Working Title: Bridging the Gaps between Engineering Education and Practice

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1. INTRODUCTION

Over the last decade, American engineers have had to contend with a new set of challenges such as globalization, shifting demographics, and rapid technological change (Duderstadt, 2008; Augustine, 2005). In response, industry, government, and the professional societies have called on educators to better prepare engineering students for the workplace by emphasizing not only technical but professional competencies (Sheppard et al., 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 Engineering Accreditation Commission, 2007; Galloway, 2008; Clough, 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Yet, despite calls for reform, research has shown that engineering programs are often based on an outdated image of engineering practice that is misaligned with reality (Duderstadt, 2008; Clough, 2004; Sheppard et al., 2008; Vest, 2008).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 their counterparts who graduated ten years earlier. A third of the faculty who taught these students also reported that they were less able and knowledgeable about math and science and had worse technical skills than their predecessors (Lattuca, Terenzini, and Volkwein, 2006). In fact, many engineering students remain uncertain about what engineers actually do, even by the time they graduate (Matusovich et al., 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 look abroad for new talent, graduates looking for engineering work are more susceptible to competition from other countries (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. Three years after graduation approximately one-third of all engineering graduates from the classes of 2003 to 2005 were working in non-engineering-related positions (National Science Foundation, 2006). Similarly, 19 percent of engineering juniors and seniors in 2007 reported that they were unsure about pursuing a career in engineering (Gilmartin et al., in press). Their uncertainty partially reflects a nationwide loss of interest in engineering, a perception that engineering careers are no longer secure, and the realization that other professions pay higher wages (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; Atman et al., 2010).

These studies 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 minted 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 NSF-funded studies, the Academic Pathways Study (Sheppard et al., 2009) and the more recent Engineering Pathways Study (Sheppard et al., 2011).

2. 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., Lattuca et al., 2006), 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. 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. A number of 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 technical 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 AWAKEN project. The respondents in this

[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.

recently published study also considered communication, problem solving, ethics, lifelong learning, and business skills to be essential to their work. Two-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).

American engineers are not unique in their perceptions of their education's relevance. Although a longitudinal study of early careers in the U.K. found that most engineers rated their undergraduate courses as good to excellent and their overall education as at least fairly relevant to their jobs, many felt unprepared to continue learning at work, and some were surprised by the workloads and responsibilities assigned to them (Eraut, in press). 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 (Seering, 2009; Anderson et al., 2009; Trevelyan et al., 2008; Trevelyan, 2008; Sheppard et al., 2010; Atman et al., 2010). Although a survey's structured questions allow respondents 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 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, in press; Trevelyan and Tilli, 2008; Trevelyan, 2007) focused exclusively on early career engineers.

In contrast, this study employs both structured *and* semi-structured interviews to elicit participants' own perspectives. The interviewees include both students and practicing engineers from multiple institutions and organizations at different points in their careers. By combining datasets, we are able to provide both retrospective and longitudinal analyses to demonstrate the

[2] This name is a pseudonym.

changing nature of engineers' perspectives as they move from their engineering programs into the workforce. The next section describes each dataset in detail.

3. METHODS

This study employs three sources of data. The Workplace and the Longitudinal Datasets were elements of the Academic Pathways Study (APS) funded by the National Science Foundation and conducted from 2003 to 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. The Engineering Pathways Study (EPS), our third dataset, extended the APS by re-interviewing a subset of the respondents in the Longitudinal Dataset four years after graduation.

Our objective is to identify and investigate major "gaps" in engineering education for preparing of engineering students for practice. We use retrospective data from the Workplace Dataset to identify how the skills and knowledge 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 our respondents' notions of engineering. Finally, we return to the Workplace Dataset for further evidence of how young engineers' images of engineering had changed since leaving school.

3.1 Workplace Dataset

The Workplace Dataset consisted of semi-structured interviews with 86 newly hired engineers 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).[4] The interviews took place in the winter of 2007 and lasted 45 to 90 minutes.[5] The engineers at Car Company were mostly mechanical and electrical engineers. They were chemical engineers at Food Manufacturer, mechanical and chemical engineers at Computer Parts Company, and civil engineers at Transportation Department. Car Company and Computer Parts Company assigned early career engineers directly to permanent positions that involved both technical and project management work. Young engineers at Food Manufacturer and Transportation Department initially rotated through three departments before being assigned to a project management position.

Of particular interest here are the 57 respondents who were in their first full-time position since graduating.[6] These individuals could best offer opinions about the differences between their engineering education and new employment. All had been working in their jobs for two

[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.
[4] All institutional names in this study are pseudonyms.
[5] For more details on the Workplace Dataset consult Sheppard et al. (2009). Previous studies that have drawn on the Workplace dataset employed only the data from Car Company (Korte et al., 2008; Korte, 2009; Korte, 2010).
[6] The remaining 29 respondents were experienced hires who had worked in at least one other job since graduating.

months to three years, with an average duration of 11 months. Forty-seven had held internships while in college. Of these, eighteen interned with their current employer. Nine respondents had master's degrees, and the rest bachelor's degrees. Respondents included men and women as well as individuals representing a diversity of racial and ethnic groups. Sixteen of the fifty-seven worked at Car Company, 18 at Food Manufacturer, 16 at Computer Parts Company, and 7 at Transportation Department.

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, interviewers asked participants to reflect on 1-2 problems or projects for which they had to apply their skills and knowledge from school. For each problem or project, the interviewer asked: (1) What knowledge and skills from school did you apply to work on that problem?, (2) What did you learn from working on this problem?, and (3) What are some of the differences between engineering in school and on the job? Throughout the interviews participants talked readily about skills and knowledge they used, 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 respondents' discussion of the problems on which they chose to focus, provide data for the present analysis.

