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The Gap Between Engineering Education and Postgraduate Preparedness

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This is to certify that the doctoral study by

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2017

Abstract

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MS, University of Kentucky, 1987

BS, University of Kentucky, 1984

Doctoral Study Submitted in Partial Fulfillment

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Abstract

Engineering students entering the workforce often struggle to meet the competency expectations of their employers. Guided by constructivist theory, the purpose of this case study was to understand engineers' experiences of engineering education, deficiencies in practical skills, and the self-learning methods they employed to advance their technical and professional competencies. Working engineers were asked about their experiences overcoming practical skill deficiencies and bridging the gap between education and practice. Interviews with 15 chemical, civil, mechanical, and electrical engineers were analyzed by coding for common statements and identifying themes. Firsthand experiences of the participants captured 3 themes: overall perceptions of engineering education, deficiencies in skills, and self-learning experiences. According to study findings, engineering education did not supply sufficient practical skills for working engineers. The study also provided descriptions of training and self-learning methods employed by practicing engineers to advance their technical and professional competencies. The study found that although universities might provide some practical skills through industry collaboration, engineering graduates still required professional development to ensure a smooth transition from academic learner to acclimated working engineer. The project is a practical training, developed for recent graduates, that could achieve positive social change by making strides toward bridging the gap between theory and practice for the participants. This study may also incite positive social change as it contributes to the evidence that there is a lack of practical experience in colleges of engineering, which may therefore improve their curriculum.

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Dedication

This work is dedicated to the memory of my parents, who chose me to be the one child they could afford to send to school. This choice came with the expectation that I fully pursue and succeed in my learning. My parents instilled in me a strong sense of purpose and focus toward my goals.

Acknowledgments

All praise belongs to God for giving me the wisdom and determination to complete this degree, attain this level of education, and live a fruitful life. I acknowledge and thank my wife, Kitty, for her encouragement, patience, and unwavering support for the past 3 decades, especially during the process of completing this dissertation. I also thank my committee members, Dr. James Valadez, Dr. Christian Teeter, and Dr. Jennifer Seymour, for their support and guidance in the process of completing the thesis. Thank you for bringing this journey to the highest point, a joyful graduation.

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Section 1: The Problem

Introduction

Stakeholders in engineering education include universities, students, government, professional and trade associations, and the employers of engineering graduates. These stakeholders have suggested that graduate engineers fall short of industry expectations regarding practical knowledge, skills, and adaptability (Duderstadt, 2010; National Academy of Engineering [NAE], 2004, 2005; Sheppard, Macatangay, Colby, & Sullivan, 2009). Other researchers (e.g., Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Borrego, Froyd, & Hall, 2010; Crawley, Malmqvist, Ostund, & Brodeur, 2007; Duderstadt, 2010; Felder, Brent, & Prince, 2011; Litzinger, Lattuca, Hadgraft, & Newstetter, 2011) suggested that engineering education has failed to prepare engineering students adequately for engineering practice.

Several reasons have been cited for the inadequate preparation of engineering students. First, the problem-solving and teaching approaches offered by universities have been misaligned with industrial practice (Duderstadt, 2010; Sheppard et al., 2009) . Second, undergraduate engineering education has emphasized the acquisition of fundamental knowledge rather than professional practice (Trevelyan, 2016). Third, most engineering faculties have been, and continue to be, engaged in theoretical research rather than engineering practice and have had limited industrial experience (Duderstadt, 2010). In response to concerns from the industry and other stakeholders, university engineering programs have strived to balance coverage of the basic curriculum by keeping up with modern technologies, adding new subjects of study, and ensuring some content for practice (Ambrose, 2013). However, adding more courses to 4-year degree programs to meet these demands has overburdened students and has taken away opportunities for practical engineering.

The burden of learning to engage in professional practice has shifted to graduated engineers (i.e., alumni), who have been left to develop their skills through self-learning as they enter the job market and continue to learn independently by employing metacognition in a process of reflecting on and directing their own learning and thinking (Ambrose, 2013; Bransford, Brown, & Cocking, 2004). This on-the-job autodidactic approach has required graduates to assess the goals and constraints of each task, develop the skills needed to complete the tasks, learn to apply the knowledge and strategies required to perform the task, and reflect on the chosen approaches (Ambrose, 2013).

The initial self-learning process needed for usable knowledge and skills could lead to lifelong learning, which might be accomplished through continuing engineering education (CEE), filling the knowledge and skills gap caused by technological advances, social and environmental changes, and globalization (Baukal, 2012). Although many employers offer CEE internally, external providers of engineering professional development (PD; see Appendix A) also provide a selection of topics for each engineering discipline. Providers include universities, professional societies, industry trade organizations, commercial education venues, government agencies, and equipment manufacturers (Baukal, 2012).

In addition, engineering jobs offer opportunities to combine theory and practice leading to accelerated experiential learning, which is learning by doing (Eyler, 2009).

Engineering researchers have stressed the importance of experiential learning and have proposed that universities engage students in practical projects to invoke experiential learning (Bass, 2012; Korte, Sheppard, & Jordan, 2008; Litzinger et al., 2011). Crawley, Brodeur, and Soderholm (2008) stated, “Experiential learning engages students in critical thinking, problem solving and decision making in contexts that are personally relevant and connected to academic learning objectives by incorporating active learning” (p. 141). The current study was designed to explore the experiences of working graduate engineers by asking them to reflect on the competencies that they developed for professional practice and how they overcame their educational deficiencies, engaged in self-learning, and managed their PD in the early years of employment.

I followed an instrumental case study approach concentrating on graduate engineers who had been employed in the industry for at least 1 year at the time of the study. I purposefully selected the participants from the chemical, mechanical, civil, and electrical engineering disciplines, as well as across several industrial institutions. These four engineering disciplines cover about 75% of graduate engineers in the United States (Finamore et al., 2013; National Association of Colleges and Employers [NACE], 2014). An underlying assumption was that these newly hired graduates would remember the significant challenges that they faced as they developed competencies for their jobs.

Definition of the Problem

There is a lack of graduate engineers’ preparedness for practice resulting from the disparity between theoretical and practical education. I explored the experiences of new engineers as they reflected on their educational preparation for engineering practice and the self-training methods that they used to fill the gap between their engineering education and professional practice. The gap includes deficiencies in technical competency, communication, teamwork, and professional skills. I designed this study to capture the experiences of working engineers to show how they overcame these deficiencies.

Rationale

Evidence of the Problem at the Local Level

The demand for engineering practitioners continues to rise in the United States, especially in the metropolitan areas where engineering industries are concentrated. Consequently, salaries for graduate engineers remain higher across the nation than for other college graduates. Engineers earned the highest average annual starting salaries of all bachelor's degree majors in 2013, averaging about $62,000 (Finamore et al., 2013). Engineering disciplines such as aerospace, chemical, mechanical, petroleum, computer, and electrical had starting salaries as high as $80,000 (Finamore et al., 2013). In comparison, the average starting salaries for business majors were $55,000 and $58,000 for majors in computer science (Finamore et al., 2013).

Moreover, job prospects for 2014 remained sound: The NACE (2014) predicted that the hiring rate for U.S. college graduates for 2014 would increase by 7.8% from the previous year. The NACE also suggested that business and engineering degrees would remain at the top of the list for undergraduate degrees in demand, followed by computer information, sciences, and communication. The top engineering degrees in demand were mechanical, electrical, computer, chemical, and civil engineering (NACE, 2014). The

NACE also identified the top attributes that employers sought from incoming candidates: an agglomeration of written communication skills, analytical skills, work ethic, teamwork, and problem solving.

The Houston metropolitan area has been ranked as the eighth largest metropolitan area employing science, technology, engineering, and mathematics (STEM) majors throughout the United States (Landivar, 2013). This high level of employment has been attributed to the concentration of companies engaged in mining, oil, and gas exploration in the Southwestern United States. The oil and gas sector normally has employed about 80% of all STEM graduates (Landivar, 2013). However, despite this high demand for engineers and high starting salaries, only one third of the engineering graduates in the United States have sought engineering work, with more than 60% seeking employment in other fields (Lichtenstein et al., 2009; Ohland et al., 2008). The reason might have been that employers were less than keen to hire graduates who required lengthy training. Consequently, employers resorted to recruiting top candidates with high grade point averages whom they deemed quick learners and contributors requiring minimum training.

Similar trends have been reported for STEM workers. The American Community Survey (2011) showed that STEM workers accounted for about 6% (7.2 million) of the total U.S. workforce of 120 million workers, whereas engineers accounted for approximately 32% of the 2.3 million STEM workers, or 2.3% of all workers ages 25 to 64 years. Overall, many STEM graduates have not been working in STEM occupations; The American Community Survey showed that only 26% of STEM graduates were employed in STEM occupations, with the other 74% working in non-STEM occupations such as management, law, education, health care, and business.

The U.S. Department of Education (USDoE, 2014) has been trying to upgrade STEM education and obtain financial support to improve STEM programs to attract and retain students. In 2014, the USDoE received the needed support and budget request from President Obama, who designated considerable funds ($2.9 billion for 2015) for various programs in STEM education (White House Office of Science and Technology Policy, 2014). The president’s 2015 budget allocation for STEM education included funds for recruiting and training STEM teachers, improving STEM education, and conducting research on teaching and education. The key objective behind efforts to improve STEM education was to retain a U.S. presence as a global leader in engineering and technology and reduce the shortage of highly skilled workers (White House Office of Science and Technology Policy, 2014).

The United States allows the immigration of skilled professionals under nonimmigrant H-1B and L-1 visas. The H-1B is a nonimmigrant visa that allows U.S. companies to hire foreign workers in some special occupations, and the L1 is a temporary nonimmigrant visa that allows foreign workers to relocate to the U.S. offices of their overseas employers (Vaz, 2012). In 2013, the visa quota was limited to 65,000 skilled workers per year, a number that U.S. employers had exhausted in the past before the end of the year, thus indicating the demand for skilled workers (Vaz, 2012).

With large numbers of skilled workers coming from abroad every year, the ratio of U.S. to foreign-born STEM workers continued to shrink, for example, from 6.2 in

1994 to 3.1 in 2006 (Sana, 2010). The science and engineering degrees earned by foreign-born students have displayed a similar trend, and U.S. colleges remain a widening conduit to foreign-born science and engineering students, who continue to populate U.S. engineering schools. Among undergraduates, foreign-born science and engineering-earned degrees jumped from 11% in 1990 to 21% in 2010 (Sana, 2010). In the engineering field, foreign-born students comprised 33% of all bachelor's degree holders (Gambino & Gryn, 2011). The percentages of foreign-earned graduate degrees have risen even higher than their undergraduate counterparts: Foreign engineers and scientists in master's and doctoral programs have outnumbered U.S.-born graduates, increasing from 40% in 2003 to more than 67% in 2011 (Landivar, 2013).

In addition to competition for jobs, U.S. engineers have faced the outsourcing and offshoring of engineering jobs to India, China, and Russia, which are regions that have continued to graduate more engineers than U.S. colleges have (Duderstadt, 2010). The offshoring engineering jobs in the United States has led to a dereliction of technological resources and workers with little experience in the engineering field (Hira, 2005). Another effect of outsourcing engineering work to other countries has been wage suppression. As STEM wages have dropped to a level parallel with other fields, U.S. workers have moved into nontechnology fields such as business, health, and administration, all requiring less challenge in math and science (Hira, 2005). However, there have been arguments that outsourcing has affected labor-intensive manufacturing jobs only and that outsourced engineering work still requires the verification and supervision of internal U.S. resources (Duderstadt, 2010).

Engineering universities are expected to graduate engineers who can fill the U.S. market demand and compete with skilled workers from other countries. However, U.S. engineering college graduates are not prepared for engineering practice and require several years of skill building, mentoring, and engagement in long PD. This kind of development requires structured PD in the workplace and persistence from engineering graduates; yet, most employers do not provide structured PD and offer only a limited selection of training courses. Graduate engineers must decide how to acquire the skills and competencies that they need to complete work assignments.

Evidence of the Problem from the Professional Literature

Engineering education has been the subject of continuous reform since the last century (Vaz, 2012). The NAE (2005), the National Science Foundation (NSF, 2008), the Accreditation Board of Engineering and Technology (ABET, 2014), the American Society of Engineering Education (ASEE, 2012), and other scholars have voiced concerns about how well undergraduate education curricula prepares students for practice. Academia have called for overall engineering education reform since the 1980s (NAE, 2005), including calls for changes to the curricula (Ambrose, 2013; Crawley et al., 2008; Sheppard et al. 2009), methods of teaching (Bransford, 2007), active learning (Adams, Turns, & Atman, 2003; Litzinger et al., 2011), and education innovation (Besterfield-Sacre et al., 2014; Borrego et al., 2010). Other recommendations have included adding a master's degree as a professional degree tailored to engineering practice (Duderstadt, 2010; NAE, 2005; Sheppard et al., 2009) and expanding the content on global perspectives (Vaz, 2012) in existing engineering programs. Although improved programs have been developed (Crawley et al., 2007; Vaz, 2012), deficiencies in the skills required for engineering practice persist (Stephens, 2013).

In response to these calls, ABET (as cited in Lattuca, Terezeni, & Volkwein, 2006) initiated changes in the accreditation requirements of teaching and assessment, and they adopted the new standards, known as Engineering Criteria 2000 (EC2000). The impact of EC2000 was assessed by Lattuca et al. (2006), who found that the new accreditation criteria had a positive impact on engineering programs and student learning. ABET (2014) requirements forced many engineering programs to broaden their curricula and emphasize engineering design, teamwork, and communication.

Other institutions, such as the NAE (2005), conducted their own studies calling for engineering reform. The NAE recommended expanding engineering curricula by adding more topics, considering the bachelor's degree as preengineering, and adding a master's degree as the engineering professional standard. Duderstadt (2010) suggested that graduate schools offer practice-based graduate degrees. Duderstadt proposed an additional 2-year practical training program taught by faculty and supported by an engineering internship program to the standard 4-year degree route. Duderstadt also recommended a supplemental structured approach to lifelong educational opportunities for practicing engineers. These programs would require a commitment of resources and leadership by the industry, professional societies, and engineering educators (Duderstadt, 2010).

Other recommendations included broadening the interdisciplinary content to keep pace with technological innovation and global competition driven by engineering

(Litzinger et al., 2011), offering advanced technical training, and ensuring that faculty members with practical experience from the industry teach practical courses (ASEE, 2012; NAE, 2005). Researchers have explored the progress made toward balanced engineering education and have stressed that the goal of engineering education should be to prepare students for professional practice and graduate research (Adams et al., 2003; Palmer, Harper, Terenzini, McKenna, & Merson, 2011).

Palmer et al. (2011) studied the engineering practices of six U.S. universities with professional practices. Each of the six universities had programs intended to graduate engineers ready for engineering practice. Palmer et al. found a common theme across all six schools, namely, the presence of strong industry links. Faculty members maintained involvement in industrial partnerships that provided applied research projects, and the experiences gained were incorporated into the curriculum. Palmer et al. found that universities could improve contextual competence by incorporating core engineering skills into the curriculum, inviting industry participation, providing facilities that supported curricular activities, and supporting student organizations that provided experiences for community services.

Researchers (Crawley, 2001; Crawley, Malmqvist, Lucas, & Brodeur, 2011) described the Massachusetts Institute of Technology's Conceive, Design, Implement, Operate (CDIO MIT) program, which was developed to provide knowledge and skills desired by the industry for graduating engineers. The goal of the program was to further prepare students who had significant practical knowledge of the technical fundamentals and who could "conceive, design, implement and operate processes and systems"

(Crawley et al., 2007, p. 1). The program implemented 12 standards of effective practice and used project-based learning as an effective means of practical learning. In project-based learning, engineering colleges use learning laboratories as an active learning approach to attract and maintain enrollment in engineering disciplines.

The CDIO initiative grew from the four original developers (MIT, Chalmers, KTH Royal Institute of Technology, and Linköping University) to more than 100 global institutions in 2014 that adopted the CDIO syllabus and standards (Edsröm & Kolmos, 2014). Through the adoption of this project-oriented initiative, many engineering colleges had begun to acknowledge the need for practical engineering education.

Korte et al. (2008) conducted a qualitative case study with newly hired engineering graduates in a manufacturing facility. These engineers each had less than 2 years of experience, a period during which graduates are likely to construct a clear visual of the sort of engineering education needed for practice. In these early years, the new engineers also acquired work practices and job requirements, and in the process, they became socially acclimated to the practices of the organization. Korte et al. sought to determine how these newly employed graduates learned job requirements, engineering practice, and the factors that affected them. Although the newly hired engineers described the difference in the complexity of the problem-solving process between school and the workplace, equally important was the influence of the social context. Korte et al. found that the transition from school to the workplace required effective integration into the work groups and that the newly hired engineers had to develop interpersonal relationships with coworkers and managers. The interviewees reported that the success of their performance and progress on the job depended on their relationships with their coworkers.

Despite the findings and recommendations from research and the efforts of educational institutions, employers have expressed concern that graduates have been inadequately prepared in the areas of engineering practice, research, and design (Stephens, 2013). Although practice-oriented programs have been developed in such universities as Worcester Polytechnic Institute (Vaz, 2012); Virginia Tech (Palmer et al., 2011); and MIT (Crawley, 2001), most universities have been restricted by congested curricula that abrogate room for additional material in undergraduate programs. Only one third of the engineering graduates in the United States have actively sought engineering work; more than 60% have looked for employment in other fields of work (Lichtenstein et al., 2009; Ohland et al., 2008). Scholars have confirmed the gap between engineering education and the skills required for engineering practice. Therefore, engineering graduates who are entering the workforce must engage in self-learning to fill the gap. The aim of this study was to provide insight into the learning methods that a sample of new engineers used to gain the practical skills that they needed to do their jobs. The results of the study will provide feedback to institutions that offer engineering education. These institutions will have the opportunity to provide undergraduate students with the same skills that graduate engineers are forced to obtain through other sources.

Theoretical Framework

I explored the experiences of graduate engineers in their initial years of practice to understand the strategies that they used to overcome deficiencies in their college education. I selected a qualitative case methodology to obtain the personal stories of 15 engineers as they worked and learned from their experience. Because the engineers were learning from interactions with their coworkers, literature, software, and engineering tools, the theory of social constructivism that coordinates learning from people and tools was the theoretical framework that was appropriate for this study.

