub	Female	No	Chemical engineering	N/A	Production engineer
Laura	TPub	Female	No	Chemical engineering	Yes	Process engineer
Leah	TPub	Female	Yes	Chemical engineering	No	Process engineer
Otis	SPri	Male	No	Computer science	Yes	User interface engineer
Paul	TPub	Male	Yes	Engineering physics	No	R&D engineer

LPub: Large Public University, SPri: Suburban Private University, TPub: Technical Public Institution;
URM: Under-represented minority (e.g., not white or Asian/Asian American)
N/A: Information not available

Table 3. *Summary of Workplace and Longitudinal Studies*

Sample	Data source	Sample description	Sample scope	Main focus of study
Workplace Sample	APS Workplace Cohort	57 recently graduated engineers, 0-3 years out in 2007	4 organizations	Where knowledge and skills used at work are learned (in school/on the job)
Longitudinal Sample	APS/EPS Longitudinal Cohort	9 early career engineers: junior college students in 2006 and graduates four years out in 2011	3 institutions	What knowledge and skills are most important to doing engineering job

APS: Academic Pathways Study, EPS: Engineering Pathways Study

Table 4. *Comparison of where knowledge and skills learned (Workplace Sample, n=57)*

	Percentage who reported using skill/knowledge at work [1]	Percentage who reported learning skill/knowledge	
		In school	On the job
Technical knowledge and skills [2]	***98***	***93***	***86***
content knowledge	72	61	16
equipment/process knowledge	60	5	60
problem solving skills	46	44	7
software skills	39	33	26
modeling and analysis skills	30	25	11
rapid iteration skills	18	11	9
programming skills	11	9	7
design skills	11	7	4
testing skills	11	4	7
systems thinking skills	5	5	0
hands-on skills	4	4	2
Professional skills	***96***	***53***	***96***
communication skills	65	25	58
working with people	60	19	49
information finding skills	58	16	51
project management skills	28	18	12
time management skills	18	5	14
leadership skills	12	5	7
documentation skills	11	0	11
context knowledge	9	0	9
work ethic	5	0	5
Organizational knowledge and skills	***67***	***16***	***56***
organizational policies and procedures	42	7	35
organizational hierarchy and structure	28	2	28
organizational background and culture	16	7	9

1. All percentages are based on the total number of participants, n=57.
2. Percentage of participants who reported using/learning at least one of the technical knowledge and skills listed in the table. The percentage of participants who reported using/learning professional knowledge and skills and the percentage of participants who reported using/learning organizational knowledge can be interpreted similarly.

Table 5. *Comparison of important knowledge and skills (Longitudinal Sample, n=9)*

	Number of participants who reported skill/knowledge as important		
	Junior year of college	Four years post-graduation	Difference
Technical knowledge and skills [1]	***9***	***6***	***-3***
math skills	8	1	-7
logic skills	5	0	-5
science skills	4	0	-4
problem solving skills	3	2	-1
technical skills (general)	2	1	-1
visualization skills	1	0	-1
content knowledge	2	2	0
software skills	1	1	0
Total # mentions	*26*	*6*	*-20*
Professional knowledge and skills	***8***	***7***	***-1***
context knowledge	3	0	-3
creativity skills	3	0	-3
teamwork skills	2	0	-2
social skills (general)	1	0	-1
self-directed learning skills	1	1	0
business knowledge	0	1	+1
documentation skills	0	1	+1
self-motivation skills	0	1	+1
working with people	1	3	+2
communication skills	2	5	+3
Total # mentions	*13*	*12*	*-1*

1. Number of participants who reported using/learning at least one of the technical knowledge and skills listed in the table. The number of participants who reported using/learning professional knowledge and skills can be interpreted similarly.