3.2 The Longitudinal APS and EPS Datasets

The longitudinal component of the APS lasted from 2003 to 2007 and focused on 40 students from each of four institutions: a Technical Public Institution in the Midwest, an Urban Private University in the mid-Atlantic region, a Suburban Private University on the West Coast, and a Large Public University on the West Coast. The researchers tracked these 160 students with interviews and surveys throughout their four years of college. The Engineering Pathways Study (EPS) followed up with APS participants from Technical Public Institution, Suburban Private University, and Large Public University four years post-graduation in the spring of 2011 (Sheppard et al., 2011). Of the approximately 100 participants re-contacted, 30 agreed to be interviewed, thus creating a 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 Longitudinal APS and the EPS studies included both qualitative and quantitative data (i.e., both were mixed methods studies; see Creswell and Plano Clark, 2006), the current study employs only qualitative data from semi-structured interviews. To qualify for the panel, respondents 1) had to have graduated with an engineering degree, 2) had to have been working in an engineering job four years later, and 3) had to have participated in the APS structured interview in their junior year (i.e. 2006). Ten respondents met all three criteria: six from Technical Public Institution and four from Large Public University.[7] That these individuals represent a much smaller number of the respondents who originally participated in the APS study is certainly 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 data.

[7] We dropped one additional student from Suburban Private University from the sample even though s/he met the criteria to create a more balanced sample across schools.

Table 1 goes about here.

Table 1 displays demographic information for the panel of ten respondents. Four of the ten were women, and four were members of an under-represented minority. Three where chemical engineers, three were mechanical engineers, and the remainder ranged across other engineering disciplines. Only two of the respondents had held internships by their junior year. Four years after graduation, these individuals held a wide variety of positions with their employers.

Researchers interviewed the respondents in person for approximately an hour when they were students and on the phone for 30 to 60 minutes four years later. We focus here on respondents' answers to three questions asked when they were juniors in the spring of 2006: (1) Are there particular skills that you would say are important for an engineer to have?, (2) Of the skills you mentioned, which ones do you possess, and how did you develop them?, and (3) In your own words, please define engineering? We also focus on their answers to two questions posed during the EPS interviews in the spring of 2011: (1) What skills and knowledge do you see as most important to doing your job? and (2) How has your idea of an engineering job changed since you graduated?

3.3 Analysis

We analyzed the interviews from all three datasets using a case study approach with each participant representing a single case (Miles and Huberman, 1994; Stake, 2006; Yin, 2003). The interviews were recorded, transcribed verbatim, and made anonymous prior to analysis. MAXQDA software was then used to code the data.

We approached each dataset independently with both qualitative and quantitative methods. For each dataset the transcripts were analyzed using an open coding approach, allowing themes or categories to emerge from the data (Patton, 2002). We continuously revised and combined codes until a consistent coding scheme emerged. We then recoded all interviews using the consistent scheme (Weber, 1990).

In this paper we refer to the analyses focusing on the 57 young engineers from the Workplace Dataset as the Workplace Study. The comparison of engineers as students in APS and early career professionals in EPS is called the Panel Study.

4. FINDINGS

4.1 Skills and knowledge in engineering practice (The Workplace Study)

The early career engineers in the Workplace Study identified the skills and knowledge that they learned in school and applied on the job. We coded the skills and knowledge they mentioned using their own language. We then clustered these mentions into 20 categories sorted into three broad types: technical skills and knowledge, professional skills and knowledge, and organizational knowledge. Table 2 shows the number of participants who mentioned learning skills and knowledge either at school or on the job, as well as the total number of respondents

who mentioned each skill regardless of where they learned it.[8] The appendix provides definitions of the skills and knowledge listed in the Table 2. As the table shows, virtually every respondent reported using technical (n=56) and professional (n=55) skills and knowledge in their work. Where they learned these skills, however, differed.

Table 2 goes about here.

Technical Skills and Knowledge. Although respondents claimed to have acquired technical knowledge from school (n=36) as well as the workplace (n=23), school was the more important source, and the difference was statistically significant according to McNemar's nonparametric test for paired samples. Respondents typically traced the technical skills they learned at school to courses ranging from basic physics and calculus to more advanced topics. Which advanced courses the respondents 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 engine courses, while their electrical engineering colleagues at Car Company relied more on their training in circuits. Compared to knowledge learned at school, technical knowledge learned at work revolved around the engineer's particular job (e.g., agricultural regulations at Food Manufacturer, traffic signal requirements at Transportation Department).

Similarly, respondents reported that school and the workplace were more or less equally important for learning about tasks and processes pertaining to their jobs and about software applications. But there were crucial distinctions in what they learned in each milieu. The tasks and processes they reported learning in school were broadly applicable to most engineering work, for example, taking measurements and graphing data. At work they learned tasks and processes specific to their job, such as knowing how to perform particular tests and calculations. On the job engineers deepened their knowledge of software applications that they had first encounter at school. In fact, many engineers who learned a new software application on the job (n=10 of the 16) told us they had learned a simpler version in school which made their learning curve less steep:

> Actually, [the organization's] LAN I was a little bit familiar with because it's similar to CAN, and I had learned that in my last semester in school. So I was a little bit familiar with how to read the messages and whatnot. (Car Company, 06-014)[9]

In sharp contrast to the technical skills discussed above, young engineers overwhelmingly reported learning problem solving skills at school (n=24) rather than on the job (n=2, $X^2(1,57)=18.375$, $p<0.001$). Furthermore, they did not credit their learning to any particular course or combination of courses. 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

[8] One of the 57 participants was excluded from this analysis because s/he was not asked these questions.

[9] To assist the reader in interpreting our qualitative data, passages from interviews end with the organization where the respondent worked or where he or she went to school as well as the individual's unique identifier.

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, 04-005)

Professional Skills and Knowledge. The workplace, however, is generally where young engineers said they learned professional skills and knowledge. Significantly more respondents reported learning professional skills and knowledge on the job than in school (n=55 versus n=27, $X^2(1,57)=26.036$, $p<0.001$). Most respondents equated learning to be professional with working with other people, acquiring communications skills, and developing information finding skills.