The theoretical roots of constructivism date back to 1916, with Dewey's assumptions about the social construction of knowledge and experience, although he had not used the term constructivism (as cited in Merriam, Caffarella, & Baumgartner, 2012). Dewey advocated that students should be the focus in the learning process and that teachers should play a central role in the development of the curriculum, instruction strategies, and assessment of student progress (as cited in Phillips, 1995).

Dewey's ideas planted the seeds for the growth of constructivist thought; however, Piaget is considered to have laid the foundation for constructivism (as cited in Phillips, 1995). Piaget proposed that the development of cognitive structures is partly the result of the growth of the nervous system and partly the result of interactions with the environment and exposure to various experiences (as cited in Merriam et al., 2012). In Piaget's view, learners continually add knowledge to previous experiences and develop new schemas (i.e., cognitive structures) that are more advanced than previous ones; these new structures facilitate the processing of more complex knowledge (as cited in Merriam et al., 2012).

Vygotsky claimed that a key role in the development of the constructivist thought includes the context in which learning takes place (as cited in Phillips, 1995). The context accounts for the cultural and social experiences of the people involved in the learning process. Dewey, Piaget, and Vygotsky laid the foundation for the development of constructivist learning (as cited in Phillips, 1995).

Constructivists assume that learning is a process of making meaning, or how people make sense of their experiences (Merriam, 2014). Unlike the postpositivist view, which retains the belief that a fixed reality exists that can be measured and known, constructivists propose that knowledge exists within the learners themselves. Quantitative researchers take a postpositivist point of view, with the assumption of an absolute truth that can only be disconfirmed (Borrego, Douglas, & Amelink, 2009). To constructivists, reality is socially constructed, and realities exist in the minds of individuals and through their interactions with the wider society (Glisne, 2011). Through a social constructivist lens, knowledge is an active undertaking; hence, learning manifests through collaboration and dialogue.

The advantage of using the social constructivist approach in this study was the interaction between myself as the researcher and the participants, who shared detailed accounts of their experiences. Engineering project activities involve groups of people engaged in active discussions and collaborative tasks, which corresponds to the concept of social constructivism that claims that making meaning is a dialogic process (Merriam et al., 2012). Based upon this theoretical perspective, I conducted in-depth interviews and discussions with a sample of practicing engineers. According to social constructivism, the transfer of knowledge takes place through such discussions, collaboration, and cooperative learning. Engineering education uses cooperative education, internships, and project teams as learning methods to apply theoretical knowledge to practical skills.

Definitions

Engineering: The profession in which mathematics and scientific knowledge are applied to utilize materials and forces of nature for the benefit of people (Duderstadt, 2010, p. 24).

Engineering education stakeholders: The main engineering stakeholders are students, university faculty, industry, and society (Crawley et al., 2007).

Engineering practice: The process of integrating engineering knowledge and skills for providing services and products (Duderstadt, 2010).

Real engineer: "One who has attained and continuously enhances technical, communication, and human relations knowledge, skills, and attitudes, and who contributes effectively to society by theorizing, conceiving, developing, and producing reliable structures and machines for practical and economic value" (Crawley et al., 2007, p. 11).

Self-learning: Taking personal responsibility for an individual's own continuing education.

Significance

The significance of this study was its provision of firsthand information about the ways that a sample of graduate engineers engaged in self-teaching and acquired the skills that they needed to address deficiencies in their engineering education. This qualitative case study provided in-depth knowledge of how these working engineers chose their own training, developed the skills needed for their jobs, and became competent engineers. The results included evidence of the types of knowledge and skills that universities and industry should consider providing to undergraduate engineering students.

The results of the study also might provide new graduates with reference information to help them to develop their careers. Recommendations could be useful to the individuals in the training departments of companies that employ graduate engineers, as well as those who provide PD. The results may contribute to the overall goals of engineering education and help colleges to equip engineering graduates with educational knowledge and skills usable in designing, innovating, constructing, and operating safe facilities. Industries and society depend on engineers to build reliable facilities and safely operate these facilities to produce goods that satisfy the needs of humankind (Stephens, 2013).

Guiding Research Question

Research questions (RQs) and theoretical frameworks normally drive researchers' choice of methodology (Creswell, 2009). This study was guided by one RQ: What are the experiences of graduate engineers currently working in the industry regarding overcoming practical skill deficiencies and bridging the gap between education and practice? I focused on how the individual engineers filled their knowledge and skills gaps during their early years of employment.

Review of the Literature

In the literature review section, I explore the deficiencies in the knowledge, skills, and abilities of graduating engineers, along with the efforts of stakeholders to improve their competencies. The review was organized under several topics: engineering education and calls for reform; resistance to change; engineering education, instruction, and learning practices; and the role of industry to prepare graduating students for practice. The chapter ends with conclusions from the literature review; the identification of gaps in engineering education; and recommendations for bridging the gaps, including further research on the subject.

I prepared this literature review not only to identify and build upon prior research on the topic of engineering education programs but also to highlight innovations that have altered or corrected earlier deficiencies in education programs. The review covers findings and recommendations from studies and reports generated over the last 10 years. Several of these scholars (e.g., Besterfield-Sacre et al., 2014; Duderstadt, 2010; NAE, 2005; Sheppard et al., 2009) called for restructuring engineering education and moving away from the traditional deductive method of instruction to the inductive, or active, method of instruction.

I conducted a search of the literature on the gap between engineering education and industry practice by searching for peer-reviewed journals in the Walden University Library, engineering journals, websites, and books. Databases included Educational Resource Information Center (ERIC), Educational Research Complete, Academic Search Premier, SAGE Full-Text Collection, and the EBSCO collection. I also searched for publications prepared by engineering associations such as the ASEE, the NAE, and the NACE. The following key words and expressions were used in the search: *Gap between education and practice, engineering education, engineering practice, engineering reform,* *skills deficiency*, *competency*, *industry practice*, *learning styles*, *project-based learning*, *and professional development.* I examined all articles for relevancy and timeliness, and I reviewed key resources to offer a foundation to the research.

Engineering Education and Calls for Reform

Engineering education has remained almost unchanged for the past several decades, despite recommendations for improved curriculum content, more effective teaching and learning methods, and the inclusion of engineering practice. Advances in education, technology, and engineering practices, as well as societal and global changes, have warranted continual reforms in the curriculum and the overall engineering education (Duderstadt, 2010). The content of engineering curriculum is generally structured to begin with fundamental courses such as science, mathematics, and the humanities, followed by discipline-specific fundamentals and culminating with a capstone design project. Engineering courses are taught deductively, mainly in lecture format, and are reinforced frequently with laboratory work. This method of passive teaching helps only a fraction of engineering students to learn (ASEE, 2012; Felder, Woods, Stice, & Rugarcia, 2000; Sheppard et al., 2009).

A desired engineering curriculum would follow the format of engineering practice that is collaborative, multidisciplinary, and global (ABET, 2014; ASEE, 2012). It would expand engineering education from the traditional STEM fundamentals and disciplinary base to include interdisciplinary studies on environmental issues, globalization, leadership, and societal concerns (ABET, 2014; ASEE, 2012; Lattuca, Knight, Ro, & Novoselich, 2017). However, engineering colleges and universities in the United States already provide a base of science and engineering fundamentals at the undergraduate level, and there has been consensus among researchers that they have been consistent in delivering engineering fundamentals and providing a base for technical education (ASEE, 2012; Crawley et al., 2007; Johri & Olds, 2011; Sheppard et al., 2009; Trevelyan, 2010).

Engineering educators have agreed on the benefit of experiential learning, but they have struggled to maintain a balance between fundamental content and hands-on projects. Bass (2012) argued that the optimal way to teach is to move reciprocally between practice and content and to emphasize practice in the curriculum early. However, engineering stakeholders have insisted that students should be prepared for practice and learn how to communicate effectively, maintain professional ethics, understand the impact of globalization, embrace lifelong learning, understand current issues, and become proficient in the use of modern tools and engineering techniques (ABET, 2014).

These concerns have been the focus of debate among the various stakeholders of engineering education since the 1980s, and they have inspired calls for engineering education reform (ABET, 2014; ASEE, 2009, 2012; Crawley, 2001; Crawley et al., 2007; NSF, 2008). By the 1990s, the industry’s calls for overall engineering education reform and the inclusion of practice into engineering programs were being acknowledged. In response, the industry, academia, and professional organizations began to persuade professional societies and universities to change the course of engineering education (Crawley, 2001; NAE, 2005; Sheppard et al., 2009). In response, ABET took a step in reforming its requirements and established goals (as cited in Lattuca et al., 2006) for engineering education.

ABET (2014) provided guidelines and minimum requirements to engineering institutions in each area of engineering study. The new ABET criteria changed the basis for accreditation from teaching inputs to learning outcomes, requiring engineering programs to assess student achievements and place an emphasis on problem-solving, communication, teamwork, and ethical skills for students. According to ABET, graduates entering the engineering profession should be equipped with theoretical knowledge accompanied by an introduction to professional practice. The criteria for program outcomes require students to apply their knowledge to the design of experiments and systems and the solution of engineering problems. In addition, engineering programs accredited by ABET demand that engineering faculty meet competencies, that is, have engineering experience, have knowledge of industrial practice, and have interactions with industrial and professional practitioners.

Engineering schools have followed ABET (2014) guidelines with a variety of curriculum and teaching methods. Each university has been given the flexibility to establish its own curriculum and allow instructors to teach courses based upon their knowledge and experience (Sheppard et al., 2009). Although many universities have adjusted their programs to meet ABET requirements, others have developed progressive programs with significant elements of change that have met the desired engineering education goals (King, 2012).

The Worcester Polytechnic Institute (WPI) implemented project-based learning programs that challenged students with complex learning experiences (Vaz, 2012). Per the WPI program, the project-based learning programs expanded from first-year introductory projects to final-year capstone projects, and in the process, students gained skills in knowledge application, communication, teamwork, use of technological tools, and understanding of social and global issues. WPI introduced four types of projects: (a) the great problems seminar, a first-year project organizing student teams to explore and solve a challenging world problem; (b) the humanities and arts requirement, wherein students focus on a humanities and arts topic that engages them in lifelong learning with the intent of embarking on self-knowledge and independent thinking; (c) the interactive qualifying project, which involves the application of research to solve social and human issues; and (d) the major qualifying project, which engages students either in design or engineering research work, usually sponsored by industry stakeholders (Vaz, 2012). These cooperative, open-ended projects satisfy all requirements of professional practice.

Although engineering colleges have made efforts to meet ABET (2014) requirements, they also have been challenged to keep up with technological advances and changes in the work processes of an industry that employs engineering graduates and supports university research projects. The industry, and other stakeholders, have continued their call for engineering education reform that aligns with industry practices and ensures improvements in engineering curricula, teaching methods, and inclusion of practice (ASEE, 2012; Besterfield-Sacre et al., 2014). Researchers have provided a picture of the status of engineering education and have offered recommendations toward solutions.

In 2005, the NAE presented a report of the status of undergraduate engineering education in the United States and recommended enriching traditional curriculum content with teachings that would support innovation, communication, professional practice, and globalization. The NAE concluded that an undergraduate degree is not adequate to prepare students for engineering practice. The NAE recommended assigning undergraduate education as a preengineering degree and adopting a master's degree as the professional degree. This recommendation meant developing a practice-based master's degree program staffed with faculty members who have practical engineering experience. In that regard, Duderstadt (2010) argued that faculty members should have experience in such areas as design, innovation, systems integration, and technology management.

Other recommendations from the NAE (2005) included introducing engineering work early in undergraduate programs to show first-year students what engineers do in practice and improve the retention of the brightest students, who might otherwise be discouraged by the intense math and science at the center of such a program. The NAE also stressed the need to prepare students for lifelong learning because of the addition of new areas of knowledge and continual changes in technology, economy, work complexities, and employment (ASEE, 2012; Baukal, 2010). Other recommendations from the NAE included introducing interdisciplinary learning in the curriculum content, setting new standards for faculty qualifications, and educating the public about engineering.

Additional recommendations for engineering education have come from various studies and reports. Duderstadt (2010) favored earlier recommendations from the NAE that supported maintaining the bachelor's status as a general engineering degree, embracing the master's degree as the professional standard, and suggesting doctoral programs for engineering scientists at the research level. Duderstadt stressed the need to shift the professional practice elements from the bachelor's degree program and eliminate the existing problem of overburdening undergraduate programs. Duderstadt suggested that undergraduate engineering education should include exposure to the humanities, liberal arts, and social sciences to build a base for cultural awareness and globalization.

Some researchers also have argued in favor of elevating engineering to the same professional status as law and medicine. Duderstadt (2010) contended that engineers should be able to claim their engineer title instead of identifying with their place of work and suggested that engineering professional societies should develop a professional engineering culture. Although proposals to elevate the status of engineering to a professional level might be the desire of engineering academics, the cost and the additional years of study are expected to create resistance in the industry that employs the engineers and the parents who pay for their education (Duderstadt, 2010). Other priorities for engineering education include the challenge of building a diverse engineering workforce that places importance on encouraging women and underprivileged minorities into the field. The overall absence of women and underrepresented minority students from engineering relative to their presence in the U.S. population has been a problem (ASEE, 2012) and must be considered in any reforms of engineering education.

Sheppard et al. (2009) provided an analysis of the deficiencies in engineering education. Sheppard et al. faulted the ways that problem solving, knowledge acquisition, and theory are taught in terms of preparing students for practice. Moreover, Sheppard et al. found that using deductive methods of teaching, structured problems, and student assessment methods failed to reflect the learning methods suggested by researchers regarding how people learn and how expertise is developed. Ethics and professionalism have been covered inadequately. The laboratory is supposed to be the place for open-ended experiments, where undergraduate students learn to use equipment and instrumentation, deal with uncertainties, and solve problems like those encountered in the real world. Instead, laboratories have been used mainly to supplement and validate classroom lectures and use structured problems that illustrate, reinforce, or test theories or principles explained in the lectures. Sheppard et al. suggested improvements to the existing engineering model and offered recommendations geared toward improving engineering education pedagogies, aiming to strengthen the principles and concepts and learning how to use them, building better problem-solving skills, engaging in professional practice in the classroom, and teaching inductively.

Other scholars have described similar scenarios, leading to initiatives to overhaul engineering education. The question of what needs to change, who is responsible for implementing the change, and how this change will be accomplished was addressed by the ASEE (as cited in ASEE, 2009), when it put forward an initiative to promote engineering educational innovation. The Phase 1 report provided a baseline for the status of U.S. engineering education and recommended sustainable and systematic innovation in engineering education (ASEE, 2009, 2012). The Phase 1 report (ASEE, 2009) identified what needs to change, who is responsible for implementing the change, and how the change is to be achieved and sustained. The ASEE identified curriculum content, instruction, and assessment as the main elements of change. Per ASEE, the best learning concepts and teaching practices are available but dispersed throughout the literature and should be replaced with a shared knowledge base driven by research and scientifically proven practice.

The ASEE (2009) also affirmed that engineering faculty and administration are responsible for developing, improving, and delivering engineering education. Because college faculty and administration develop the content, deliver the lectures, and structure the teaching environments, they also should be responsible for the quality of engineering education. However, university faculty and administrators need to be equipped with the knowledge and tools to assume that responsibility. The ASEE recommended PD for faculty and administrators in teaching, learning, and education improvement throughout their careers.

Researchers have presented their visions for engineering education but have failed to explain how these visions might be accomplished and sustained (ASEE, 2012; Felder et al., 2011). In Phase 1, the ASEE (2009) proposed a model for scholarly and systematic educational innovation that answered this question: “How do we create an environment in which engaging and empowering engineering educational innovations can flourish and make significant difference in educating future engineers?” (p. 1). The model was based upon the collaborative link of educational practice and research, wherein educational practice would provide enquiries and educational research would continually provide answers and insights. The success of this model depended on the collaboration of practitioners and researchers in education who were committed to advance the boundaries of knowledge and practice (ASEE, 2009).

In Phase 2, the ASEE (2012), also based upon a large sample of U.S. university faculty, chairs, and deans, was carried out to evaluate the Phase 1 report (ASEE, 2009) recommendations and to gather data to establish the current state of U.S. engineering education. The ASEE (2012) confirmed the recommendations of the Phase 1 report and proposed others, such as raising "awareness of the proven principles and effective practices of teaching, learning, and educational innovation, and raise awareness of the scholarship of engineering education" (p. 8). The engineering community should raise "awareness of the considerable educational infrastructure that already exists, both within and outside engineering, and the substantive body of knowledge of proven principles and effective practices in teaching, learning, and educational innovation" (ASEE, 2012, p. 50).

For the most part, engineering education continues to be delivered in the deductive method, meaning that theory and abstractions are taught in the initial years and progress toward application in the later years (ASEE, 2012; Sheppard et al., 2009). The ASEE (2012) recommended using pedagogies of engagement, such as project-based learning and inquiry-based learning, both of which combine inductive and deductive learning. In addition, engineering education needs to be relevant to the needs of its graduates. Engineering programs should align their curricula, instruction, and assessment with the professional needs of graduate engineers.

Organizations such as ABET have highlighted the need for a stronger bridge between theoretical learning and professional practice. This slight augmentation can initiate points of interest in the profession and help with program retention. By beginning at the first-year level, leading engineering academic bodies might introduce a new hierarchy resembling those of legal and medical programs.

Resistance to Engineering Education Reform

Despite calls from professional societies and the industry, engineering education reform has been slow. Although universities aim to provide graduates with a base in engineering fundamentals, the industry wants engineers who are ready for practice. The appropriate method to achieve this balance is addressed by engineering research, with the aim of adding new knowledge into the education curriculum and identifying areas of practice that can be adopted by engineering education (King, 2012). However, the teaching and learning practices promoted by engineering researchers have yet to be implemented in the classroom (Matusovich, Paretti, McNair, & Hixson, 2014), and recommendations from researchers have not resulted in changes in universities' curricula. For example, although student-active pedagogies have been proven to be effective methods of teaching, the adoption rates of active learning methods have been reported as low (Borrega et al., 2010).

The reason for universities' low adoption of recommended practices is that the objectives of universities and the engineering industry have not necessarily been congruent. The aim of engineering research has been to suggest ways to improve engineering education, address deficiencies, add new knowledge, and suggest methods that incorporate engineering practice; the overall goal of universities' engineering programs is to teach science and engineering fundamentals and meet students' need to develop some skills for engineering practice. However, when the tested methods have clear and immediate benefits, universities' low awareness and adoption rates have limited implementation of these methods (Borrego et al., 2010).