Working with people was the most commonly cited professional skill, and young engineers told us they learned it almost exclusively on the job (n=40 versus n= 8; $X^2(1,57)=25.289$, $p<0.001$). In addition to getting along with coworkers and supervisors, respondents spoke of learning how to work with people who were not engineers like themselves. Perhaps because three of the four employers were manufacturers, 17 respondents reported needing to work with – and sometimes even manage – workers on the production floor, including foremen, machine operators, and maintenance workers. Others found they needed to learn to work with contractors, suppliers, and customers. Learning to work with members of such groups was an eye opening experience for many:

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, 07-009)

I think 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, 04-012)

For young engineers, working with people also meant getting to know coworkers personally, establishing relationships with them, networking to gain visibility and identify key resources, and motivating collaborators on projects. These skills and abilities are reminiscent of those that Singh and Fouad (2011) associate with high "organizational self-efficacy," defined as the confidence in one's ability to navigate an organization's climate and its cast of characters.

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 just sort of flagged those people in my mind. (Computer Parts Company, 07-020)

[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, 06-003)

Effective communication (both oral and written) was another important professional skill that young engineers claimed to have learned mostly on the job (X^2 (1,57)=7.840, p<0.001). For respondents, learning to communicate effectively encompassed not only delivering better presentations, but acquiring tips on how to communicate better with their coworkers. Such tips included following up an email 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:

> [My supervisor told me that] you just have to do what you can do [to meet deadline] and then the rest is up to them [coworkers]. But you need to follow up and make sure that they're on top of it … She has told me, "If you give a group a certain time for them to give you a response back and they said okay … and they don't, come tell me and I can escalate that further and make sure it gets done." (Car Company, 06-014)

> 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, 07-009)

Nearly forty percent of the young engineers reported having to learn information-finding skills on the job (X^2(1,57)=8.522, p<0.001). For a few, information finding meant becoming familiar with their organization's databases, but many more (n=22) discovered that their coworkers were the most significant source of information. As Korte et al. (2008) documented, coworkers not only helped these young engineers learn about work tasks but also about the culture of the work group.

Respondents mentioned a variety of other professional skills, but with far less frequency: project management skills, time management skills, creativity, context skills, leadership skills, organizational skills, and a work ethic. With the exception of project management skills, the young engineers told us they also had learned these skills primarily or exclusively in the workplace.

Organizational Knowledge. Many respondents reported applying knowledge about their organization in their technical work. As one might expect for engineers first entering employment, they all reported learning this knowledge on the job (n=0 versus n=32; X^2(1,57)=4.167, p<0.001). Furthermore, most equated knowledge of an organization with knowledge of the organization's bureaucratic procedures. Twenty-three respondents spoke of specific organizational policies and procedures that they had learned (for example, how to write test protocols or submit work orders) while only a few talked the organization's history or culture. Fifteen also 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 even though 26 of the respondents had held internships, none of them mentioned what they had learned about organizations or life in organizations during that time. In fact, even after becoming employees, few acknowledged using any organizational knowledge in their technical work. In most cases, it was not until the interviewer asked them about how things worked in their organization that they addressed this topic.[10] As such, it is possible that organizational knowledge may be more implicit than technical or professional skills. Conceivably the young engineers may have been aware of their organizations and how they operated but did not feel they consciously applied that knowledge in their work. Being relatively new to the organization, perhaps they had not yet been confronted with problems that required organizational savvy. Furthermore, we asked the respondents about skills and knowledge they used while doing specific tasks. This may have focused their response away from what they learned in other contexts such as meetings, conversations with coworkers, and even co-ops and internships.

To summarize the findings in this section, engineers early in their careers reported employing a variety of technical, professional, and organizational skills and knowledge in their work. Technical work required knowledge of specific content, tasks, and processes, as well as general problem solving skills. Professionalism involved working with many different groups of people, as well as communication and information finding skills. The organization knowledge 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 upon and refined at work, they learned most of their professional skills at work. Additionally, though they might have gained some organizational knowledge through their internship or co-op experiences, they could not explicitly connect this knowledge to their technical work. The findings suggest that engineering programs may not be adequately preparing students for the professional and organizational aspects of their work.

4.2 Students' views of engineering practice (The Panel Study)

Comparing the technical and professional skills that juniors thought important in the APS study with those they thought important five years later in the EPS study provides a sense of how engineers' perceptions change as they move from being students to being practitioners. Table 3 shows the number of respondents who mentioned various technical and professional skills or areas of knowledge at both points in time.[11]

Table 3 shows that all engineers comprising the panel considered technical skills to be important both as students and as young practitioners. Nearly all also thought professional skills were important to engineering at both points in time. While the respondents' perceptions of the general importance of professional skills remained relatively constant over time, the notion of the importance of technical skills declined considerably. Specifically, after working for four years

[10] Analysis of this interview question was outside the scope of the current study. It has been a primary focus in other papers (Korte et al., 2008; Korte, 2009, 2010).

[11] Definitions of the skills and knowledge in Table 3 can be found in the appendix. The skills listed in Table 3 differ slightly from those found in Table 2 because we coded and labeled skills based on the language informants used.

these engineers were less likely to mention math[12], science, critical thinking, and problem solving skills as being crucial for their work. The pattern suggests that engineering students may mistakenly overemphasize the relevance of hard technical skills to engineering practice.

This notion is supported by responses that the engineers 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.