In the absence of specific requirements, each school must decide whether to enhance its own programs, develop new ones, or just adopt existing successful programs. However, engineering schools might not be aware of existing programs. When they are, adoption of such programs still might not be pursued. Low awareness and adoption rates limit the widespread use of tested programs (Borrego et al., 2010). Schools that are awarenes and desire to change may adopt programs developed by others, whereas others try to improve their existing programs or seek innovations for effective learning programs (Borrego et al., 2010).

Borrego et al. (2010) studied the awareness and adoption rates of engineering education innovation programs that introduced students to practice. Using survey responses from the engineering department chairs of several U.S. universities, Borrego et al. studied the awareness and adoption rates of seven innovation programs: student-active pedagogies, first-year design projects, interdisciplinary capstone design projects, summer bridge programs, learning communities, curriculum-based learning projects, and artifact dissection. Borrego et al. indicated an overall awareness of innovation programs of 82% and a low adoption rate of only 47% of the innovation programs. Use of such student-active pedagogies as group work, classroom activities, and instructor questions scored an 82% adoption rate. The "interdisciplinary capstone design projects in the first-year course had the highest levels of awareness, while artifact dissection had the lowest" (Borrego et al., 2010, p. 194).

There also has been a mismatch between what university faculty and administration value and what they practice in the classroom. Besterfield-Sacre et al. (2014) analyzed the ASEE (2012) Phase 2 data to investigate how engineering departments valued each of collaborations with stakeholders, in-class pedagogies, learning environments, faculty PD, and policies and practices and the extent to which these items were routinely practiced. Besterfield-Sacre et al. indicated that the engineering departments significantly valued collaboration with engineering stakeholders but practiced collaboration only within the industry among employers, excluding interdisciplinary university departments. The faculty valued, but did not practice, such elements as active learning approaches (experiential, collaborative, and inquiry-based learning); learning environments (engineering competitions and extracurricular activities such as mentoring); continuous teaching and learning development programs; and policies and practices that supported the use of research-based teaching pedagogies and resources to improve teaching and the learning infrastructure. Furthermore, the engineering faculty did not value international programs, entrepreneurship programs, and service learning programs, although these programs have been highlighted in national and international reports such ASEE (2012). Besterfield-Sacre et al. concluded that engineering faculty and administration supported, but did not practice, most elements of change advocated by engineering stakeholders.

Learning Styles Versus Teaching Methods

Another criticism of engineering education has been the mismatch between established methods of teaching and learning. The dominant teaching method in engineering is deductive: Professors give lectures on the principles in well-organized and logical manners, followed by blackboard demonstrations and, possibly, experimental explanations (Felder et al., 2000; Sheppard et al., 2009). Students take notes, work through problems, and learn by preparing for quizzes and exams. Engineering researchers have argued that this method of teaching should be replaced by inductive teaching (Besterfield-Sacre et al., 2014; Duderstadt, 2010).

In the inductive method of teaching, teachers provide cases for students to reflect on before introducing the principle topics. The practical cases in context allow students to experience or observe the concepts in real terms and learn interactively. In this way, students reflect on the learning experience to connect theory and practice. Brodeur, Young, and Blair (2002) advocated the integration of project-based learning across undergraduate engineering courses to ensure a natural progression from structured to more complex problems that emulate real-world situations. Dym, Little, Orwin, and Spjut (2004) reported that the early introduction of project-based learning to engineering students leads to improved retention rates and increased student satisfaction. Dym et al. supported project-based learning as the preferred method for teaching engineering design. Litzinger et al. (2011) noted that project-based learning is an effective learning method for supporting the development of expertise in engineering practice. Khalaf, Balawi, Hitt, and Radaideh (2013) used project-based learning in a first-year course and reported improved student design thinking, problem solving, and motivation.

Felder et al. (2000) reported inconsistencies between students' learning styles and the teaching methods. Felder et al. asserted that teaching methods must match the learning needs of sensory and intuitive learners, visual and verbal learners, and active and reflective learners.

The sensory learning style, which favors experimentation, factual data, and less detail in the presented material, matches the concrete teaching style. The intuitive learning style favors theories and concepts, and requires an abstract method of teaching. Although most students are sensory learners, engineering courses are offered in a conceptual format, which results in a teaching-learning conflict. This intuitive learning method conflicts with engineering practice, where attention to detail, practicality, and experimentation are required. Therefore, engineering material should be offered by blending concrete and abstract concepts for effective learning.

Another point of conflict between teaching and learning styles in engineering is in perception. Information is received in the form of visual, verbal, or kinesthetic cues. Visual learners do well if the material is presented in the form of charts, pictures, and diagrams (Katsioloudis & Fantz, 2012). Verbal learners are better at retaining what they hear and prefer verbal explanations; kinesthetic learners learn best through experience and physical activities. Although many college students are visual learners, engineering courses are presented verbally as lectures. Katsioloudis and Fantz (2012) noted that because engineering and technology students prefer the kinesthetic learning style, faculty should teach in this manner. However, they also noted that faculty who were taught using the verbal style continued to teach in the same way.

Yet another area of learning mismatch pertains to active, reflective, and passive states of learning. Engineering students expectedly do well in experimentation and active participation in discussions, debating, and brainstorming sessions. In addition to active learners, engineering students include reflective observers, who do equally well by just listening and reflecting on the material. Felder et al. (2000) explained that engineering classes are taught with students sitting in a passive mode, an instructional strategy that benefits neither active nor reflective learners. Felder recommended that instructors balance active discussions and problem-solving activities with intervals of reflection. Other recommendations emphasized incorporating drills and open-ended problems for practice, as well as striking a balance between practical problem solving and a fundamental understanding, thus providing opportunities for active participation and experimentation.

The goal of education should be to include teaching and learning practices that lead to the development of expertise (Litzinger et al., 2011). Although some traditional teaching methods such as project-based learning, internships, design projects, and laboratory exercises lead to student gains of expert knowledge, new nontraditional methods are needed for effective practice. Litzinger et al. (2011) expanded on areas which student learning can be improved that include improving students' conceptual understanding of their disciplines, improving analytical skills, solving multifaceted problems in context, solving complex problems, enhancing experimentation skills, and adding liberal arts to engineering curricula.

Project-based learning is another method of student-centered learning. Unlike problem-based learning, where problems are solved, project-based learning is concerned with making products as solutions to problems. Hall, Palmer, and Bennett (2012) studied students' perceptions of project-based learning in a two-part, first-year design course. They reported that students enjoyed the practical project and learned the concepts very well. The CDIO program is another project-based learning program developed by MIT and the Swedish Royal Institute of Technology. Through a complete project life cycle from conception to operation, students experience problem solving, teamwork, communication, and professional ethics, and then apply their engineering knowledge (Yang et al., 2014).

Resistance and lethargic responses to academic reforms in engineering have been spawned by incongruences at the university level. Although several universities have acknowledged the need for more inclusive programs that better prepare students for practical application, few have followed through. Failing to more closely adopt engineering awareness among students has been a primary example. In addition, the exclusion of vital experiences such as international and entrepreneurship programs within academic programs have been detractors and have reinforced archaic status quos within programs.

One-dimensional teaching styles such as lecture-based learning has generally been retained, despite the call for more innovative instruction. Focusing on project, analytical, and experimentation-based learning is strongly encouraged to propel engineering academics and serve as a true vessel of change.

Gap Between Engineering Education and Industry Practice

Historical perspective. The gap between engineering education and engineering practice has been widening since the last century and has been acknowledged by many researchers (Borrega et al., 2010; Crawley et al., 2007; Felder et al., 2011; Johri & Olds, 2011; Litzinger et al., 2011; Rugarcia, Felder, Woods, & Stice, 2000; Sheppard et al., 2009; Trevelyan, 2010). Historically, engineering education was based upon practice (Crawley et al., 2007; Duderstadt, 2010; NAE, 2013). However, as college research gained prominence in the 1950s, engineering education deviated from practice, and engineering science became the norm for engineering colleges (Crawley, 2001). The difference between education and industrial practice continued to widen, as acknowledged by academia and the industry. Engineering research was driven by partnerships among government, industry, and universities, which eventually shifted their focus from practice to research. Although the efforts of engineering research have undeniably produced technological innovation, products, and processes critical for high economic growth (Duderstadt, 2010), its effect on engineering practice within engineering colleges has not been positive. Subsequently, engineering graduates have continued to struggle as they enter the manufacturing, design, and operations fields, where practice is the dominant activity.

Competency deficiencies. Most engineering practitioners work in the industry, where specific competencies are needed to ensure satisfactory performance. Entering graduates are expected to have the proper attributes that identify them as competent engineers. Crawley et al. (2007) defined a real engineer as "one who has attained and continuously enhances technical, communication, and human relations knowledge, skills, attitudes, and who contribute to society by theorizing, conceiving, developing and producing reliable structures of practical and economic value" (p. 11).

Once engineering colleges began to recognize competency gaps among graduating engineers in comparison to the work of established engineers in industrial organizations, they began to investigate ways to reduce the gap in education and initiate changes in the curriculum content. Crawley et al. (2007) compared the knowledge, skills, and attitudes required of graduate engineers to the competencies needed by the industry employing them. Crawley identified inadequacies in engineering skills, testing and measurement skills, communication skills, and teamwork skills.

Engineering students should be trained to engage in engineering practice in the field. In the absence of this training, engineering graduates will be required to self-train and develop the required competencies on their own. This self-training could be successful for engineers who have experienced mentors working with them, but it also could be a painful and lengthy experience for others who lack opportunities for mentoring and coaching in the early years of practice. Students gain valuable knowledge and skills if mentored during college, and it has been reported that undergraduate students who participate in undergraduate research or projects benefit from mentoring by graduate researchers (Ahn & Cox, 2016). Overall, researchers have identified the main deficiencies in technical competency, practical application of engineering fundamentals, engineering design, interpersonal skills, teamwork, communication, and engineering profession and ethics (Crawley et al., 2009; Paul & Cowe Falls, 2015; Sheppard et al., 2009). Each deficiency is discussed next.

Technical competency. The employers of engineering graduates expect that the engineers developed technical competency while completing their degree programs. The skills developed in college must align with current practices in the industry, a goal that is difficult to achieve, even with great efforts by the colleges. The need for technologically competent engineers grew exponentially as the opportunities for employment expanded through new fields including biotechnology, computer science, health, safety, and environmental engineering (Johri & Olds, 2011; Rugarcia et al., 2000). In the United States, ABET (2014) was expected to keep pace with changes in technology and provide guidelines to engineering colleges, but ABET set only the basic requirements that must be satisfied for accredited programs. Students are taught to use this knowledge to formulate, analyze, and solve theoretical problems.

Practical application. Critics of engineering education have faulted universities for the low application of technical knowledge and the lack of opportunities for practice. Sheppard et al. (2009) reported that the intense theoretical knowledge covered in undergraduate curriculum content left little room for student exposure to professional practice and remains the main reason for deficiencies in students’ technical competency. The application of engineering knowledge at the undergraduate level has been incorporated in the form of laboratory classes, design problems, and problem-solving assignments. Laboratory practice has been offered to ensure that students capture the fundamental concepts, and as students have moved toward their senior year, colleges have begun to introduce engineering practice in the form of design projects.

Sheppard et al. (2009) reported that design problems meant to be an introduction to the real world are introduced in the last year of college, leaving no base to build on additional experience. One area where engineering colleges have provided opportunities for practice is problem solving. Graduating engineers have barely been exposed to solving practical problem parameters that are unstructured, ill defined, and unconstrained. Instead, they learn to solve constrained and abstract problems for learning and easy solution (McNeil, Douglas, Koro-Ljungberg, Therriault, & Krause, 2016).

Findings from several studies have shown that these topics have not been covered in depth because of the late introduction of these topics and the limited amount of time for practice (Duderstadt, 2010). Engineering colleges provide limited opportunities for practice in the form of laboratory assignments and design projects, but this limited practice does not develop sufficient skills. Litzinger et al. (2011) suggested that "only practice performed with the intention of developing a skill will lead to the development of expertise" (p. 125). For students to develop the skills necessary for professional practice, engineering programs should provide them with multiple opportunities to apply their knowledge in practical situations (Litzinger et al., 2011).

Design knowledge. Engineering design is a major area of engineering practice, a rigorous process based upon the application of science and technology to generate products that benefit society (Duderstadt, 2011). In a study of the impact of ABET's engineering criteria of 2000, Lattuca et al. (2006) found that the employers of engineering graduates rated design as one of the most important attributes of new hires. Design is what most engineers do in the industry, so engineering curricula should make design the main goal of educating engineers (Dym, Agogino, Eris, Frey, & Leifer, 2005).

Dym et al. (2005) asserted that design education is challenging because of the need for faculty with industrial experience and allocation of funds for design projects, laboratories, and other facilities; however, in the face of these challenges, the outcome of effective design education will be fruitful. Most universities teach a first-year engineering design course, known as a cornerstone, and a capstone course in the last year of a degree program. The intent of the cornerstone course is to introduce engineering solely to attract students and improve retention. The capstone design project offered in the last year of a degree program is supposed to equip graduates with design knowledge, but one design project is not enough to prepare graduates for engineering practice (Ambrose, 2013).

Interpersonal skills. Interpersonal skills are essential for successful teamwork in engineering because of the constant interactions with coworkers, operators, clients, management, contractors, and craftspeople. Honken and Ralston (2013) discussed the importance of interpersonal skills and the ability to work with others. In a study about first-year engineering retention, Honken and Ralston found that students who study with others in high school are likely to continue to study engineering. Martin, Maytham, Case, and Fraser (2005) stressed that engineers should develop such interpersonal skills as listening, sharing information, cooperating with other disciplines, and learning how to deal with difficult personnel. Interpersonal skills can be developed through teamwork and group assignments, but sometimes, these skills must develop by graduate engineers themselves as they enter the workforce.

Teamwork. Teamwork is encountered in all engineering disciplines because engineering projects require the collaboration of members from diverse groups, including engineering, craft, business, and support disciplines (Paul & Cowe Falls, 2015). Graduate engineers who lack these team skills face difficult adjustment periods in their early careers. For example, the design, construction, and operation of a power generation plant for a community involve the work of civil, mechanical, electrical, structural, and chemical engineers, as well as many craft skills, business majors, and other support personnel. These multidisciplinary teams comprise individuals with different levels of education, background experience, and cultural beliefs and behaviors who absolutely must support each other to reap benefit from the strengths and experiences of other members (Oladiran, Uziak, Eisenberg, & Scheffer, 2011). For these reasons, organizations create interdependent teams to execute challenging projects and train their engineers to work collaboratively with diverse groups and teams so that they learn how to contribute to common objectives (Johri & Olds, 2011). ABET (2014) requirements did and still do include instructions for teamwork so that engineering students develop their interpersonal skills during their undergraduate education.

Passow (2012) studied the relative importance of ABET competencies for professional practice. The study was based upon the opinions of graduate alumni with two, six, and 10 years of experience, respectively, who represented 11 engineering disciplines. The 4,225 survey respondents ranked teamwork, communication, problem solving, and data analysis the top four of 12 competencies. These four top competencies were significantly higher than the bottom cluster of contemporary issues, experiments, and impact of work.

Many researchers (e.g., Dunsmore, Turns, & Yellin 2011; Korte et al., 2008; Martin et al., 2005; McSpadden & Kelly, 2012; Oladiran et al., 2011) reported the significance of teamwork in engineering. Martin et al. (2005) reported that the working engineers in their study commented that 60% to 80% of their working day was spent in teamwork. Oladiran et al. (2011) reported on the successes of the global engineering teams (GET) program used to promote teamwork in engineering design and manufacturing.

Communication. Communication is amongst the paramount professional competencies. Engineers spend over 60% of their time communicating with others at work (Paul & Cowe Falls, 2015). Therefore, clear and persuasive oral and written communication is required for engineering work. Engineers should gain broader exposure to written and verbal communication while attending university to develop a wide range of skills, including grammar and pronunciation, technical writing, corporate communications, interpersonal skills, and leadership (Lappalainen, 2010). Hall et al. (2012) studied students' perceptions of project-based learning in their first-year design course and reported that although the students enjoyed the practical aspects of the course, report writing and oral presentations scored the lowest satisfaction ratings.

Trevelyan (2007) related communication for engineering students to technical coordination, the work that most engineers are engaged in during their daily work.

Trevelyan studied the work of engineers in the field and learned through interviews that engineers engage in technical coordination more than problem-solving activities. Technical coordination activities included supervising the work of others; persuading others such as construction workers, operators, maintenance personnel, and managers to perform duties; gaining cooperation; mentoring; and reviewing and even organizing social activities (Trevelyan, 2007). These technical coordination activities were accomplished through clear verbal and written communication. In the absence of adequate communication skills after graduation, engineers develop effective skills themselves through self-learning, selective professional development, and on-the-job learning during early employment.

Professionalism and ethics. Engineering graduates are not prepared for professional practice because most engineers are not required to obtain professional engineering licenses and pass professional licensure examinations that require them to study and answer questions about codes of conduct (Sheppard et al., 2009). Professional practice includes ethics, social responsibility, integrity, and lifelong learning. Engineering codes of conduct stress professional competence and a commitment to protect the public and the environment; they require engineers to act with honesty and accountability (Sheppard et al., 2009). In some engineering disciplines, licensure is recommended, and professional practice material might be covered in undergraduate degree programs. ABET (2014) stipulated that the curriculum content for civil engineering must include professional licensure and faculty incorporate it in the design course. These requirements vary with the engineering discipline, but each university is responsible for developing programs that meet the criteria.

Interdisciplinary skills. Research has addressed the need to expand the curriculum to include interdisciplinary studies and multiple perspectives in engineering education. The NAE (2005) stressed interdisciplinary education, reasoning that engineering work requires consideration of the constraints (environmental, financial, societal, and global) and consequences that require the collaboration of multiple disciplines. The NAE also recommended curricular and instructional changes to strengthen interdisciplinary competence, in addition to the design and contextual competence.

Litzinger et al. (2011) conducted a case study to explore the ways that undergraduate engineering programs prepare students to think and work in interdisciplinary ways. Litzinger et al. conducted personal and group interviews that they triangulated with archival records, class observations, and other artifacts. The results showed that interdisciplinary learning was assumed to happen in the co-curriculum, particularly in activities such as design competitions and humanitarian projects. Other instructors introduced interdisciplinary activities into courses and programs to bring engineering, business, and other majors to work together on a project.