> I think engineering is just … open ended problem solving. (Technical Public Institution, CSM01F00048, APS)

> Engineering is just coming up with solutions to problems using math and science. (Technical Public Institution, CSM01M00039, APS)

When they were students, the respondents told us they learned these skills 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 math and science. We suspect that the students' images of engineering revolved around technical skills because engineering is commonly linked to math and science in school. Several explicitly said as much:

> College is where I've learned what I know so far that's specific to engineering, but I couldn't have done it without building a foundation. Plus, I'm definitely interested [in engineering] because of science classes in high school and elementary school. That's the sort of thing that I enjoyed, I guess. (Large Public University, UW01M00030, APS)

> 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. (Large Public University, UW01M00018, APS)

The findings also suggest that even though the respondents ascribed some importance to professional skills when they were students, they were not attuned to those professional skills most needed in practice. As students, the engineers thought teamwork was most important. However, other skills such as communication were deemed more valuable four years later. Mentions of communication skills doubled from the APS to the EPS study. This change is consistent with the previously discussed evidence from the Workplace Study in which young engineers spoke of needing to work with different groups of people, but not necessarily in teams. Given the recent popularity of cooperative learning in engineering programs (Smith et al., 2005), this could be another case of students aligning their perceptions of what is important to engineering practice with what they experienced in the classroom. Or, to put it differently, engineering program 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 Study, after working for four years

[12] McNemar's tests revealed significant differences for math skills only ($X^2(1,10)=4.17$, $p<0.05$). In this analysis, McNemar's test was used to compare the number of participants that believed each skill or area of knowledge was important in the APS versus in the EPS.

respondents talked about the need to communicate with different groups of people, including other engineers, operators, managers, and customers.

> 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. (Technical Public Institution, CSM01F00020, EPS

> We've got to interface with clients and be able to get them interested. We want to be able to tell them, "You're bad," without making them feel turned off by it and that's a really important skill that is not really taught [in school]. (Technical Public Institution, CSM01M00045, EPS)

Nevertheless, despite the forgoing similarities, participants in the Workplace Study and the Panel Study had somewhat different notions of the skills that engineers require. For instance, respondents in the Panel Study did not mention specific job tasks and processes, information finding skills, or organizational knowledge. Perhaps this difference merely reflects the fact that the Panel Study included fewer engineers than the Workplace Study and hence, the Panel Study did not include enough people to surface the additional skills. Perhaps the difference reflects the fact that the two studies framed the issue differently; respondents in the Workplace Study were asked about skills and knowledge that had proved to be important in their first couple years at work, while respondents in the Panel Study were asked about skills and knowledge at two very different points in their career. Alternately, it could be that the two groups of engineers actually thought different skills and knowledge were important because respondents in the Panel Study had been working longer than participants in the Workplace Study. As they work longer, engineers may simply come to take some skills and knowledge for granted or it may be that after four years in the workforce the typical engineer performs less technical jobs with broader scope.

Particularly curious is that no engineer in the Panel Study mentioned the importance of project management skills either as students or after four years on the job.[13] Yet, when asked whether their idea of an engineering job had changed since they graduated, six of the ten panel respondents said that they had not realized their work would include project management-related tasks such as dealing with people, attending meetings, writing documents, and creating schedules and budgets. Given the high frequency with which some participants needed to perform these tasks, it is unclear why they did not name project management skills as important. One possible reason is that they did not perceive project management to be "real engineering".

> 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. (Technical Public Institution, CSM01F00020, EPS)

[13] One longitudinal participant reported that goal setting was important to their work. While goal setting may constitute one step in project management, the subject did not talk about this skill in this context, thus warranting a separate code.

> 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, Technical Public Institution, CSM01M00039, EPS)

The Panel Study suggests that students may have an unrealistic view of engineering. As students our panel members saw engineering practice as primarily technical, and their perceptions of the social/professional side were inaccurate. 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.

4.3 Students' expectations for engineering practice (The Workplace Study, revisited)

With the results of the Panel Study in mind, we can return to the Workplace Study to gain further insight into how students expectations of engineering practice compared to the realities they faced as early career engineers. Unlike the Panel Study, the Workplace comparison is retrospective but nevertheless informative. We asked the 57 engineers in the Workplace Study to tell us how engineering practice differed from the expectations they had when they were in school. Sixteen claimed there were no differences and they had been well prepared for work by their classes, extracurricular activities, internships and co-op experiences. 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, 06-004)

> 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, 07-006*)*

More prevalent, however, were discussions about differences. We have covered many of these elsewhere; 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 as much social interaction as it does technical work, and that it is more cross-disciplinary than school led them to appreciate.

Of the 29 respondents 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 respondents 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, 05-017)

> 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, 04-005)

Some of the young engineers had theories as to why their work was so different. One believed that his/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,07-003)

Others believed that their organizations outsourced the 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, 04-003)

Still others thought the amount of technical work varied widely by position, and that even though they were not doing a 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, 05-004)

> 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, 05-017)

Sixteen respondents 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 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, 06-011)

But the other twelve were surprised when their employer made them responsible for projects outside their expertise. At Car Company three mechanical engineers found themselves doing electrical or computer engineering-related work. Chemical engineers at Food Manufacturer and Computer Parts Company (n=8) became involved in mechanical and civil engineering-related work. Some respondents 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 (n=5), who were not working with any of the processes or equipment they had learned in school felt like they had been thrown into a completely different field:

> You kind of have to be like a jack of all trades almost. You have to have a good basic knowledge of everything basically. (Food Manufacturer, 04-004)

> 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, 07-005)

Over all the reflections of the practicing engineers in the Workplace Study 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 skills and knowledge on the job. Given the 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 in the following section.

5. DISCUSSION

5.1 Summary

Our interviews with early career engineers in the Workplace and Panel Studies point to two distinct but interrelated sides of engineering practice: the technical and social 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 of several kinds of skills and knowledge, 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. To be sure, as the data indicate, the technical skills and knowledge that students learn in school are indeed important to engineering practice. Furthermore, most young engineers continue to refine and expand their skills and knowledge after starting work.[14] This later learning, however, focuses primarily on the doing of a specific job. The importance of general technical skills and knowledge of math, science, and engineering analysis declines after four years on the job.

But as technical skills and knowledge become less important , the importance of professional skills and knowledge increases. Even when students are exposed to the professional side of engineering work in school, they may not fully grasp what these skills look 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 employed engineers mentioned teamwork as important. Instead, young practicing engineers speak of needing to work and communicate with different groups of people, including other engineers, operators, managers, and suppliers. In short, not only does the young engineers' appreciation of professional skills and knowledge become more nuanced on the job, he or she also becomes better at articulating this understanding to others.

Finally, just under half of the young engineers in the Workplace Study reported that organizational knowledge was crucial for engineering practice. Although some had internships or co-op experiences as students, none claimed to have acquired an appreciation for the realities of working in an organization as students. They also failed to see connections between this knowledge and their technical work. It is puzzling none of the respondents in the Panel Study mentioned the importance of organizational knowledge, 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 organizational knowledge is required. We suspect, however, that young engineers fail to mention organizational dynamics and processes either because they do not see them as a form of knowledge unless explicitly cued to do so or because they have not advanced far enough in the organization to encounter its political realities.

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

[14] National data showing that 66% of all employed engineers pursue further training within three years after graduating and primarily to improve their skills and knowledge (National Science Foundation, 2006).

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 knowledgeable of engineering theory, 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 (Salzman and Lynn, 2010; Lattuca et al., 2006).

Like our own, these studies point to deficiencies in the current model of engineering education that hampers it from producing engineers with skills and knowledge that are requisite for being effective in the workforce. In particular, professional skills and organizational knowledge need to be elevated to the same level of importance as technical skills and knowledge. Complicating such a change is the fact that most engineering programs are burdened by an already overcrowded curriculum, which makes adding content a challenge (Trevelyan, 2010; Sheppard et al., 2008; Salzman and Lynn, 2010). 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, social, and organizational skills to achieve tighter connections with practice. We consider recommendations for engineering education and the engineering workforce next.

5.2 Implications for Engineering Education

Implications for academia. To develop competent and productive graduates, the narrow technical education that most engineering schools now offer must be expanded to emphasize both the technical and the social 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 their 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 Newman, 1989; 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 develop abilities needed for practice, especially pedagogies for teaching professional skills and organizational knowledge.

The most important professional 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, both of which emphasize small group work, are particularly promising (Johnson, Johnson, and Smith, 1991; 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.

Engineering students also need to be taught 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 skills including the management of tasks and schedules. 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 (Woods, 1994; Smith et al., 2005).

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 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 sociology and organizational behavior. The goal is for students to develop an understanding of how organizational dynamics influence jobs and frameworks for making sense of how their employers' 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 apply skills and knowledge learned in school at work (Haag, Guilbeau, and Goble, 2006). Students who participate in internships and co-ops are better prepared for the workplace and, thus, more employable. Internships and co-ops may also help students more knowledgably choose an engineering discipline or even whether they want to pursue an engineering career. Internships also provide a head start on developing a professional network. 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 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 (Howard and Verma, 2011; Galloway, 2008). 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 to teach.

Implications for other stakeholders. Other stakeholders can also help tighten the connection between schooling and work, and the foremost of these are employers themselves (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, provide feedback and coaching to students, and serve as adjunct faculty. Firms and trade associations can also sponsor fieldtrips, design projects, internships and co-ops.

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. Our data 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 skills nor sending the right messages to students about engineering (Katehi, Pearson, and Feder, 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 (Giddens, 2008). Connections between pre-college engineering education and engineering practice also need to be made more explicit. In addition exposing students both to technical and professional skills, K-12 educators also need to expose students to realistic images of how engineers actually use their skills.

5.3 Implications for Engineering in the Workforce

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 orientation and training, 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 skills and knowledge that they learned in school apply to their jobs, particularly if they will primarily be doing project management. Similar coaching and mentoring would enhance internships and co-op experiences by transforming them into more realistic job previews.

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 communicate their conclusions to engineering educators and researchers so that engineering curricula can be updated accordingly.

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 skills they value (Lichtenstein et al., 2009; Atman et al., 2010). 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 the engineering more attractive. Students without this confidence may find engineering less attractive. It is also possible that more realistic images of engineering would attract new kinds of 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 respondents remarked, "I'm just seeing more of the opportunities I didn't even know existed when I was in school" (Technical Public Institution, CSM01F00020, EPS). 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' perceptions of the nature of engineering work affect their career decisions.

BIOGRAPHIES

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APPENDIX

Definitions of Skills and Knowledge Mentioned in the Workplace and Panel Studies

Skills/Knowledge	Datasets*	Definition
analytical skills	APS WD	Ability to analyze, interpret, and judge the validity of data
business knowledge	EPS	Awareness of the organization's business needs
communication skills	APS WD, APS LD, EPS,	Ability to convey information and ideas effectively
contextual knowledge	APS WD, APS LD	Awareness of contextual issues affecting engineering solutions, e.g., politics, the economy
creativity	APS WD, APS LD	Ability to be innovative and think outside the box
critical thinking skills	APS LD	Ability to draw conclusions using logic and reasoning
goal setting ability	EPS	Ability to establish specific milestones for a task or project
information finding skills	APS WD	Ability to locate resources and information on one's own
job tasks/processes	APS WD	Knowledge of tasks and processes needed to do a job
leadership skills	APS WD	Ability to provide direction for a team or project
lifelong learning skills	APS LD, EPS	Ability to learn new skills and knowledge
math skills	APS LD, EPS	Ability to apply math knowledge
organizational culture/history	APS WD	Knowledge of the organization's culture and history
organizational hierarchy	APS WD	Knowledge of the organization's labor hierarchy
organizational policies/procedures	APS WD	Knowledge of the organization's policies and procedures
organizational skills	APS WD, EPS	Ability to take good notes and keep track of records
problem solving skills	APS WD, APS LD, EPS	Ability to define and solve engineering problems
programming skills	APS WD	Ability to program, e.g., in C or C++
project management skills	APS WD	Ability to plan, organize, and manage project resources
science skills	APS LD	Ability to apply science knowledge
social skills (general)	APS LD	General skills required to do the social aspects of a job
software skills	APS WD, EPS	Ability to use software applications, e.g., CAD or MS Excel
systems thinking skills	APS WD	Understanding of the relationships among a system's parts, as opposed to just the parts themselves
teamwork skills	APS LD, EPS	Ability to function on teams
technical knowledge	APS WD, APS LD, EPS	Ability to apply technical knowledge, including engineering, math, and science
technical skills (general)	APS LD, EPS	General skills required to do the technical aspects of a job
time management skills	APS WD	Ability to meet all goals in a timely manner
troubleshooting skills	EPS	Ability to identify and solve problems in a system/process
work ethic	APS WD, EPS	Willingness to keep working until the task is finished
working with other people	APS WD	Ability to work with different groups of people