Adams et al. (2011) explored the topic of multiple perspectives in engineering education that can provide a map of new innovations for engaging engineering students. Among other perspectives, Adams et al. stressed the need to make connections between understanding and applying in an active learning process. Recommendations from these researchers pointed to deficiencies in interdisciplinary skills in engineering education and the importance of these skills for practice.

Incorporating Engineering Practice into Engineering Education

The objective of engineering education is to prepare engineering graduates for professional practice in their areas of specialization. From the perspectives of practitioners, engineering practice is the work that engineers do routinely as they conceive and design systems, build facilities, and operate production facilities to provide useful products (Crawley, Brodeur, et al., 2008) as well as solve problems that arise during each stage of these activities. The path to engineering practice for working engineers is laid in the four stages of facility development: conception, design, construction, and operation. Although some engineers might spend their entire careers at any one of these stages, others may conduct feasibility studies, carry out preliminary and detailed design work, develop and execute projects, and operate these facilities. Engineers engaging in these work stages are expected to use their fundamental knowledge, interpersonal skills, and abilities to complete the tasks required during each step of the work (Crawley, Brodeur, et al., 2008).

Engineers continue to solve the problems that arise in conception, design, construction, and operation. Conversely, engineering education focuses on theoretical problem solving and looks at practice from the perspectives of practice-like activities that approximate engineering tasks, such as laboratory work or design projects. However, engineering education stakeholders want to narrow the difference between engineering knowledge and the skills needed for practice. Great efforts have been made to narrow this gap.

Crawley (2001) constructed a comprehensive catalogue of skills that encompassed the contributions of stakeholders (i.e., alumni, industry, academia, and students); searched new ways of teaching and learning; and used assessment data to develop a project-based program. The skills that Crawley developed approximated the functions of working engineers. The outcome of these efforts was the CDIO syllabus, developed by MIT in 2001 to summarize formally "a set of knowledge, skills and attitudes that alumni, industry and academia desire in a future generation of young engineers" (Crawley, 2001, p. 1). The Crawley called for reforms in engineering as well as demands to incorporate practice in the same manner as expected in the real world.

Other universities have continued their efforts to include practical engineering in their courses. McSpadden and Kelly (2012), researchers at Purdue University, described their approach of teaching preservice engineering and technology teachers to solve real-world problems experienced in society and require the use of engineering knowledge and skills. McSpadden and Kelly reported that diverse student teams were formed to select, develop, and build a prototype for an ill-defined engineering problem. The teams were set up to mimic engineering teams and work the problem from the conception stage to the completion stage using a budget and project constraints mirroring the real world. Valuable learning experiences for students included practical experience, teamwork, communication, and appreciation of their technical knowledge, and the recommendation to use this approach as an enhancement toward the learning experiences of engineering students (McSpadden & Kelly, 2012).

Swart (2010) compared the merits of teaching theory before practice or teaching practice before theory in a course that offered theoretical instruction followed by laboratory practice. They compared the scores of two classes. In one class, theory was taught before practice; in the other class, practice preceded theory. Students in the class that taught practice before the theoretical method scored 20% higher. Student responses also showed that the practical experiments helped them to understand the theoretical instruction more clearly.

Industry Role and Feedback

The role of industry in preparing students for practice could manifest in several ways. Industry might provide funding to projects initiated by universities that are designed to provide problems that include practice. Industry can provide projects or problems needed to solicit solutions as student projects and provide funding. In addition, global programs may be designed to solve real problems while giving students opportunities to work on projects that prepare them for practice. The significance of developing professional skills is illustrated in the GET program, where hard engineering skills and soft professional skills are used to complete engineering projects (Oladiran et al., 2011).

In the GET program, university and industry partners collaborate to form multifunctional student teams to complete engineering projects. The GET program uses project-oriented, problem-based methods to give students the opportunity to engage in challenging engineering team projects. The GET program gives students field training in the areas of teamwork, cooperation, interaction with the industry, and global experience. The industrial partners gain qualitative solutions to problems. Partner universities include MIT, Pennsylvania State University, and Rennselaer Polytechnic Institute in the United States, as well as such international university partners as Hasso-Platner Institute, Germany; Technische Universität, Germany; Stellenbosch Universiteit, South Africa; University of Botswana, Botswana; Universidade de São Paulo, Brasil; and Pontificia Universidad Católica de Chile, Chile.

Engineering students in operations, design, and manufacturing programs have expressed dismay because of their need for high levels of practical familiarity. The dismissals of such requirements have created a dereliction of industrial intangibles, such as familiarity with industry technology and practical application. It also has created a gap in areas such as design knowledge, teamwork, interpersonal skills, and workplace ethics. Though these are not science-based skills, they remain high on the list of industrial expectations and should be included in engineering curricula.

Conclusions from the Literature Review

The researchers confirmed the existence of a widening gap between engineering education and industrial practice. A significant portion of this gap has been attributed to engineering faculty's lack of industrial experience, and the heavy focus of universities on research. The National Effectiveness Teaching Institute (as cited in Felder & Brent, 2010) recommended setting effective instructional development programs tailored for engineering faculty to cover specific disciplines such designing for active and project-based learning experiences.

The adoption of ABET’s engineering criteria in 2000 has taken U.S. engineering schools closer to practice (Dym et al., 2005). Although universities continue to equip graduates with solid scientific knowledge and engineering fundamentals, their ability to include practice in engineering programs has been limited by time and resource constraints. Engineering schools alone cannot realistically produce graduates who are equipped with all the knowledge and skills required by the industry. Engineering colleges must develop close collaboration with industry; employ faculty with industrial experience; and solicit input from relevant stakeholders in engineering education, that is, educational institutions, professional societies, students, and the industry (Litzinger et al., 2011). Including practice in engineering education requires willingness from academia to change and more contributions and commitment from industry, an effort that has already been initiated.

The ASEE (2012), with support from the NSF, started a multiyear sequence of workshops, “Transforming Undergraduate Education,” between academics and industry in 2013 with the objective of promoting changes in curricula, pedagogy, and academic culture to produce required qualities for graduating engineers. The final workshop, scheduled for 2018, is expected to produce the ultimate framework for transforming undergraduate engineering education. The findings derived from my study will produce some feedback from working engineers and present data that might be useful in transforming engineering education.

Summary of Literature Review

Deficiencies in engineering education have been documented in the literature. Industry, professional societies, and engineering research have called for strengthening fundamentals and technical competencies, adding practical engineering design and operation instruction, as well as soft skills such as communication, teamwork, and interpersonal skills, and professional ethics. Feedback from industries that employ engineers has suggested the need for reform and the inclusion of practice in engineering teaching and learning. The viewpoint of industry is that the most desirable employment attribute of graduate engineers is their ability to apply theoretical knowledge to industrial problems (Lamb et al., 2010).

From the 1980s and 1990s, concerted efforts from industry, academia, and professional societies started to change the course of engineering education (Crawley, Brodeur, et al., 2008). ABET revamped its accreditation program, and leading engineering universities developed curricula that added practice to the content. The most notable program, the CDIO, was developed at MIT in 2006. The CDIO syllabus was based upon supplementing the fundamentals with skills that allowed students to conceive, design, implement, and operate facilities. The syllabus was adopted not only at MIT but also by other universities in the United States, Canada, and Europe (Crawley, Jianzhong, Malmqvist, & Brodeur, 2008). Other schools either reinforced their internal programs or adopted successful programs from other universities (Borrego et al., 2010).

Sheppard et al. (2009) reported inefficient practices of theory before practice and the poor use of laboratories and practical facilities. Hence, the practical application of engineering knowledge remains a challenge for graduate engineers. Technical competency, practical application of engineering knowledge, teamwork, and professional skills remain areas of high deficiency for graduating engineers (Crawley et al., 2007; Felder et al., 2000; Johri & Olds, 2011; Litzinger et al., 2011; Sheppard et al., 2009).

The current gaps in competency cannot be fulfilled using outdated teaching (Felder et al., 2000). The content of engineering curricula is saturated, so Felder et al. (2000) recommended (a) adopting innovative and effective instructional strategies from general and technical education programs, and (b) having professors develop instructional objectives that cover knowledge content and higher level problem-solving skills, along with the soft skills. In this way, student learning would strike a balance between practical and abstract information presented in lectures. Active and cooperative learning in a team environment promotes interpersonal skills and teamwork (Felder et al., 2000).

The efforts of researchers, engineering educators, and industry have narrowed the gap between education and practice. However, these efforts have not resulted in widespread engagement in engineering practice. In addition, feedback from practicing engineers has not been abundant in the literature. I conducted this study to investigate the experiences of engineering graduates at work and provide feedback to engineering education stakeholders.

Section 2: Research Method

Introduction

The objective of this study was to capture the experiences of engineers who were at least 1 year removed from receiving their degrees regarding their preparation for professional practice. In the data collection and analysis, I focused on their experiences, perceptions of gaps in their engineering skills, ways in which they confronted deficiencies in their engineering education, and the strategies that they used to build practical skills. In addition, I investigated each participant’s route toward self-development and the building of engineering experience. Although the gap between college education and practice narrows with PD and years of experience, overcoming deficiencies in the core education requires personal effort by individual engineers.

I selected a case study approach to conduct this study. To gain personal, in-depth knowledge of the participants, I interacted with graduate engineers in a social setting through interviews. The case study design and the reasons for its selection are described further in the following section.

The Case Study Design

A case study is an in-depth examination of a bounded unit over time. Scholars use case studies to focus on specific, unique, and bounded systems to gain information about the experiences of individuals or groups in particular settings (Stake, 2005). Researchers conduct case studies to examine current issues in real-life situations involving individuals, groups, entities, or institutions in certain contextual settings (Glisne, 2011).

Stake (2005) pointed out the importance of describing the realities of each case, noting that the activities of the case are determined by the perceptions of reality as seen by those involved in the case, be it contextual, situational, social, or other. The data collection and analysis protocols cover both the phenomenon under study and the context under which the phenomenon exists (Hatch, 2002; Stake, 2005; Yin, 2013).

Case study research is suitable to answer RQs of the "how" and "why" type, and it allows researchers to explore complex situations where multiple perspectives can be considered through the data collected from various sources (Stake, 2005; Yin, 2013). The case of interest is generally a real-life phenomenon that a researcher wants to develop. The researcher conveys a deep understanding of its unique features from sources of evidence where there are several variables that cannot be captured as data points (Yin, 2013).

I selected the case study method to understand the experiences of working engineering graduates and how they coped with deficiencies in their engineering education. Given the opportunity to elaborate their challenges, failures, and successes, the sample of working engineers provided their perspectives and in-depth knowledge of the problem. The case study method was appropriate to extract the stories of the participants in individual interviews and detailed discussions.

Reasons for Selecting the Case Study Method

In this study, the phenomenon of interest was the acquisition of knowledge and skills required for engineering practice. I focused on the experiences of graduate engineers and the ways in which they went about learning the application of engineering knowledge and developing the skills required for their jobs. These objectives aligned with the case study method, in which the experiences gained during the research through the activities, narrations, and interactions with the participants are reported. Stake (2005) suggested that case study researchers help readers to construct new knowledge from the experiences gained from the cases. Given these assumptions, the knowledge acquired from this qualitative case study will add to the body of knowledge required to improve engineering education.

Use of the Qualitative Method in Engineering Education Research

Although past engineering research has been largely quantitative, engineering researchers over the last 10 years have taken an interest in qualitative methods, and an increasing number of investigators have recommended the use of qualitative methodologies. Koro-Ljungberg and Douglas (2008) found that the authors of only a few published articles in engineering had used qualitative methods. Koro-Ljungberg and Douglas urged engineering researchers to take advantage of the alternative views and ways of knowledge acquisition afforded by qualitative research, reasoning that qualitative methods capture the complexity of people differently than quantitative methods do.

Borrego et al. (2009) also reviewed the use of quantitative, qualitative, and mixed-methods approaches in engineering research and reported on the low use of qualitative studies in the engineering education literature. Borrego et al. noted that even though the quantitative approach has been used in engineering studies, the increased use of qualitative methods would expand the range of RQs addressed in engineering research. Borrego et al. noted that most engineering education researchers have been, and continue to be, engineering faculty who have trained in the quantitative method, and the audience has tended to comprise engineering college faculty. Case and Light (2011) described several qualitative methods that are promising for use in engineering research including case study, grounded theory, and action research. Case and Light noted that although case study research has lacked generalizability, it has been compensated by the precise and context-dependent nature of the knowledge gained through the study.

In addition to more recent interest in the method, case studies have been used successfully in past engineering research. Magin and Churches (1995) used a case study approach to investigate the success of peer tutoring for a course in which computer graphics replaced traditional pencil-and-paper engineering designs. The purpose of the study was to understand the level of learning improvement afforded by peer tutoring over traditional teacher-led methods. In the case study, Magin and Churches incorporated various data collection methods, including individual interviews, group interviews, informal observations, and open-ended surveys. Magin and Churches found that tutored students and peer tutors gained value from the peer tutoring method and that more than 50% of the students preferred this method.

The purpose of the critical case study method is to gather data that facilitate logical deductions rather than generalizations. Daly, Mosyjowski, and Seifert (2014) used the critical case study method to examine engineering pedagogical practices and to document how these practices enhanced students' creative growth. In the analysis of data from student and instructor interviews, student surveys, and course material, Daly et al. showed growth in convergent thinking, but not in divergent thinking.

Mosalam, Hube, Takhirov, and Günay (2012) also conducted a case study to investigate teaching innovation through hands-on experience. The case study was designed to evaluate the merits of the active learning approach, in which students solve open-ended and ill-structured, real-world problems that might have multiple solutions. These scholars, along with many others, have confirmed the applicability of case studies in engineering research, where having in-depth understanding of an issue is requisite.

Research Question

The RQ and the theoretical framework typically drive the choice of methodology (Creswell, 2009). One RQ guided the current study: What are the experiences of graduate engineers currently working in the industry regarding overcoming practical skill deficiencies and bridging the gap between education and practice? The case included two issues: identify gaps between education and practice experienced by each engineer and identify the methods that the engineers used during the early years of employment to build practical skills that led to professional practice. Although most engineering researchers have used quantitative methods, the research method used in a study should be driven by the RQs, not by traditional quantitative methods (Borrego et al., 2009). That perspective aligned with this study in that the RQ required an in-depth knowledge of the problem under study from the perspectives of individual graduates.

Research Design

The research design of a case study requires the selection of the case type, the context, and the phenomenon under study. Stake (2005) identified three types of case studies: intrinsic, instrumental, and collective. The intrinsic case study is used to gain a deep understanding of a particular case. The instrumental case study is used to examine an issue where an in-depth understanding is required or when it is necessary to draw a generalization about the case (Stake, 2005). The collective case study or multiple cases use two or more cases to study the same phenomenon.

I chose to use the instrumental method for this case study because I wished to examine the competency problems experienced by newly hired engineers in the field, with the intention of generalizing the results to the wider graduate engineering population in the United States. I used the instrumental case study based on the need to gain a close understanding of what the graduates experienced in their early careers and how they educated themselves to become competent engineers. The knowledge gained from these experiences was expected to expose the gap in engineering education and contribute to improvements in learning and teaching at engineering colleges. However, case study researchers have stressed the need to select the case appropriately and describe the context (i.e., the natural setting) and the phenomenon being studied adequately (Stake, 2008).

Yin's (2013) detailed case study provides a roadmap for researchers. According to Yin, the researcher should describe the case, the RQs, the theoretical propositions, the unit of analysis, the phenomenon under study, and the data collection and data analysis processes. In the following text, I describe the case, the context, and the phenomenon that were under study.

The Case

Based on the literature that engineering graduates are not equipped with the relevant practical knowledge and skills needed for successful engineering practice, I chose to study how a sample of engineering graduates filled the gap in their education and covered the deficiencies stated in the literature. The use of a qualitative case study approach allowed me to derive knowledge about the participants' lived experiences based on my interactions with them. The strategy then was to analyze the experiences of the graduate engineers concerning the programs and tools that they used individually to keep up with the competencies required for their work practices to be successful.

In case study research, a theoretical proposition guides the type of data to collect and the strategy to analyze the data (Yin, 2013). Following this logic, I assumed that engineers entering the workforce usually fill the education gap through public courses, workshops, employer training, on-the-job training, as well as mentoring and coaching from senior engineers and supervisors. The assumptions in this proposition were that (a) the gap between education and practice needs to be bridged; (b) graduate engineers need to fill the gap by themselves with self-education; and (c) graduate engineers must pursue the resources available to gain the knowledge, skills, and abilities required to make them competent on the job.

Another requirement of the case study design is to select the unit of analysis. The unit in this study comprised the individual participants, that is, engineering graduates who were employed in their respective disciplines and who had at least 1 year of experience at the time of the study. The context included the physical environment of the work setting, the nature of the work, and the participants' educational backgrounds. In this study, the phenomenon of interest was the acquisition of the knowledge and skills required for engineering practice. I explored how the graduate engineers acquired the knowledge and skills that were missing from their college education.

Generalizability of Case Study Data

The generalizability of case study data was addressed in the literature (Curtis, Gesler, Smith, & Washburn, 2000; Stake, 2005; Yin, 2013). Case study findings are specific to the phenomenon under study, and grand generalizations to the wider population are not recommended. However, Yin (2013) pointed out that the significance of a study depends not only on the findings but also on the general implications of these findings. To generalize case study results, Yin recommended using analytical generalizations, meaning that researchers should construct arguments or hypotheses at the start of their studies based on a higher conceptual level than any particular case. The findings should support the hypotheses, which then can be generalized to similar studies (Yin, 2013).

In addition to the analytical, a case-to-case transfer (Curtis et al., 2000) also is applicable to case study generalizations. A case-to-case transfer involves making generalization from one case to a similar case. Stake (2005) called the process naturalistic generalizations, referring to the making of generalizations based on similarities in participants, contexts, settings, and times.

Participants

Criteria for Selecting Participants

This case study involved interviewing engineers who had graduated from U.S. universities at least 1 year at the time of the study. The objective was to select the sample from work locations in Texas. This selection was based on two factors: (a) I live and work in Houston, so it was convenient for me to meet and interview individual participants within a day’s travel distance and (b) there is a high concentration of engineering companies, oil companies, refineries, and chemical plants in the area where many representative engineers live and work. In addition, Texas has several highly ranked universities, including the University of Texas, the University of Houston, Texas A&M, and Rice University, all of which have graduated engineering who are now working in the selected region. Sampling engineers from these locations best represented typical engineering graduates who are employed in the primary disciplines of engineering practice.