* APS WD = Workplace Dataset (Academic Pathways Study)
APS LD = Longitudinal Dataset (Academic Pathways Study)
EPS = Engineering Pathways Study Dataset

REFERENCES

ABET Engineering Accreditation Commission. *Criteria for Accrediting Engineering Programs*, Baltimore, MD, accessed August 10, 2011, http://www.abet.org/Linked%20Documents-UPDATE/Criteria%20and%20PP/E001%2009-10%20EAC%20Criteria%2012-01-08.pdf.

Anderson, Kevin, Sandra S. Courter, Mitchell J. Nathan, Amy C. Prevost, Christine G. Nicometo, Traci M. Nathans-Kelly, Thomas D. McGlamery, and Amy K. Atwood. "Special Session: Moving Towards the Intended, Explicit, and Authentic: Addressing Misalignments in Engineering Learning Within Secondary and University Education." In Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Vancouver, British Columbia, Canada, June 26-29, 2011.

Anderson, Kevin J.B., Sandra S. Courter, Traci Nathans-Kelly, Christine Nicometo, and Thomas McGlamery. "Understanding the Current Work and Values of Professional Engineers: Implications for Engineering Education." In Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Austin, TX, June 14-17, 2009.

Atman, Cynthia J., Sheri D. Sheppard, Jennifer Turns, Robin S. Adams, Lorraine N. Fleming, Reed Stevens, Ruth A. Streveler, Karl A. Smith, Ronald L. Miller, Larry J. Leifer, Ken Yasuhara, and Dennis Lund. Enabling Engineering Student Success: The Final Report for the Center for the Advancement of Engineering Education. San Rafael, CA: Morgan and Claypool Publishers, 2010.

Augustine, Norman R. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D.C.: National Academies Press, 2005.

Brunhaver, Samantha, Russell F. Korte, Micah Lande, and Sheri D. Sheppard. "Supports and Barriers that Recent Engineering Graduates Experience in the Workplace." In Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Louisville, KY, June 20-23, 2010.

Bucciarelli, Louis L., and Sarah Kuhn. "Engineering Education and Engineering Practice: Improving the Fit." In Stephen R. Barley and Julian E. Orr (eds.), Technical Work and the Technical Workforce. Ithaca, New York: Cornell University Press, 1997.

Capobianco, Brenda M., Heidi A. Diefes-Dux, Irene Mena, and Jessica Weller. "What is an Engineer? Implications of Elementary School Student Conceptions for Engineering Education." Journal of Engineering Education 100, vol. 2 (2001): 304-328.

Clough, G. Wayne. The Engineer of 2020: Visions of Engineering in the New Century. Washington, D.C.: National Academies Press, 2004.

Collins, Allen, John S. Brown, and Susan E. Newman. "Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics." In Lauren B. Resnick (ed.), Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser. Hillsdale, NJ: Erlbaum Associates, 1989.

Creswell, John W., and Vicki L. Plano Clark. Designing and Conducting Mixed Methods Research. Thousand Oaks, CA: Sage Publications, 2007.

Duderstadt, James. *Engineering for a Changing World: A Roadmap to the Future of Engineering Practice, Research, and Education.* Ann Arbor, MI: The Millennium Project, University of Michigan, 2008.

Dunsmore, Katherine, Jennifer Turns, and Jessica M. Yellin. "Looking Toward the Real World: Student Conceptions of Engineering." Journal of Engineering Education 100, no. 2 (2011): 1-20.

Dym, Clive L., Alice M. Agogino, Özgur Eris, Daniel D. Frey, and Larry J. Leifer. 2005. "Engineering Design Thinking, Teaching, and Learning." Journal of Engineering Education 94, no. 1 (2005): 103-120.

Eraut, Michael, Frederick Maillardet, Carolyn Miller, Stephen Steadman, Amer Ali, Claire Blackman, and Judith Furner. The LiNEA Project: The Engineering Chapter. In press.

Galloway, Patricia D. The 21st-Century Engineer: A Proposal for Engineering Education Reform. Reston, Virginia: The American Society of Civil Engineers Press, 2008.

Giddens, Don P. Changing the Conversation: Messages for Improving Public Understanding of Engineering. Washington, D.C.: The National Academies Press, 2008.

Gilmartin, Shannon G., Anthony L. Antonio, Helen L. Chen, Samantha R. Brunhaver, and Sheri D. Sheppard. Career Plans of Undergraduate Engineering Students: Characteristics and Contexts. In press.

Grohowski-Nicometo, Christine, Traci Nathans-Kelly, and Kevin J.B. Anderson. "Work in Progress: Educational Implications of Personal History, Undergraduate Experience, and Professional Values of Practicing Engineers." In Proceedings of the Annual Frontiers in Education Conferences, San Antonio, TX, October 18-21, 2009.