Preferred participants were graduate engineers who were engaged in such areas as design, operation, project development, or similar fields where engineering practice is evident. The objective was to examine a specific situation in great depth, not to seek a generalizable outcome that would represent all situations (Borrego et al., 2009). The sample comprised individuals employed in the industry and practicing in their fields of engineering. Purposeful sampling was used to choose the participants.

Justification for the Number of Participants

Even though case studies tend to concentrate on a small number of participants, I recognized that the target population represented by the study was vast. For this reason, I selected a broad sample of 15 participants who were chemical, civil, mechanical, and electrical engineering graduates with work experience of at least 1 year at the time of the study. This representative sample comprised engineers who were fully engaged in engineering practice in the areas of design, operation, project development, or similar fields. There are many engineering disciplines, but the chemical, civil, mechanical, and electrical disciplines represent more than 70% of graduate engineers in the United States.

Gaining Access to Participants

The initial plan for participant recruitment was to identify several companies that employed large numbers of engineers in the Houston area and contact the participants' engineering managers to request that they forward letters of invitation to engineers who fit the criteria for participation. Several managers indicated that they had only a few engineers in their departments who fit the criteria; in addition, the number of replies from those who received the request for participation also was low. I then contacted more companies to increase the likelihood of recruiting more people who fit the criteria. I also contacted several university professors to request the names and contact information of their alumni. In addition, participants whom I interviewed referred other engineers who were willing to participate in the study. These combined strategies provided me with enough participants who met the criteria for participation. I developed an interview protocol to guide the data collection process. A consent letter, an invitation letter to participants, and a letter to facility managers were sent as part of the participant recruitment process.

The participants were engineers working in various industrial institutions in Texas and Louisiana and in various departments that included operations, engineering design, project engineering, engineering software sales, and research. Only three participants worked for the same company as I did at the time of the interviews. None of the participants was working with me or was supervised by me.

Ethical Protection of Participants

Following Walden University's ethical requirement process, I took the Human Research Protection training and obtained the certificate of completion from the National Institute of Health. The training provided me with an understanding of the ethical limits on data collection from research subjects. Next, I applied to Walden's Institutional Review Board (IRB) for approval to conduct the study (IRB approval #04-05-16-0149 213).

Participant Profiles

I contacted four company representatives to recruit working engineers and two universities to recruit alumni. As mentioned previously, I asked the participants to provide me with the names of other engineers who might have been interested in joining the study. I sent invitation letters to 21 engineers, 15 of whom accepted the invitation; six declined. I interviewed three engineers from each of chemical, civil, electrical, and mechanical disciplines who had at least 1year of experience. The participant's levels of education were as follows: bachelor's degree (n = 8), master's degree (n = 2), MBA (n =

4), and PhD (*n* = 1). They represented nine different universities; they were ethnically diverse: European American (*n* = 7), African American (*n* = 3), Asian American (*n* = 3), and Other (*n* = 2); and they were nearly gender balanced with eight male and seven female participants in the study (see Table 1).

Table 1

Summary of Participants

Pseudonym	Engineering major	Degree	Gender	Ethnicity	Data collection time
Kai	Chemical	BS	F	European American	10 minutes
Mel	Chemical	PhD	F	European American	8 minutes
Suchi	Chemical	BS	F	Asian American	20 minutes
Shali	Chemistry	MS	F	Other	11 minutes
Viji	Chemical	MBA	M	Asian American	16 minutes
Atta	Chemical	MS	M	African American	9 minutes
Dany	Civil	BS	M	European American	16 minutes
Jona	Civil	MS	M	European American	20 minutes
Rebe	Civil	BS	F	European American	12 minutes
Abd	Electrical	BS	M	African American	13 minutes
Gani	Electrical	BS	M	African American	20 minutes
Sultan	Electrical	BS	M	Other	15 minutes
Broos	Mechanical	BS	M	European American	21 minutes
Crista	Mechanical	BS	F	European American	10 minutes
Nisha	Mechanical	BS	F	Asian American	22 minutes

Data Collection

After the IRB approval, I began to collect the data. The objective of the study was to capture the experiences of engineers related to their preparation for professional practice in their areas of specialization. I used interviews only to obtain my data. Although interviews can be used in conjunction with other data collection methods, interviews represent the only data source or the primary data source for qualitative research (Hatch, 2002; Roulston, 2010; Stake, 2008; Yin, 2013). I audiotaped the interviews and asked targeted questions to allow the participants to reflect on their postgraduate preparedness for engineering practice and share their experiences in the training venues taken toward professional practice.

Conducting the Interviews

I asked formal, open-ended interview questions. I used unstructured and structured interview questions to capture the views of working engineers. I also asked informal questions to build rapport and gain an understanding of the setting and the environment. The interview data recording times are shown in Table 1. The time for room set up, meet & greet and wrap up of the session was not included in Table 1. The interview times varied based on the participant personality as well as their passion to share their experience on a subject. Three of the participants had significant internship experiences they wanted to elaborate. Two participants described their perceived thoughts about deficiencies of their skills at graduation. Overall, the less experienced participants provided short answers to questions. The interviews were conducted in various locations. I interviewed some participants in private offices at their places of work to minimize lost time; sometimes, it was the only time and place I could interview them. Other interviews took place in private rooms in a public library, and a few were conducted in an unoccupied hotel conference room.

Recording and Transcribing the Interviews

I audio-recorded the responses to the interview questions. I then transcribed the data and maintained accurate records to leave an audit trail for future researchers to verify the data collection methods (Creswell, 2009; Stake, 2008; Yin, 2013). Transcribing the data was time-consuming and required 2 to 4 hours of listening and typing depending on the length of the interview. The transcription duration was close to the transcription times cited in the literature (Hatch, 2002). I kept logs of each interview location, timing, and duration. I stored the interview data and transcriptions on a password-protected personal computer.

Role of the Researcher

I am an experienced engineer with more than 20 years of applied engineering, and I have had responsibilities teaching, mentoring, and supervising new engineers during my working years. I have traveled the road of professional progression that other graduate engineers likely take. These experiences gave me   profound understanding of the topic under study and helped me extract pertinent information from the participants. However, I was aware of the possibility of injecting my thoughts during the interviews. To guide against the urge of leading the participants to my point of view, I decided to ask the questions and let the interviewee provide the answers. The follow up questions gave me some concerns and, at times, I had to limit the questions to avoid leading the participant. But there were some natural limits for interjection. Each participant had a distinct experience because of the specificity of their experience or the nature of their work that was different than mine. Additionally, since my main experience was on chemical engineering, I was not well-versed with the civil electrical, and mechanical engineering disciplines.

Data Analysis

In qualitative research, data analysis and interpretation start with the initial data collection and continue to completion of the findings (Hatch 2002; Yin, 2013). Researchers must read and interpret the data in the process of coding, recording, and creating themes. Additional data might be required to confirm patterns developed during the analysis. Creswell (2009) compared data analysis to the peeling of onion layers, in that the process involves repeated steps of analysis and data collection.

I processed the data obtained from the interviews through the inductive method of analysis, that is, from the specific to the general. I analyzed the evidence for patterns that led to general statements that supported the phenomenon under study. Unlike the deductive method of analysis, in which theory guides the development of the hypotheses, the inductive method derives the theory from the phenomenon (Hatch, 2002).

The analysis of the transcribed data involved coding and categorizing the data, and developing themes. Coding involved marking statements that described the participants' views related to the RQ. I then sorted the coded data into categories and studied them for theme development. The themes and corresponding categories that emerged from the data are summarized in Table 2.

Table 2

Data Analysis: Themes and Categories

Theme	Categories
1. Perspectives on engineering education	
	Engineering fundamentals
	Application of knowledge
	Exposure to industrial facilities
	University's focus on research
	Faculty members' industrial experience
	Internship
	Lifelong learning
2. Deficiencies in engineering skills	
	Practical application of knowledge
	Laboratory experimentation
	Problem solving
	Engineering design
	Use of engineering tools
	Teamwork
	Communication
	Interdisciplinary subjects
3. Training & learning for engineering competency	
	Employer training
	On-the-job training
	Learning from peers and coworkers
	Learning from mentors and coaches
	Self-learning

Theme 1: Participants' Perspectives of Overall Engineering Education

Quotations from the participants supporting these themes appear later in the section. Theme 1 showed the strengths of engineering education as well as areas of weakness. Most participants confirmed that the university covered math, science, and engineering fundamentals generously and that engineering education provided them with broad knowledge that equipped them for wide career choices. Participants stated that having a college education prepared them for lifelong learning.

On the negative side, the participants stated that engineering education fell short in preparing them for engineering practice for two reasons: (a) Universities are focused on research, which provides funding for the university, rather than on engineering practice (Sheppard et al., 2009), and (b) engineering faculty have limited industrial experience and cannot provide students with the skills needed in the industry. The participants related their experiences in internship programs that gave them valuable exposure to industrial skills. Internships served as an important introduction to practice their classroom learning and gave them a glimpse into what engineers do in the field. Successful internships provided valuable experiences, but internships that were not useful also were identified. Furthermore, the participants noted that not everyone gets internship opportunities (Sheppard et al., 2009).

Theme 2: Deficiencies in Engineering Skills

The practicing engineers in this study identified deficiencies in the practical application of knowledge, problem solving, laboratory practice, engineering design, and use of engineering tools. The cause of these deficiencies was attributed mostly to faculty's lack of practical knowledge and the university's focus on engineering research rather than practical engineering. Furthermore, the engineers spoke about deficiencies in the soft skills of the profession as communication, teamwork, and engineering economics and business.

Theme 3: Training and Learning for Engineering Competency

As new engineers are employed in the industry, it becomes evident to them that industrial practice is different from academic life. Employers make new engineers take the responsibility to develop the skills required for their work. The participant engineers recommended that a combination of training methods be used so that they could gain practical knowledge. Training methods were employer training, on-the-job training, self-training, learning from peers and coworkers, and proper mentoring. The participants saw continuing education as important.

Before presenting the feedback from the participants is a reiteration of ABET's (2014) guidelines for engineering skills. ABET-accredited engineering colleges must teach the skills listed here and report the outcomes. However, it is up to each university to develop a curriculum that ensures compliance with ABET's requirements. Graduate engineers must perform five core (technical) skills, and six soft (professional) skills. Engineers must be able to do the following core skills:

1. Apply engineering knowledge (application of knowledge).
2. Design and conduct experiments (laboratory experience).
3. Design systems (engineering design).
4. Solve engineering problems (problem solving).
5. Learn to use engineering tools (engineering tools).

Engineers must be able to do the following professional skills:

1. Function in multidisciplinary teams (teamwork).
2. Understand ethics and professional responsibilities (ethics).
3. Communicate effectively (communication).
4. Understand the impact of engineering on global, economic, environmental, and societal context (globalization).

5. Engage in lifelong learning.
6. Have knowledge of contemporary issues (current issues).

Engineering graduates are expected to have developed these technical and professional skills before graduation. Although many engineers have acquired aspects of these abilities, not all of them mastered all skills in their junior and senior years of college (Shuman, Besterfield-Sacre, & McGourty, 2005).

Despite ABET's (2014) requirements, the competencies have different weights for practicing engineers, the reason why feedback from engineers working in the industry serves as reference for engineering colleges. The analysis and interpretation of the data collected in this study identified the competencies that are important for working engineers and provided useful feedback to engineering education stakeholders. The findings are presented next.

Data Analysis Results

The data analysis identified a mix of experiences and perceptions related to the RQ. Participants expressed their views about the strength of universities in teaching math, science, and engineering fundamentals, as well as universities' lack of focus on practical engineering. Reasons for the poor practical engineering experience were given as ineffective application of knowledge, low exposure to industrial facilities and industrial jobs, focus on research, and faculty members' lack of industrial experience. The participants spoke about their positive experiences during internships as well as their poor experiences or lack of opportunities for internship experiences.

The participants shared their views about the deficiencies in core and professional skills that they considered important to do their jobs. Core skill deficiencies were in the practical application of knowledge, laboratory experimentation, problem solving, engineering design, and use of engineering tools. Deficiencies in the professional skills were in teamwork, communication, and interdisciplinary topics. In addition, the participants shared their experiences with the methods employed toward PD. Some of the training and self-learning methods that the participants used to advance their skills included company training, on-the-job training, self-learning, learning from peers, and PD.

I also explored the generalizability of the findings to the target population of working engineers and concluded that the results might not be generalizable for the following reasons: (a) The sample size was small compared to the general population of engineers employed in the industry, (b) the sample was limited to four engineering disciplines only, and (c) the participants represented a few industrial institutions. Therefore, making grand generalizations about the outcomes to the overall engineering population was not possible. However, it might be useful to test the insights developed in this study in future studies using larger samples of working engineers from wider disciplines and larger industrial outfits.

The participants provided valuable responses to the interview questions that I immediately transcribed and analyzed. Data analysis involved coding and categorizing the data and then developing themes. The main themes and corresponding categories that emerged from the data are described next.

Theme 1: Participants' Perspectives of Overall Engineering Education

Math, science, and engineering fundamentals. The theoretical knowledge provided by U.S. engineering colleges exceeds what is needed to carry out engineering work in any single industry because universities provide a wide technical base for diverse industrial activities. Although college education offers instruction in engineering fundamentals and scientific knowledge, it does not teach or ensure the real-world application of this knowledge sufficiently. It was evident from the interview responses that the participants understood the gap between theory and practice, and recognized that only a fraction of this knowledge is applied in practice.

Kai explained:

> School is very technical and not very applied, and so when I got to my internship, it was about applying the concepts I had learned in school. You learn 100 things in university and then you try to apply may be 20 of them. The other 80 maybe you don't touch on directly.

Universities also teach theoretical solutions that form the base for engineers to build on. As Donh explained, "That's what engineering school taught you well how to do is at least know the textbook solution and show good judgment, gather information, and modify it based on the facts you do know."

Lifelong learning (continuing education). The interviewees indicated that a college education had prepared them to be lifelong learners. Lifelong learning prevents technical obsolescence and provides opportunities for the ongoing development of professional skills critical to the success of engineering careers (Duderstadt, 2010).

Several participants in the study expressed their engagement in lifelong learning to keep pace with societal and technological changes. Gani explained, “Advancement of the technology dictates that we stay on our toes and improve and learn new skills on a yearly basis.”

Shali explained the lifelong learning strategies that she used:

> So that came from a lot of self-training, self-education or a lot of talking to my other co-workers who have been here, sitting one on one, reading books, going online, searching through our internet, our website, doing a lot of hands on learning.

Application of knowledge. Engineering graduates echoed what has been stated in the literature (Male, 2010; Sheppard et al., 2009) that graduates are deficient in the application of engineering knowledge. The participants felt that universities can play a role in filling this gap, but it is unlikely under established curricula and accepted norms for them to provide sufficient practical projects and hands-on activities for students. As Gani explained, “I think that there’s a lack of incentive at a university level to teach practical applications to young graduates that are exiting the program.”

In some instances, participants felt that training will bridge the gap for some individuals, but it is not possible to provide explicit training for each engineering discipline (Sattler, Weatherton, Chen, Mattingly, & Rogers, 2011), especially in the early years of career development.

Data gleaned from the interviews aligned with several important deficiencies cited in the literature (Besterfield-Sacre et al., 2014; Borrego et al., 2010; Duderstadt, 2010;

Felder et al., 2011; Litzinger et al., 2011) that included the low practical application of knowledge. The participants in my study confirmed their satisfaction with the university's teaching of engineering fundamentals but voiced their opinions that practical aspects of teaching engineering fell short of preparing students for practice. Several reasons were expressed in this regard, and two factors stood out: (a) Universities are not focused on engineering practice, and (b) engineering faculty lack industry experience. They noted that universities are tasked to raising funds through research while trying to meet ABET's (2014) accreditation requirements.

Jona, a civil engineer, explained:

> That goes into tenures, tenured professors, right? What is their incentive to really understand what's going on out the real world? If professors at a university are just doing research and they spent all their life in academia, there could be an absolute ... you know. What their world is, is trying to figure out how to get more budget to fund their research or to get tenured. There's really no incentive to teach or align with what the real-world practical aspects will be of a work environment once you get out school. I think that there's a lack of incentive at a university level to teach practical applications to young graduates that are exiting the program.

Sheppard et al. (2009) asserted that most college professors have not worked in the industries where their graduates might spend their entire professional lives. Participants in the current study stressed their dismay at professors who had no practical experience and engaged solely in academic research. When asked how well the university prepared them for practice, Suchi commented, “I don’t think it prepared me very well. I think if I were to scale it, 1 being super-prepared and 10 being unprepared, it was probably like a 4, like I was there, but not really there at all.” Regarding their professors’ lack of industrial experience, the participants were very vocal. Suchi stated, “I think the biggest thing that became clear is that [the] university tends to be people who always worked in academia and never worked in industry.”

Several interviewees expressed that they did not know much about the types of jobs that engineers do or even the types of industries that employ engineers.

Kai, chemical engineer, commented:

> Honestly, I didn’t even know when I was graduating that most chemical engineers go to work for refineries and chemical plants, so we didn’t really get a good understanding of what people do on daily basis or what kind of jobs are even out there for us to consider.

In the industry, engineers might seek work or specialize in broad types of work within an engineering discipline. Mechanical engineers can take positions in such specialized career paths as piping engineer, rotating equipment engineer, manufacturing engineer, maintenance engineer, or project engineer. Engineering professors or a university’s career development department can help students to understand these options within each discipline. Some of the mechanical engineers whom I interviewed reported that they had no idea what areas of the industry engineers work in or specialize in before being employed.

Some of the participants spoke about the learning curve that they had to undergo as they transitioned from college to industry. Understandably, every job requires learning and familiarization, but training is important for all jobs. As Kai explained, “I’m having a huge learning curve, and it’s kind of just starting from Square 1 because I didn’t learn any of this before. And learning about refineries! I didn’t study that in class as well.”

Internships. Internships play a key role in the development of young engineers. Interns are exposed to practical engineering applications, and they have opportunities to work in teams and on diverse projects (Sattler et al., 2011). Interns who are selected by major engineering, production, or manufacturing companies gain valuable experience. Gani stated, “Well, my very first exposure to electrical engineering work in the industry was my internship work with IBM Semiconductors Division when I was taking my second year of electrical engineering coursework.”

Another participant, Nisha, had internships with two major facilities because of her high grade-point average. She explained, “My first internship was at a nuclear facility in Massachusetts, so it’s a nuclear power plant. My second one was at GE, working for their bids department.” Internships give students an understanding of what engineers do and which specialties in their majors are more suited to their career preferences. Gani explained that “and really, it was the internship programs that I’ve been doing since my second year of college that actually prepared me to which discipline of electrical engineering that I should go.”

Another participant, Kai, placed great value in her internship, noting, “Well, I feel like all of the engineering that I draw on for my current position comes from what I learned in that 3-month internship." Some of the participants expressed their pride in their internship assignments. Abd stated, "When I was a student, I actually did internships. One I did in a company called Delphi Automotive, in which I was able to design the airbag sensor." He went on to explain the work that he did during his internship and the great value it had for society by stating, "I was actually designing the material that you put in front of the bumper in which if an impact happens, you sense the temperature. The temperature indicates the signal to go, let the airbag come on."

Most of the participating engineers indicated that their internship programs served as a gateway to the industry and engineering practice. The knowledge that they gained during the internships, especially internships taken early in their engineering programs, helped them to gain a firm understanding of other engineering subjects. Nisha said, "I can tell you that I was not effective at my first internship, but I was much more effective at my second."

Many engineering students do not get internship opportunities, as noted by Gani, who stated, "So that is too specific to my own situation, but in general, there are my colleagues who did not have the opportunity to go to internship." Several participants noted that not everyone can be involved in relevant internships with useful outcomes. Two participants mentioned that some internships end up being summer jobs with little relevance to engineering. As Suchi explained, "I had two internships. One was just as a research assistant. Nothing really related to what we do here."

Theme 2: Deficiencies in Engineering Skills

The engineers expressed their concerns about deficiencies in core and professional skills. In the core engineering subjects, deficiencies were reported in the practical application of knowledge, laboratory experience, problem solving, design, and use of engineering tools. Regarding deficiencies in soft skills, participants mentioned communication, teamwork, and such interdisciplinary subjects as engineering economics and business, and codes and regulations. They did not express any opinions about ethics, globalization, and other current issues included in ABET's (2014) soft skills. The participants addressed deficiencies in ABET competencies that were important to their jobs. Because I did not rank the competencies in this study, findings are discussed next in the order in which they are listed in the ABET guidelines. The technical competencies as practical application of knowledge, laboratory experimentation, problem solving, engineering design, and the use of engineering tools are discussed first. The professional competencies such as teamwork, communication, engineering economics & business, and codes & regulations are discussed second.

Core Skills: Practical application of knowledge. Practical application of knowledge has been a subject of great concern not only to graduating engineers but also to industry. Several participants voiced their discontent with the university's low application of engineering knowledge and low exposure to industrial facilities. Four participants indicated that they did not see industrial equipment, visit industrial facilities, or be exposed to real-world industrial applications before graduation. Although the participants learned about equipment such as pumps, compressors, and heat exchangers, most of them knew equipment only as symbols in books. They were shocked about the physical size of equipment when they visited a refinery or an industrial plant. Suchi explained the deficiency in the practical application gap by stating, “I think that was a huge gap that we had. Then I think even just practical knowledge. We didn’t visit any refineries. We didn’t go to any plants.”

Another engineer, Rebe, expressed her frustration in her first job. She stated, “I was awful at my job for the first year. I’m positive of it.” Kai overcame her frustrations. As she explained, “So you know, just, you get familiar with the requirements of your job. You do it, repetition over and over again. Ask a lot of questions, and that’s the only real training that I had.”

Several other participants reported learning through repetitive practice and relying heavily on peers. Three graduates who had joined engineering companies were shocked about the extent of the design calculations as well as the industry tools, rules of thumb, software used for sizing, and the industry standards that governed the specifications for the design of equipment.

Jona discussed the problem of alignment between education and industry:

> I think programs need to really align their incentives to what industry is looking for. I know this has been talked about quite a bit in the engineering profession, but I really think program…educational programs should go back and look at where their incentives are aligned and do those incentives for the professors aligned with the goals that corporate America is trying to achieve what they need out of young engineers better exiting a program today.

Core Skill: Laboratory experience. Engineering is a profession based on practice, and the instructional laboratory plays an important role in preparing engineering graduates for practice. In the laboratory engineers can design, build, and run experiments as well as analyze and interpret data. However, modern engineering education has tended to emphasize theory and limit practice (Feisel & Rosa, 2005). A properly run laboratory can provide engineering students with valuable practical experience. The participants in the study confirmed the lack of opportunity in their laboratory experience. Two interviewees reported that the laboratory experience was a waste of time; while others did not have anything positive to say about it. The university laboratory equipment was either too simple or did not work at all, and the laboratory tests were conducted by oversimplifying assumptions with the provision of input data.

Suchi, who had graduated from a highly ranked university, stated that the laboratory experience was just a waste of time because the equipment in the laboratory did not work and so there was not much to learn. She explained, “And the labs that we had didn’t work. It is really funny for a privately endowed, really expensive college. Not a lot of things worked in the lab, which is interesting.”

Abd explained that college laboratories use outdated methods, noting, “The gaps that I see in the real world versus the schools are, there are not a lot of labs in which students do experiments that mimic real life experience. They have textbook-based labs.”

Core Skill: Problem solving. The participants had various opinions about problem solving. Although most participants acknowledged having sufficient exposure to problem solving while at university, most agreed that theoretical solutions did not match the competency required to solve real-world problems. Participants claimed that the university taught problem solving using oversimplified examples that were far removed from problems encountered in the real world.

Participants felt that engineering problems solved in the university setting are well defined, with unknowns given or assumed. As Broos stated, “Certainly, you solve a problem in your thermo book or your fluids book, but I feel like it was so divorced from the reality of solving problems.” However, real-world problems are ill-defined, have many unknowns, and require input from many disciplines and resources.

Three participants commented that universities do not teach students some of the tools used by the industry to solve everyday problems. One participant stated even though excel spreadsheet calculations can be a powerful tool in helping to solve engineering problems, he was not taught the depth of the software while solving engineering problems in college. Broos commented, “Something I wish I would have learned more in school is how powerful Microsoft Excel really is for engineering calculations or even just as a sketch pad.” None of the other participants commented negatively on using excel spreadsheet in college.

Core Skill: Engineering design. Engineering design, as defined by Dym et al. (2005), is “a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients’ objectives or user’s needs while satisfying a specified set of constraints” (p. 104). Design engineering is one of ABET’s (2014) required skills for graduating engineers. However, most of the engineers whom I interviewed indicated that they did not have a solid background in the subject other than participating in their senior-year design projects.

Jona described the magnitude of the gap between education and industry on the subject as, “Definitely there’s a gap between when you’re in school getting prepared for design, [then] coming out of school and engineering design.”

Broos, a system engineer in a major company, explained the problem of not seeing the big picture in design by commenting, “How do you engineer a system? Because very fairly, are you engineering just one little part of something, and even if you are, you need to understand how it fits into that bigger system.”

Core Skill: Use of engineering tools. Feedback from the participants about technology use provided some insight into the gap between the software used at the university and contemporary industrial software. Crista explained that even though universities have expensive software, it often does not match the software used in the industry. She said, “I also think they use different software in industry than they do in school, and so I think if they could bridge that gap and both of them could use the same software, it would make the transition easier.”

Nisha, a mechanical engineer who worked for a major company in the United States, also discussed the mismatch between software used at the university and the one that she encountered on the job by noting that “our design software was ProE, but the work that I went to was using CAD, or we used ProE stress analysis, but the work was using ANSYS.”

Universities might not be able to keep pace with technological advancements, so they must continually update new versions of software programs. Naturally, the cost of the professional software continues to rise annually, requiring ever-increasing licensing and maintenance fees. Yet universities can expose students to standard government software programs that are used throughout the industry for design.

Jona, a civil engineer, commented on the basic programs used in engineering design that were not used in the university that he attended:

> What are accepted software programs for completing design? There's a total gap in that, that type of stuff. When I say software programs, these are not private software programs. They're designed by the US Army Corps of Engineers. We're talking about standard governmental programs that are industry prevalent throughout the civil engineering industry for, say, floodplain modeling.

Turning now from the Core Skills to the Professional Skills, the participants strongly expressed the need for such professional skills as teamwork, communication, and interdisciplinary subjects. The responses aligned with recent studies addressing the ranking of ABET (2014) competencies for working engineers. Passow (2012) reported that when graduate alumni were asked which ABET competencies were important in their professional practice, they placed teamwork, communication, data analysis, and problem solving in the top cluster. The experiences and perceptions of the participants about each of these professional skills are discussed next.

Professional Skill: Teamwork. Engineers work routinely with multidiscipline teams that can comprise non-degreed skilled workers, degreed professionals in nonengineering fields, and engineering teams. Although university teaching of interdisciplinary activities has been and continues to be limited to senior projects with classmates assigned in the last year of college, industrial team members are diverse in their levels of education, types of work, ages, ranks, and experiences (Sheppard et al., 2009). Interaction with such diverse teams is essential for completing work assignments or projects.

Broos expressed the importance of seeking answers from others by noting, "Where do you go? Who do you go talk to? Who would know? What do those other disciplines do? Who would have the information that I need?" To get answers to urgent questions, solve problems, or complete projects, real-world team members support each other. Jona explained this interdependence of team members by stating, "Getting out to real-world practice and working in an environment where you have to lean on others to get the job accomplished, lean on, and support others."

Two participants mentioned that young engineers run into problems when working with highly experienced, non-degreed workers who see them as young, inexperienced, and disillusioned by their engineering degrees. On the other hand, young engineers see operators or maintenance personnel as people doing menial jobs. These attitudes can cause problems for young engineers, particularly those who might need to learn the benefit of humility.

Gani explained this point:

> I think coming out of school a lot of people, certainly myself, came out with a very heightened sense of our own skills and abilities, and I had to learn to be

> humble and modest and [realize that] I don't know everything. In fact, I don't know anything. This person who doesn't have a college degree, but has been doing this for 30 years, probably understands the system far better than I ever could.

Two participants explained that proper coaching and mentoring helps young graduates to learn proper attitudes and work ethics, as well as align with team spirit. As Gani explained, "I put a lot of effort in spending a lot of hours with mentors." Mentored engineers are coached during assignments so that they can learn from workers in the field, learn their language, chat with them during lunch breaks, and respect their views and their experiences.

Vija explained how a young engineer ends up supervising more experienced multidiscipline teams:

> I have a chemical engineering degree, I go in, do my training, and then I get appointed as shift field engineer, but then there are plant operators who don't have engineering degrees, but they have been working in process unit for 15 to 20 years. Now, you go in with couple of months of training, you supervise these people with 20 years of experience.

Four participants commented that the professional experience that they gained by interacting with experienced personnel was invaluable. They indicated that universities can help graduating students by giving them assignments relevant to multidisciplinary projects that mimic industrial environments and involve them in real-work team projects.

In summary, multidisciplinary teamwork is more complicated than a senior class team working on one project. It involves working with teams that are diverse in terms of age, experience, academic major, status, level of education, and type of work, as well as rank ranging from labor to managerial levels. Universities can provide some experience by assigning engineers to work with local contractors or in petrochemical plants or factories for a summer, a semester, or some other reasonable time during the school year.

Professional Skill: Communication. Practicing engineers are required to have strong communication and persuasion skills to complement their technical abilities (Trevelyan, 2016). Most of the participants shared the notion that engineers need to communicate effectively not only with team members but with managers, contractors, operators, construction workers, and the public.

Abd, an electrical engineer, explained the importance of written communication by noting, “You have to be able to communicate effectively. You have to be able to actually write in a manner such that a fifth grader can read what you wrote.” Abd elaborated on the reason for using nontechnical language by sharing that “when you are trying to explain a complex idea to upper management, you can’t talk about transistors and process-related stuff. You should be able to transfer that into a common language.”

Verbal communication was another skill expressed by the participating engineers. Broos, a mechanical engineer, stressed the need to develop verbal skills and the ability to explain to management or other engineers verbally in a clear and concise manner, given busy managers’ limited time. He noted, “Okay, I don’t have a whole report written, but I just need to talk to you and get this across quickly and succinctly or even, I have a question."

Kai gave a different viewpoint, addressing e-mail communication and the need to know how to write proper e-mails. He said, "What I was wondering is how do you write the best, appropriate professional e-mail? I would type up my e-mails and send them to my manager, and he would read them and comment."

One interviewee stated that although technical writing is an important skill for engineers to have, some companies hire English majors to do the technical writing, a decision that frees engineers for their engineering work. As Gani explained, "We don't worry about technical writings, to be honest with you. We have teams that are focused on technical writing, and they are from English major, and some other discipline, that actually do the technical writings for us."

I discovered an interesting outlier during the interviews. Engineers who had obtained an MBA degree reported engaging in high level of communication covering team discussions, presentations, and business communication. Suchi explained, "I think my business classes did a better job of that. There was one class which is devoted entirely to just presenting like we had eight or something presentations within a semester where they would record us." She also stated that her engineering classes did not cover communication, noting that "but in our engineering classes, there was nothing, literally nothing, that taught you how to make a presentation, how to effectively communicate your idea, how to talk in front people." At work, she stressed the need to communicate in chronological order, like storytelling, instead of giving bits and pieces of information when talking to upper management, telling them what they needed to know succinctly. She explained that she learned communication from her coworkers.

Professional Skill: Engineering economics and business. Having a solid understanding of economics and business finance is a valuable skill for working engineers. Several participants stated that engineers are expected to prepare budgetary cost estimates, develop business cases for small and/or large projects, and prepare decision support packages. Nisha, a mechanical engineer, explained, “When I was asked to build cost models for my design, that was a bit of an alien concept. Or when the company was talking about why a project would be viable or not viable, I couldn’t understand that.”

Although a course in engineering economics is taught in university, it is normally in the form of theoretical equations, not the bottom-line calculations done in industry. Abd said, “We’ve taken engineering economy, what did we learn? Equations, but we did not take that to correlate into the real-world experience.”

Two participants explained that universities teach engineering economics, but the practice problems are oversimplified, and cost figures are either given or read from reference tables and charts. In the workplace environment, engineers compile cost figures by contacting suppliers, manufacturers, contractors, and licensors. That information is then fed into spreadsheets or cost estimate software to complete the economic analysis. In the university setting, engineering economics is discussed briefly, but it is not given the importance that it has in the real world. Broos explained, “Engineering economic analysis was something that I think we touched on very, very, very briefly, but becomes very important in the real world."

Professional Skill: Codes and regulations. Two participants expressed the need for a university course on codes and regulations. Most engineers are required to comply with local, state, and federal regulations in the design, construction, and operation of industrial facilities.

Jona, a civil engineer, explained:

> There are industry standards, but then there's also codified rules that need to be followed, so from a civil engineer's standpoint by, say, TCQ or the Texas Administrative Code for designing public infrastructure, and then there's a total gap in understanding what the code or regulation for the development is in prepping a young civil engineer for understanding how they are to design and meet codes and specifications.

The regulations are written in legal language that engineers are not versed in. Rebe pointed out that "in the environmental profession and in civil engineering in general, a lot of what you do is reading codes and regulations and rules, it is very legal based profession." She also noted that "interpreting the legal language is not always something intuitive" and suggested that a course at the university would benefit many practicing engineers.

In the absence of structured training at the university level in codes and regulations, young engineers become frustrated not knowing where to start. Jona explained, "Now, I have to meet design standards from the City of Austin for the Lower

Colorado River Authority from Texas Commission on Environmental Quality," and he asks how he would know where to find the rules without prior knowledge of the Texas Department of Transportation. He mentioned, "It took me years to really understand and become proficient in the code of regulations for just the state of Texas." Universities need to provide instruction on code and regulations relevant to graduating engineers.

The interview responses revealed gaps in the overall preparedness of engineers regarding the practical application of knowledge, problem solving, engineering design skills, use of technology, interdisciplinary teamwork, communication, and working knowledge of such essential subjects as engineering economics and business. Exposure to the legal language used in engineering codes, standards, and regulations would benefit all engineers.

Theme 3: Training and Learning for Engineering Competency

Theme 3 captured the training and learning methods that the engineers used to gain practical skills in their early years of practice. The participants identified and discussed the following postgraduate training and learning methods during the interviews. Some engineers received structured training from their employers, whereas others learned on the job. All the engineers engaged in self-training that involved learning from peers, coworkers, and mentors, as well as taking professional courses.

Employer training. Some employers have extensive training programs, and others offer no training. Some employers send their engineers to public courses offered by professional training companies. Other companies offer training geared to the type of work that the engineers are engaged in; they also might offer safety and general training programs. Some employers leave training to the employees themselves. As Rebe stated, “We never had a formal training at all; basically, the only way to really succeed in your career at that point is to be self-motivated and to fail a lot.”

For the engineers in the study, 25% of them (*n* = 4) mentioned that they had received company training. Some companies had very structured and intense training, as was the case with Nisha:

> The training went for 1 full year with about 4 weeks of break total, so 1 week for summer, 1 for fall break, and then 2 weeks for Christmas and New Year’s. We did everything from your basic understanding of the turbines that we were manufacturing on our facility or across aviation so you would learn your basic thermodynamics, performance calculation, and that type of stuff, and then you would move on to different segments of what the engineering teams did, including control work, design work, performance evaluation testing. Part of the instruction also included assembly and disassembly of the equipment that we manufactured because none of us had ever actually seen any machinery at all.

Abd explained that there was a less structured training for fresh graduates joining the company. He stated, “Then also our company has opportunities like fresh out of school kids come in. We pair them with a practicing engineer, give them a little bit of flavor, send them to professional training classes.”

On-the-job training. Three of the participating engineers stated that they went through an on-the-job training program with their employers. This type of training program involves work rotations and classroom training designed for working engineers.

On-the-job learning is performed by the engineers as they learn how to do their jobs, that is, while they are developing skills to do the assigned work. On-the-job training is usually designed to provide broad knowledge and skills about disciplines connected to specific jobs.

Vija gave an example of typical on-the-job training:

> During the initial 3-month period, I got to spend 15 to 20 days each with [the] mechanical department, learning about the various pieces of equipment, exchangers, compressors, trays, columns, all those things. Then I moved on to [the] electrical department, trying to understand what kind of buses and step-down transformers, step up, all those things. Then I went to [the] instrumentation department, learned about various types of control valves, fail open, fail close, safety valves, PSVs emergency shutdown systems, SIL, SIS, all those things.