Grossman, Pamela L., Christa Compton, Danielle Igra, Matthew Ronfeldt, Emily Shahan, and Peter Williamson. "Unpacking Practice: Decompositions and Approximations." In Proceedings of the Annual Meeting of the American Educational Research Association, Montreal, Quebec, Canada, April 11-15, 2005.

Haag, Susan, Eric Guilbeau, and Whitney Goble. 2006. Assessing Engineering Internship Efficacy: Industry's Perception of Student Performance. International Journal of Engineering Education 22, vol. 2 (2006): 257-263.

Howard, D., and R. Verma. Should the Standard Undergraduate Engineering Education be Extended to Five Years? IEEE Potentials 4 (2001): 7-9.

Johnson, David W., Roger T. Johnson, and Karl Smith. Cooperative Learning: Increasing College Faculty Instructional Productivity. (ASHE-ERIC Higher Education Report No. 4). Washington, D.C.: The George Washington University, School of Education and Human Development, 1991.

Katehi, Linda, Greg Pearson, and Michael Feder. Engineering in K-12 Education: Understanding the Status and Improving the Prospects. Washington, D.C.: National Academies Press, 2009.

Korte, Russell F. "How Newcomers Learn the Social Norms of an Organization: A Case Study of the Socialization of Newly Hired Engineers." Human Resource Development Quarterly 20, vol. 3 (2009): 285-306.

Korte, Russell F. "First Get to Know Them: A Relational View of Organizational Socialization." Human Resources Development International 13, vol. 1 (2010): 27-43.

Korte, Russell F., Sheri D. Sheppard, and William C. Jordan. "A Qualitative Study of the Early Work Experiences of Recent Graduates in Engineering." In Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Pittsburgh, PA, June 22-25, 2008.

Lattuca, Lisa R., Patrick Terenzini, and J. Fredricks Volkwein. Engineering Change: A Study of the Impact of EC2000, Full Report. Washington, D.C.: ABET, Inc., 2006.

Lichtenstein, Gary, Heidi G. Loshbaugh, Brittany Claar, Helen L. Chen, Kristyn Jackson, and Sheri D. Sheppard. "An Engineering Major Does Not (Necessarily) an Engineer Make: Career Decision-Making among Undergraduate Engineering Majors." Journal of Engineering Education 98, vol. 3(2009): 227-234.

Lowell, B. Lindsay, and Hal Salzman. Into the Eye of the Storm: Assessing the Evidence on Science and Engineering Education, Quality, and Workforce Demand. Washington, D.C.: Urban Institute, 2007.

Matusovich, Holly M., Ruth Streveler, Ronald L. Miller, and Barbara A. Olds. "I'm Graduating This Year! So What IS an Engineer Anyway?" In Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Austin, TX, June 14-17, 2009.

Miles, Matthew B., and A. Michael Huberman. Qualitative Data Analysis. Thousand Oaks, CA: Sage Publications, 1994.

National Science Foundation, Division of Science Resources Studies, Scientists and Engineers Statistical Data System (SESTAT). *2006 National Survey of Recent College Graduates*, Arlington, VA, accessed August 10, 2011. http://www.nsf.gov/statistics/sestat.

Patton, Michael Q. Qualitative Research and Evaluation Methods. Thousand Oaks, CA: Sage Publications, 2002.

Perlow, Leslie, and Lotte Bailyn. "The Senseless Submergence of Difference: Engineers, Their Work, and Their Careers." In Stephen R. Barley and Julian E. Orr (eds.), Technical Work and the Technical Workforce. Ithaca, New York: Cornell University Press, 1997.

Salzman, Hal. Globalization of R&D and Innovation: Implications for U.S. STEM Workforce and Policy. (Testimony before the U.S. House Subcommittee on Technology and Innovation.) Washington, D.C.: Urban Institute, 2007.

Salzman, Hal, and Leonard Lynn. "Engineering and Engineering Skills: What's *Really* Needed for Global Competitiveness?" Presented at the Association for Public Policy Analysis and Management Annual Meetings, Boston, MA, November 4, 2010.

Seering, Warren. "A Curriculum that Meets the Customers' Needs." Presented at the workshop, "Implementing the recommendations of 5XME," sponsored by National Science Foundation, Orlando, FL, November 12-13, 2009.

Sheppard, Sheri, Cynthia Atman, Lorraine Fleming, Ronald Miller, Karl Smith, Reed Stevens, Ruth Streveler, Mia Clark, Tina Loucks-Jaret, and Dennis Lund. An Overview of the Academic Pathways Study: Research Processes and Procedures (TR-09-03). Seattle, WA: Center for the Advancement for Engineering Education, 2009.

Sheppard, Sheri D., Holly M. Matusovich, Cynthia J. Atman, Ruth Streveler, and Ronald Miller. "Work in Progress: Engineering Pathways Study: The College-Career Transition." In Proceedings of the Annual Frontiers in Education Conference, Rapid City, SD, October 12-15, 2011.

Sheppard, Sheri D., Kelly Macatangay, Anne Colby, William M. Sullivan, and Lee Shulman. Educating Engineers: Designing for the Future of the Field. San Francisco, CA: Jossey-Bass, 2008.

Sheppard, Sheri, Shannon Gilmartin, Helen L. Chen, Krista Donaldson, Gary Lichtenstein, Özgur Eris, Micah Lande, and George Toye. Exploring the Engineering Student Experience: Findings from the Academic Pathways of People Learning Engineering Survey (APPLES) (TR-10-01). Seattle, WA: Center for the Advancement of Engineering Education, 2010.

Shuman, Larry J., Mary Besterfield-Sacre, and Jack McGourty. "The ABET "Professional Skills" – Can They be Taught? Can They be Assessed?" Journal of Engineering Education 94, vol. 1 (2005): 41-55.

Singh, Romila, and Nadya Fouad. "Understanding Women's Persistence in Engineering Careers." In Proceedings of the Women in Engineering Program Advocates Network Annual Conference, Seattle, WA, June 21-23, 2011.

Smith, Karl A., Sheri D. Sheppard, David W. Johnson, and Roger T. Johnson. "Pedagogies of Engagement: Classroom-Based Practices." Journal of Engineering Education 94, vol. 1 (2005): 87-101.

Stake, Robert E. Multiple Case Study Analysis. New York, NY: The Guilford Press, 2006.

Sullivan, William M., and Matthew S. Rosin. A New Agenda for Higher Education: Shaping a Life of the Mind for Practice. San Francisco, CA: Jossey-Bass, 2008.

Trevelyan, J. "Technical Coordination in Engineering Practice." Journal of Engineering Education 96, vol. 3 (2007): 191-204.

Trevelyan, James. 2008. *Longitudinal Study of UWA Engineering Graduates (Class of 2006),* Perth, Australia, accessed August 10, 2011, http://school.mech.uwa.edu.au/~jamest/eng-work/long/info-htm.

Trevelyan, James. "Steps Toward a Better Model of Engineering Practice." In Proceedings of the Research in Engineering Education Symposium, Palm Cove, Queensland, Australia, July 20-23, 2009.

Trevelyan, James. "Mind the Gaps: Engineering Education and Policy." In Proceedings of the Australian Association for Engineering Education Conference, The University of Technology, Sydney, Australia, December 5-8, 2010.

Trevelyan, James, and Sabbia Tilli. "Longitudinal Study of Australian Engineering Graduates: Perceptions of Working Time." In Proceedings of the American Society for Engineering Education Annual Conference and Exposition, Pittsburgh, PA, June 22-25, 2008.

Vest, Charles M. "Context and Challenge for Twenty-First Century Engineering Education." Journal of Engineering Education 97, vol. 3 (2008): 235-236.

Yin, Robert K. Case Study Research: Design and Methods (3rd ed.). Thousand Oaks, CA: Sage Publications, 2003.

Weber, Robert P. Basic Content Analysis (2nd ed.). Newbury Park, CA: Sage Publications, 1990.

Woods, Donald R. Problem-Based Learning: How to Gain the Most from PBL. Waterdown, Ontario, Canada: Donald R. Woods, 1994.

Table 1.
Demographic information for participants in the Panel Study

Institution *	**Gender**	**Under-represented Minority**	**Reported Major in APS[+]**	**Internships in APS**	**Reported Occupation in EPS[○]**
TPub	Female	Yes	Chemical engineering	no	Process engineer
TPub	Female	No	Chemical engineering	not asked	Production engineer
TPub	Female	No	Chemical engineering	yes	Process engineer
TPub	Male	Yes	Engineering physics	no	R&D engineer
TPub	Male	No	Petroleum engineering	yes	Operations engineer
TPub	Male	No	Mechanical engineering	no	HVAC engineer
LPub	Female	Yes	Civil engineering	yes	Structural engineer
LPub	Male	Yes	Computer engineering	no	Software engineer
LPub	Male	No	Mechanical engineering	no	Mechanical engineer
LPub	Male	No	Mechanical engineering	no	General engineer

** TPub: Technical Public Institution, LPub: Large Public University*
[+] *APS: Academic Pathways Study*
[○] *EPS: Engineering Pathways Study*

Table 2
Comparison of skills and knowledge learned in school and on the job (The Workplace Study)

	Total # participants that reported learning knowledge/skills		
	Learned in School	**Learned on Job**	**On Job or School**
TECHNICAL SKILLS/KNOWLEDGE	***53***	***49***	***56***
technical knowledge*	36	23	45
job tasks/processes	24	29	41
problem solving skills***	24	2	25
software skills	19	16	22
programming skills	5	4	6
analytical skills	5	0	5
systems thinking ability	3	0	3
Total # mentions	*150*	*96*	*246*
PROFESSIONAL SKILLS/KNOWLEDGE***	***27***	***55***	***55***
working with other people***	8	40	43
communication skills**	10	25	30
information finding skills**	7	22	26
project management skills	9	7	15
time management skills	3	8	10
creativity	2	5	7
contextual knowledge	1	5	6
leadership skills	2	4	6
organizational skills*	0	6	6
work ethic	0	3	3
Total # mentions	*50*	*173*	*223*
ORGANIZATIONAL KNOWLEDGE***	***0***	***32***	***32***
organizational culture/history	0	5	5
organizational policies/procedures***	0	23	23
organizational hierarchy***	0	15	15
Total # mentions	*0*	*47*	*47*

* $p<0.05$, ** $p<0.01$, *** $p<0.001$; according to McNemar's nonparametric test for paired samples

Table 3.
Comparison of important skills and knowledge from the APS and the EPS (The Panel Study)

	Total # participants that reported learning knowledge/skills		
	APS*	**EPS+**	**Difference**
TECHNICAL SKILLS/KNOWLEDGE	***10***	***10***	***0***
math skills	9	3	-6
science skills	5	0	-5
critical thinking skills	5	0	-5
problem solving skills	5	1	-4
technical knowledge	3	3	0
technical skills (general)	2	2	0
software skills	0	1	+1
troubleshooting skills	0	2	+2
Total # mentions	*29*	*12*	*-17*
PROFESSIONAL SKILLS/KNOWLEDGE	***9***	***9***	***0***
contextual knowledge	3	0	-3
creativity	3	0	-3
social skills (general)	2	0	-2
teamwork skills	4	2	-2
goal setting ability	0	1	+1
lifelong learning skills	1	1	+1
organizational skills	0	1	+1
work ethic	0	2	+2
business knowledge	0	2	+2
communication skills	3	6	+3
Total # mentions	*16*	*15*	*-1*

***** *APS: Academic Pathways Study*
+ *EPS: Engineering Pathways Study*