In this case, Vija was given an induction course and was then rotated to various departments to gain practical knowledge in equipment, electrical, instrumentation, mechanical, safety and control systems related to his work. The 2- to 3-week assignment in each area was sufficient time to help him to understand the connectivity of the work.

Learning from peers and coworkers. Several interviewees stated that learning from peers and coworkers is the most common learning method for new engineers. They said that when new engineers are hired, supervisors put them in touch with experienced personnel who are ready to help, often without reservation. Broos explained that seasoned engineers feel obligated to mentor young engineers and teach them what they know about the job. Two factors enhance the learning process: New engineers' eagerness to ask questions and listen, and the willingness of senior engineers to share their technical knowledge and experience.

The participants stated that experienced workers are ready to help young engineers, but the successful transfer of knowledge depends on the ability of new engineers to approach and learn from experienced engineers. Shali explained the open invitation given to her by other workers by commenting, “Pretty much everyone at Aspen helps each other, but you go to them, and I remember when I first started this job, everyone after they greeted me. They’re like, ‘I'm here to help[with] anything you want.”

Learning from mentors and coaches. Some companies assign mentors and peer coaches to direct new engineers through the developmental process. Mentors are senior engineers who can pass their knowledge and experience on to mentees. Mentors foster supportive relationships that promote learning, social interactions, and development within the work environment (Fletcher & Mullen, 2012). Most engineers work with supervisors and managers, and supervisors might assign mentors to new engineers. They ensure that the new engineers have the resources to do their work; they also assign, direct, and monitor their progress on the job; and they ensure that the new engineers complete their assignments. Supervisors assess the skills of new engineers and assign timely training to develop competencies progressively.

Several interviewees expressed their experience with mentoring. Gani, an electrical engineer, explained his experience as mentor and mentee:

> Yes, I put a lot of effort in spending a lot of hours with mentors. I put a lot of effort and time even before I graduated I was doing a lot of internships with IBM that helped me quite well.

As an experienced engineer who benefited from the mentoring program, Gani was a proud mentor, stating that “and now, I am one of the mentors who mentors newly graduated engineers who come into the workforce.”

Mentors may assess the education gaps of new engineers and direct them to appropriate training activities that reinforces their skills. However, the greatest value of mentoring is lifelong learning and self-reflection upon learning by the engaged mentees (Fletcher & Mullen, 2012).

Self-learning. Perhaps self-learning is the most important quality of new engineers, and it is one of ABET’s (2014) required professional skills, described as “the recognition of the need for, and an ability to engage in lifelong learning” (p. 2). Several of the participants explained their abilities to self-learn and commented that it was the best education that they received from college. Through assignments, homework, and self-study, universities prepared the students for self-learning.

Suchi remarked, “I think what they do pretty well is help us teach ourselves, which sounds really weird to say. But like I think part of university, in college and education in general, is just being able to teach yourself things.”

Participants expressed their commitment to self-learning as a lifelong goal and recognized that technological and societal changes dictate new paradigms and new ways of applying technical knowledge. Kai expressed that her desire for self-learning was to catch up and communicate with more skilled engineers. She said, “I need to back fill my technical, my engineering experience to be able to communicate with others, that's something that I need to develop.”

Jona expressed the need for self-learning to teach himself the skills not normally taught in university, but used frequently in the industry. He commented, “There are software programs like HEC-HMS, HEC-RAS, these were flood plain modeling programs that I had to learn by just getting manuals and learning.”

Writing proper e-mails, making PowerPoint presentations, and scheduling projects are skills required in business communication, but are not necessarily taught in college. Two interviewees spoke about e-mail etiquette and presentation skills. Kai stated, “The e-mail writing etiquette, presenting PowerPoint presentations, those things are also self-taught, at least from my point of view.”

Data Evaluation (Evidence of Quality)

Trustworthiness of the data should be established in qualitative studies. Various ways of establishing the trustworthiness of the findings have been cited in the literature (e.g., Borrego et al., 2009; Creswell, 2009; Stake, 2005). These methods include the use of sound theoretical perspectives, triangulation of the data, provision of thick descriptions of the data, member checking, peer debriefing, and a statement of researcher subjectivity.

Creswell (2009) suggested that qualitative researchers employ reliability and validity procedures to check for the consistency (i.e., reliability) and accuracy (i.e., validity) of their findings. Procedures for checking consistency in this study included reading and checking of the transcriptions for mistakes to ensure that I had typed the participants' statements correctly. I used the constant comparison method to check the codes against the data to ensure that the codes represented the data accurately.

I employed validity strategies to ensure that the findings were accurate from the perspectives of myself and the participants. I used member checking by sending the transcriptions to the participants to check the accuracy of their statements. I used peer debriefing by asking an experienced researcher to review and question my analysis and interpretations of the data. I prepared thick, detailed descriptions of the findings to ensure the internal validity of the data. Finally, I addressed my role as the researcher whose bias might have influenced the interpretation of the findings.

Summary of outcomes from the study

The study addressed the problem that engineering education falls short of preparing graduating engineers for successful entry into the workforce. Many researchers have documented the problem in engineering reports and studies cited in the literature section of this study. The study sought to answer the research question: What are the experiences of graduated engineers currently working in the industry regarding overcoming practical skill deficiencies and bridging the gap between education and practice? It is evident from the results that the problem was sufficiently addressed and the research question was answered. Three major themes emerged from the data:Participant's perspective on engineering education, participant's perceptions and experiences on deficiencies in engineering skills, and the training and learning methods employed by participants to gain competency in the workplace.

In theme 1, perspectives on engineering education, the study confirmed that engineering colleges cover math, science, and engineering fundamentals generously. Additionally, universities provide broad knowledge for wider career choices, and prepare students for self-learning. However, engineering education is focused on research in lieu of practical application of knowledge, and most engineering faculty has limited industrial experience.

In theme 2, deficiencies in engineering skills, the study found shortcomings on both core and professional skills. In the core skills, participants reported deficiencies in the practical application of knowledge, laboratory experimentation, problem solving, engineering design, and the use of engineering tools. On the professional skills, the study identified teamwork, communication, engineering economics & business, and codes & regulations as areas that are not adequately covered in engineering education.

In theme 3, the study identified various methods that participants employed to gain practical skills and develop their competencies. Study participants reported employer training, on-the-job training, learning from peers and co-workers, and self-learning as the means of acquiring the skills needed to do their jobs.

As an outcome of the findings of the study, the next section provides project details that sufficiently address the deficiencies identified in themes 1 & 2 of the study. The program selected for the project is professional development using project-based learning (PBL). The project selected for the PBL is based on student teams engaged in the design of realworld project with the help of instructors that are experienced in industrial work. The learning outcomes for the professional development are designed to cover the core technical skills as well as the professional skills.

Conclusions

For this case study, data collection was based on personal interviews with 15 chemical, civil, mechanical, and electrical engineers. I analyzed the data to explore the gap between engineering education and engineering practice and how the participants managed to bridge the gap with training and self-learning. Thick, detailed descriptions of the interview data were prepared, interpreted, and reported. Three major themes emerged from the study, namely, participants' perspectives of the overall engineering education, deficiencies in technical and professional skills, and training and learning programs that working engineers can pursue to develop competency for their jobs.

Results confirmed the gap between engineering education and industrial practice in the skills critical to engineers entering the workforce. Included in this section were descriptions of the training and self-learning methods used by the participating engineers to advance their technical and professional competencies. Findings suggest that engineering education at the university level might fill some of the gaps with suitable internships, exposure to industrial tools and equipment, and adding practical coursework to current curricula.

This study includes a PD project that will ensure the smooth transition from academia to engineering practice. The project selected to fill the gap is practical PD given at the end of engineering students' last academic year or post-graduation. The objective of the PD is to introduce new engineers to engineering practice and give them an opportunity to apply their knowledge, gain hands-on experience, and participate in a real-world engineering project.

Section 3: The Project

Introduction

According to the study findings, there is a need to fill the gap between engineering education and industry practice for graduate engineers entering the job market. The project that I selected to fill the gap entails offering practical PD at the end of the engineering students' last academic year or postgraduation. Included in this section is information about the description, rationale, literature review, and details of project implementation and evaluation. In Section 3, I also present a discussion of the implications for social change.

Description and Goals

The project comprises 5 days of PD designed for graduating or postgraduate engineers. The sessions cover areas common to most engineering disciplines: chemical, civil, mechanical, and electrical engineering disciplines. This project-based PD combines hands-on work with lectures on topics. In project-based learning, the instructor's task changes from transferring knowledge to facilitating learning (Kolmos, 1996). Each 5-day PD session is equivalent to a 3-hour/week semester course at a public university covering 40 hours of practical training.

The PD will be implemented as a combination of lectures and project work taught by practicing engineers instead of university faculty. The PD will include visits to live production facilities that will be arranged early in the 5-day session. In addition to knowledge and skills development, the PD is intended to change the attitudes and work paradigms of graduating/postgraduate engineers from theoretical to practical application of knowledge. As an introduction to practice for new engineers entering the workforce, the PD will cover the areas of competency deficiencies identified in the study, including engineering design problem solving, communication, teamwork, and economic evaluations, as well as elements of construction and unit operation. After completing the PD, the participants will enter the workforce equipped with knowledge and practice of the main tasks that they will encounter on the job. Participants also will be able to communicate more readily with workers from other disciplines.

The goal of the PD is to introduce graduating students to engineering practice and to give them an opportunity to apply their knowledge and gain hands-on experience in real-world engineering projects. The PD has three objectives: (a) introduce subjects that are important to the industry but hardly touched upon in college; (b) facilitate practical application of theoretical knowledge; and (c) develop professional skills such as teamwork, communication, and interdisciplinary skills.

Rationale

I selected the project based on the analysis of the research data. I found that most of the problems that engineers encounter early in their careers can be addressed in PD conducted before they graduate or immediately postgraduation. In the data analysis, I generated a list of deficiencies in engineering knowledge and skills that can be remedied over time. For example, several participants expressed their lack of awareness of industry codes and standards, simulation tools, shortcut methods, and systems design procedures. They had faint ideas about detail design, engineering economics, and project development. Other engineers stated that they were unaware of what jobs engineers do or which industries employ them. These topics can be covered in sufficient detail during the PD, equipping the participants with an understanding of engineering tools, shortcuts, design methods, and industry jargon. The PD instructors will be engineers with many years of industrial experience who can guide the graduates in project-based activities similar to those encountered in the industry. The PD will cover each area in project application. For example, the participants will work in teams to design process equipment, specify materials, and conduct economic evaluations. They will use engineering drawings, design tools, simulations, and cost-estimating software, and they will engage in group communication and discussion.

Among the project types (evaluation study, curriculum plan, white paper, PD, and position paper) in the project study outline, PD offers the best solution for the problems identified in the findings. I chose project-based learning for the PD to create a team environment for graduate engineers to engage in reflective practice. The project will consist of a conceptual design of an industrial facility requiring completion of engineering tasks such as detailed engineering, selection of construction materials, development of engineering drawings, preparation of equipment lists, development of cost estimates, and assessments of the constructability of a portion of the facility in a team environment. The project teams will be multidisciplinary, comprising chemical, civil, electrical, and mechanical engineers.

The PD will be delivered by practitioner instructors who will be invited to explain the work of engineers and address the participants’ questions. Moreover, the same PD will be available to graduates of the local university, and with a proven success rate, the PD could be offered to other engineers graduating from national universities.

Review of the Literature

The genre selected to address the problem was PD. I based this selection on the results of the study on the deficiencies identified in the literature. I found that graduate engineers lack the practical skills to apply their knowledge, leading to a misalignment between engineering education and industry practice. PD taught by seasoned engineers and practitioners could fill some of the knowledge and skills gaps that I identified in the study. This project-based PD not only is applicable to the problem but reinforces the skills gained in the capstone project that engineering students complete in the last semester before graduation. The capstone programs of the top universities reportedly employ project-based learning and active industry involvement (Ward, 2013).

A recent search of relevant education sites for PD returned a plethora of literature, but most of it addressed teacher education (Blair, 2016; Garet, Porter, Desimone, Birman, & Yoon, 2001; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Yoo, 2016). PD has been in use for many years as a necessary element of educational change. Garet et al. (2001) identified three core features of PD for teachers that contributed to the outcomes: (a) content that enhanced knowledge and skills, (b) content that included active learning, and (c) coherence regarding how experiences aligned with the goals and encouraged communication among the participants. Further, Attenbury (2017) offered suggestions on what to include in the PD: choose PD to address issues identified by the participants; keep a balance between the participant’s desire and other matters that affect the program such as cost, and method of delivery; and envision long-term interactions such as forming virtual communities for sharing knowledge in future (Attebury, 2017). These features of PD will have similar effects for graduating engineers entering the workforce.

In the engineering field, PD has been used in the form of continuing education for working engineers. Continuing education is required for engineers to maintain technological competence, learn new skills, and stay current in their respective disciplines (Kerr, 2010). Various institutions, ranging from professional organizations, private companies, as well as some universities, offer continuing education courses. Continuing education catalogs are available on the sites of such professional associations as the American Institute of Chemical Engineers, American Society of Civil Engineers, ASME, ASEE, and others.

Some organizations offer PD in an array of disciplines. PetroSkills (2016) offered a list of more than 100 types of PD in 16 areas of engineering. These public PD sessions are taught throughout the year in cities in the United States, Canada, and overseas countries. Although the PD sessions are accessible, high tuition and travel costs make them affordable to the few individuals whom employers select for training. The project-based PD will be informed by adult learning theories, engineering education research, as well as teaching and learning methods.

Adult Learning Theories

As adults, graduating engineers bring to the training many years of learning and life experiences (Brookfield, 1986; Knowles, 1984; Merriam et al., 2012; Trotter, 2006). The subject of adult learning has been addressed in the literature. Although many adult education models have been developed, in this section, I address the four main theories relevant to my project that have played roles in adult education: Knowles's (1980) andragogy, self-directed learning (SDL), experiential learning, and transformational learning. Knowles provided the basic assumptions about adult learners in the andragogy theory, in which adult learners are self-directing, bring a reservoir of experience, are ready to learn, are problem-centered and highly motivated, and inquire why they need to learn. Although Knowles's andragogy was criticized for ignoring the context for learning, it formed the conceptual framework for the development of adult education and remains a common adult learning model, along with self-directed, experiential, and transformational theories (Merriam et al., 2007). Based on these assumptions, engineering graduates are adult learners who can engage in this project-based PD.

Adult learners are self-directed, according to Knowles's (1984) assumptions. SDL, using Knowles's description, is "a process in which individuals take the initiative, without the help of others, in diagnosing their learning needs, formulating their learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes" (p. 301). SDL plays a role in the personal development of adult learners. Adults engage in self-learning to seek knowledge or develop skills based on their own time options and preferences. Moreover, they manage all aspects of the process, including setting goals, engaging in the learning process, and evaluating the learning outcomes. However, SDL depends on motivation and persistence as well as context and extant support systems (Garrison, 1997). Because of its importance in adult education, the subject of SDL has been researched. Garrison

(1997) expanded the earlier conceptual foundations of SDL and proposed a theoretical model that combines self-directed approaches into three dimensions: self-management, self-monitoring, and motivational issues. Garrison stressed the need for a comprehensive SDL model extending from the multidimensional model.

SDL applies to lifelong learning, job-related learning, and online learning. In professional practice, SDL is important for practitioners who need to develop their skills to stay current in their respective fields. For example, licensed engineers are mandated to continue learning to maintain their practices. Although engineering schools must develop the foundation and motivation of self-learning during college, as stipulated in ABET guidelines, the engineering profession expects practitioners to be lifelong learners (Merriam et al., 2007). Engineering graduates depend on SDL to develop their professional skills and competency.

Experiential Learning and Project-Based Instruction

The PD in this study will be informed by experiential learning, in addition to the other learning methods mentioned earlier. Experiential learning pedagogy, with its characteristics of learner-centered, active, and engaging instruction, has been recommended for PD (Blair, 2016). Experiential learning is based on the constructivist framework and its assumption that knowledge is constructed and developed through reflection on experience (Merriam et al., 2012). In the learning cycle, Kolb (1984) proposed that learning is the process of creating knowledge through the transformation of experience and indicated that the experiential model links work, education, and personal development. Experiential learning connects job competencies (i.e., real-world work) and educational objectives (Kolb, 1984). Implementation of experiential learning is exemplified by project-based learning, which has been used to enhance active learning and prepare students for practice. The question of whether active learning methods are superior to the traditional lecture format has been answered in the literature (Freeman et al., 2014; Streveler & Menekse, 2017). The biggest learning gains are achieved when two or more learners work together collaboratively (Chi & Menekse, 2015).

Project-based learning encompasses individual learning and collaborative learning (Tilchin & Kittany, 2016) and has been used in all fields of education. Project-based learning is appropriate for engineering education as a method of transferring skills to students in senior engineering classes (Ward, 2013). For example, the capstone project offered to the senior class in engineering colleges is meant to emulate real-world projects that are completed through the efforts of multidisciplinary teams focusing on real projects to prepare students for engineering practice (Dym et al., 2005). The project-based PD used in the current study might be construed as a continuation of the capstone project.

Project-based service learning programs that some students participate in during the college years have been reported to serve as a bridge between practice and education (Huff, Zoltowski, & Oakes, 2016). Huff et al. (2016) reported that the alumni of the Engineering Projects in Community Service (EPICS) gained workplace experiences and developed professional skills during their participation of the program. In a study on project-based service learning, Litchfield, Javernick-Will, and Mau (2016) reported gains in professional skills for engineers involved in service learning.

Project-based learning is suitable when students are working in teams to create products or services within limited amounts of time. In the project-based learning process, instructors might select problems and become facilitators to guide the teams as needed. Team members on the projects collect information through self-directed efforts and work toward solutions (Bagheri, Ali, Abdullah, & Daud, 2013; Kean & Kwe, 2014). Teaching is active and learner-centered, and learning takes place in the group.

Project-based learning is a flexible alternative to the traditional lecture format and has been credited as facilitating the transfer of knowledge gained in one context to new situations (Dym et al., 2005). Efstratia (2014) reported that the success of project-based learning depends on the facilitator's ability to engage the team, ask meaningful questions, structure the tasks, and assess learning outcomes. Moreover, project-based learning requires effective communication and collaboration efforts among the project team.

Several universities have adopted project-based learning as their base strategy to ensure the inclusion of practice (Edström & Kolmos, 2014). The University of Aalborg in Denmark and Worcester Polytechnic and Olin College in the United States are examples of colleges that strive for inclusion of practice in the curriculum. Aalborg University in Denmark was the first institution of higher education to offer fully integrated project-based learning (Edström & Kolmos, 2014). The Aalborg premise is that project-organized education is multidisciplinary by nature, addressing the design-oriented education that deals with the "know-how" and the problem-oriented education that deals with the "know-why" of a subject.

Other universities have developed full programs based on project-based learning. Crawley et al. (2011) developed a program based on CDIO. In this program, students use equipment and systems to cover the full cycle of work encountered in engineering practice: where engineers conceive, design, implement, and operate facilities to develop products. CDIO uses 12 standards of effective practice using project-based learning, and it has been implemented at MIT for its aerospace programs and has been adopted by other national and international engineering colleges (Crawley et al., 2011). The program is conducted in collaboration with industry, uses integrated project teams, employs hands-on projects, and assesses the outcomes.

Experiential learning pedagogy is best implemented through project-based learning. The PD training developed for this project will use best learning and teaching practices recommended in the literature. The PD will include a visit to an industrial facility where learners can spend a day seeing, hearing, feeling, and touching equipment and carrying on discussions with engineers and operators who work in the field.

Transformational Learning

Transformative learning changes the ways that individuals view themselves and their world. Mezirow (2003) stated, “Transformative learning is learning that transforms problematic frames of reference, sets of fixed assumptions and expectations (habits of mind, meaning perspectives, mindsets), to make them more inclusive, discriminating, open, reflective, and emotionally able to change” (p. 58). When individuals reflect on their assumptions about the world, they might experience shifts in their frames of reference. Mezirow explained that transformative learning requires the critical reflection of assumptions. With prompting, adult learners self-reflect and exercise thoughtful judgments; the goal of adult education is to help them to develop “the skills, insights, and disposition essential for their practice” (Mezirow, 2003, p. 62)

For engineering students entering the workforce, the change from gaining theoretical knowledge to applying this knowledge on the job will require a transformation of their familiar learning process. I designed the 5-day PD to promote active engagement in the learning process by focusing on the application of knowledge. Graduate engineers must question, discuss, and understand how to apply engineering principles in the design, construction, and operation of facilities. Participants need to engage in reflective discourse and have accurate information about the subject of discussion (Mezirow, 2003). Engineers need accurate information and data to ensure the proper design and operation of equipment and facilities. The PD instructors will promote these concepts and ensure that the participants gain an understanding of applied engineering practices.

Engineering Education Research

A wide range of studies and reports dating back to the 1980s informed this project. Many researchers recommended the promotion of practical experience in engineering pedagogy to narrow the gap between education and practice (ASEE, 2012; Carberry, Lee, and Swan, 2013; Duderstadt, 2010; Litzinger et al., 2011; NAE, 2004; Sheppard et al., 2009). Although there has been consensus that engineering education should shift the focus away from theory and toward professional practice, the process to find a solution and agree on its implementation has not been easy (Sheppard et al., 2009). Researchers on the subject have addressed topics such as adopting active teaching and learning methods, transforming the curriculum toward practice, adding professional subjects, and improving assessment methods.

Research efforts toward the addition of engineering practice related to my PD project can be categorized as (a) research on education reform and the inclusion of engineering practice, (b) research on teaching and learning methods to bridge the gap, and (c) work on project-based learning to prepare students to undertake professional work. Research on engineering reform established the justification for this study. Moreover, studies on teaching and learning methods, along with the work on project-based learning, formed the basis of the PD.

Many researchers have addressed the gap between engineering education and practice and have recommended improvements in curriculum content, teaching and learning methods, and the inclusion of engineering practice (ASEE, 2012; Duderstadt, 2010; Felder et al., 2000; NAE, 2005; Sheppard et al., 2009). Sheppard et al. suggested improvements to the current engineering model and offered recommendations to improve engineering education pedagogies, including strengthening the principles and concepts and learning how to use them, building better problem-solving skills, engaging in professional practice in the classroom, and teaching inductively. Sheppard et al. affirmed that the undergraduate curriculum is overcrowded, making it difficult to add any new courses. The ASEE (2012) recommended curricular changes that reflect the practical, multidisciplinary, and collaborative nature of engineering practice. Lattuca, Knight, Ro, & Novoselich (2017) recommended promoting interdisciplinary skills for engineering students and pointed to make use of the curriculum to promote interdisciplinary competence.

In 2005, the NAE presented a comprehensive report on the status of undergraduate engineering education in the United States and recommended enriching traditional curriculum content with teachings that would support innovation, communication, professional practice, and globalization. The NAE suggested an undergraduate degree is not adequate to prepare students for engineering practice and recommended adopting a master’s degree as the professional degree. Duderstadt (2010) urged adopting a practice-based master’s program staffed with faculty members who have extensive practical experience, arguing that doing so would eliminate the problem of overburdening undergraduate programs. This strategy, however, will require educational policies that are not on the horizon. A change of educational public policy calling for the addition of a professional degree must be justified in terms of added value and cost to students and families (Duderstadt, 2009).

Other researchers described similar scenarios, leading to initiatives to overhaul engineering education. The ASEE (2009, 2012) identified curriculum content, instruction, and assessment as the main elements of change. The ASEE has suggested indicated that the best learning concepts and teaching practices are currently available but are dispersed throughout the literature and should be replaced with a shared knowledge base driven by research and scientifically proven practice. In response to calls for change from industry professional societies and educators, ABET established a new criterion that changed the basis for accreditation from teaching inputs to learning outcomes (as cited in Passow, 2012).

Engineering scholars have agreed on the benefit of practical learning, but keeping a balance between content and hands-on projects has been difficult. Most educators have suggested moving reciprocally between practice and content and emphasizing practice in the curriculum as early as the possible (Bass, 2012). Offering PD in the last semester of college or post-graduation might solve some of these conflicting issues and ensure a smooth transition to successful employment. The PD that I developed for this study will use research-recommended teaching strategies to convey the material.

Effective Teaching Methods

Felder et al. (2000) addressed the teaching methods that are effective for engineering education. Suggested methods included formulating and publishing clear instructions, establishing the relevance of course material and teaching inductively, balancing concrete and abstract information, promoting active learning, using cooperative learning, giving challenging tests, and conveying concern about students' learning. Felder et al. provided a description, recommendation, and justification for each of these methods.

Most of the research on adding practice to engineering education has focused on project-based learning methods using group efforts. Finelli, Daly, and Richardson (2014) stressed the adoption of effective teaching practices in engineering education. They used student teams and real problems to develop institutional teaching plans to improve teaching practices. Gonczi (2013) reviewed the competency-based approach to professional education and assessment. He addressed issues relevant to teaching and learning and recommended the integration of theoretical knowledge and practical application. This integration would mean the “growth of cross-disciplinary teaching, problem-based approaches, the use of case study approaches and simulations, project work and the use of portfolios to gather evidence” (Gonczi, 2013, p. 1302).

In addition to these teaching methods, the PD may be structured to use some currently effective teaching practices. The current trend in engineering and science education is to use the flipped, or inverted, classroom method. In this strategy, traditional work in the classroom and home settings is inverted so that the lecture is delivered in the form of a video lecture that students watch before they come to the classroom. In class, students engage in such learner-centered activities as problem solving, concept understanding, and other interactive activities that require the instructor to act as a guide (Velegol, Zappe, & Mahoney, 2015). Researchers have indicated that the inverted classroom approach improves concept understanding, problem solving, and student interaction because of the active engagement of students in the classroom (Schrlau, Stevens, & Schley, 2016). Recommendations for effective flipped classroom instruction include a 10-minute video lecture, which is short enough to ensure sufficient time for class activities, and the addition of real-life applications (e.g., trips, guest speakers, discussions, or projects) of the course content (Velegol et al., 2015). Several researchers have shown that the flipped class method have achieved higher scores than the traditional style (Cotta, et al., 2016). However, the flipped classroom method was reported to give similar efficiency as the team-based learning methods (Nishigawa, et al., 2016).

Learning and Teaching Skills Developed Through Project-Based Learning

Project-based learning is intended to align with professional practice (Edström & Kolmos, 2014), and it has been used in teaching design engineering, which has been the central goal of engineering education (Dym et al., 2005). In undergraduate education, design knowledge is transferred to students during the cornerstone and capstone design projects. The skills and experience gained through these projects can be used by graduate engineers during the PD to build more expertise in engineering design.

Improvements in the teaching methods pertinent to engineering education also have been addressed in the literature. For example, engineering researchers have suggested that inductive methods should be adapted to teach engineering (Besterfield-Sacre et al., 2014; Duderstadt, 2010). These inductive methods could include project-based learning, internships, and laboratory exercises (Litzinger et al., 2011). The project-based method of teaching and learning engineering will inform this PD training and will be adapted to build the knowledge and expertise of engineers entering the job market.

In summary, I tailored the project-based PD in this study to facilitate the rapid transfer of practical knowledge to new graduates to ensure their smooth entry into the job market and to equip them with readily usable skills. Participants in the PD will have practice in reading engineering drawings, designing equipment, learning and applying industrial codes and standards, learning about engineering economics, and developing their skills in communication and teamwork.

Project Description

Implementing education and training programs such as PD requires planning and coordinating them with participants, stakeholders, and support groups (Caffarella & Vella, 2010). The PD will require prior arrangements and coordination with the sponsoring university, industrial partners, instructors, and other engineering practitioners that will support students during the PD. Planning includes identifying program objectives, designing instructional plans, specifying evaluation methods, and choosing a suitable facility. Selecting and sourcing instructional materials, computer equipment, and software should be arranged ahead of time.

The PD, titled "Preparing Engineering Graduates for Practice," employs project-based learning; participants will engage in the conceptual design of a facility. PD activities will involve the design of an industrial facility requiring the completion of such engineering tasks as sizing major equipment; selecting construction materials; developing engineering drawings; preparing equipment lists; developing cost estimates; and constructing a portion of the facility in a teamwork environment. Experienced practitioners will guide the participants through the PD and help them complete the project. The PD instructors will provide prerecorded lectures on topics that are important in the workplace but are not covered sufficiently in college courses.

The project requires the approval of the sponsoring university, engineering faculty, and industrial partners. I will prepare a PowerPoint presentation of the project, and send a copy of the project document to the engineering faculty and industry representatives for their review and comment. Approval and agreement from the stakeholders will signal implementation of the PD. The next step is to invite training instructors, organize the learning resources, schedule the course venue, and arrange for facility visits for the participants.

Potential Resources and Existing Supports

The PD can be completed before graduation using existing resources and with the help of engineering practitioners and industry collaboration. The PD will be offered at the university for graduating engineers and open invitations will be e-mailed to newly employed engineers in the local industry. In this case, the engineering faculty will arrange the venue for the PD, training supplies, faculty advisors, administrative support, and library resources. Because the relationship between industry and university exists, the faculty can easily arrange industrial visits and request that experienced engineers guide student tours. Engineering faculty will collaborate with industry partners to arrange practitioners to teach portions of the PD and organize visits to their industrial facilities. Trainees should converse with practicing engineers, examine industrial equipment, and use industry tools during the PD.

Candidates for the PD will be graduating engineers and newly hired engineers working in the local industry. Over the long term, after gaining positive feedback, the PD might be offered as an independent public course, as part of other college seminars, or as professional societies' continuing education efforts. Potential sources of support are engineering professors at the university, engineers from the industry, and the industry itself. The outcomes and practical benefits of the PD will be clearly communicated for attendees to envision their value. Marketing efforts will be required to convince university administrators to accommodate the project, but as the value of the PD becomes more evident, other local institutions are expected to adopt the training voluntarily.

Potential Barriers

The ideal venue for the course is a large university that is willing to have the PD delivered to senior engineering students before graduation. The first barrier facing the project is whether faculty and students agree on PD that will take 5 days. The timing of the PD becomes crucial for graduating students, given other school or work commitments.

Another potential barrier is finding a willing industrial partner. One requirement of the PD is that participants must visit a production facility such as a refinery, a chemical plant, or industrial complex where they can see, feel, and touch equipment and talk to working engineers, operators, and designers. Although there are many of these facilities in the local area, facility managers likely will be concerned about the safety of the visitors and the potential for litigation in case of injury during visits. Plant visits might inconvenience personnel and management.

A third barrier might be resistance from administrators of the local university because of the potential cost of the PD. Attendees from outside the university can participate for a fee to cover all expenses, including advertisements, instructor payments, and accommodations. The PD could be offered as a workshop at one or more of the annual conferences of professional organizations such as ASEE, American Institute of Chemical Engineers, or ASME.

Proposal for Implementation and Timetable

The PD might start as a pilot training seminar offered free of charge to graduating engineers. Feedback from attendees will be used to restructure the PD to fulfill the research objectives and provide value to the participants. In a subsequent step, a full version of the PD will be conducted at a local university for its graduating engineers, with feedback from the first group of engineers being incorporated into the PD to improve it. The PD sessions over the 5 days will start at 7:00 a.m. and finish at 5:00 p.m., with coffee and lunch breaks being scheduled each day. The PD will have two parts, namely, a lecture portion delivered by the instructors and a project version for student implementation. The overall schedule of the PD is shown in Table 3. A detailed time line for the lecture portion and the project activities portion appear in Tables A1 and A2.

Roles and Responsibilities of Students and Others

The project stakeholders will include participating students, training instructors, supporting engineering practitioners, PD organizer, and university faculty. The roles and responsibilities of each stakeholder follow:

- Role of students: watch daily lectures video, attend morning instructions, work in teams and complete scheduled project work, prepare end-of-day reports, give team presentations at the end of the PD, and complete evaluation survey.
- Role of instructors: prepare course content; present training schedule; organize daily course instruction; facilitate project activity; be a resource to the teams; arrange outside resources as needed; ensure that engineering tools,

simulation software, and reference materials are available to students; and announce lunch and coffee breaks.

- Role of engineering practitioners: act as subject matter experts for the group, direct teams to use appropriate tools, advise students during project execution, and support instructors to lead the teams to complete the project.
- Role of program organizer: arrange training equipment; supplies for coffee and lunch; select the proper venue for the course; arrange transportation for stakeholders attending the PD; and send invitations to chemical, mechanical, civil, and electrical engineering practitioners as well as safety and environmental specialists.
- Role of university faculty: arrange industry support and sponsorship of the PD, arrange group facility visit, and solicit engineering practitioners to participate in the project as support or as instructors.

Table 3

Overall Project Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
7:00	Introduction; daily plans; resources; engineering principles and ethics; health, environment, and safety topics	Engineering codes & standards, regulations, conceptual design (feasibility studies, front-end engineering design (FEED), economic evaluations.	Detailed engineering design, systems engineering, design criteria; rules of thumb	Material selection, control & instrumentation systems, special topics for engineering disciplines	Project management: project schedule & budget; project implementation: constructability study and construction activities; facility operation: operation, maintenance, and inspection
9:00	Project activities (see Table A1)				
10:00					
11:00					
12:00	Lunch				
1:00	Project execution activities				
2:00					
3:00					
4:00	Teams: Daily reports and next-day plans				Team presentations
5:00	End	End	End	End	End

Project Evaluation

The overall goal of the assessment is to determine whether the PD will add significant value to the practical application of knowledge and provide the quick transfer of knowledge on topics that are important to the industry but are barely touched upon in education. The evaluation should show significant shift from student view to practitioner outlook. Feedback from the participants should confirm that the PD achieved the learning objectives, met content expectations, and suited the participants’ schedules, and that the instructors were qualified and efficient in their delivery of the material.

The evaluation process will determine whether the predetermined PD outcomes were met. Program evaluations can involve the collection of formative or summative data. Formative evaluations are used to improve or alter programs while they are in progress, whereas summative evaluations are used when the focus is on program outcomes (Lodico, Spaulding, & Voegtle, 2010). In this project, summative data will be collected to measure the outcomes and their relationship to the overall objectives of the PD (see Appendix C).

A summative evaluation will identify the perceptions of the participants indicating whether the PD met their expectations. In this assessment, the participants will complete a 5-point Likert-type summative evaluation at the end of the PD based on their opinions about the course content, instructors, and the length and the timing of the PD. Participants also will be asked to suggest any additions or deletions to the 5-day PD.

The target audience for the evaluation will comprise sponsoring university faculty, local employers in the industry, PD instructors, and the participating engineering students. The evaluation will be distributed to the key stakeholders, including the university faculty who support the PD, local industry partners, and the instructors who are teaching the PD. The PD is expected to meet the following learning outcomes:

- Apply engineering knowledge to facility design.
- Design industrial equipment.
- Follow the design criteria, rules of thumb, and shortcuts used in industry.
- Apply engineering codes and standards.
- Use engineering tools and software.

- Prepare engineering drawings.
- Understand how to select piping and construction materials.
- Understand control systems.
- Apply engineering economics.
- Communicate with teams effectively.
- Understand health, environment, and safety issues.
- Communicate constructability issues.
- Understand facility operation.
- Apply data collection, analysis, and reporting techniques.

Performance measures for the PD include completing the project promptly; using engineering tools to design the facility and perform calculations; and using shortcuts, practical skills, teamwork, and communication skills to complete the work. The last step in the PD is to use suggestions in the student evaluations to improve future offerings of the PD. Evaluation results will be discussed with the instructors and faculty to improve the PD. I am also planning to ask the PD participants to share their contact information with the intention of following up with those who provide the contact details.

Implications for Social Change

Local Community

This PD project might be implemented at one of the local engineering universities in Texas that has an engineering program. Several universities with established engineering programs are within an hour’s drive of my home. I plan to implement the project in one of the two historically Black universities in the nearby Houston vicinity.

The university has had proven success in educating students from the underserved community and claims to be one of the schools graduating minority professionals in Texas (Quddus, Quazi, Williams, & Langley, 2006). The engineering college at this university has six undergraduate engineering programs, including chemical, civil, electrical, and mechanical engineering. The PD will provide graduating engineers with a understanding of industry practices, along with skills that they can use in their first jobs. The university will have a proven practice-oriented program for the next generation of graduates. The PD project will help students express their new skills to prospective employers, subsequently elevating their chances of employment in the Houston metropolitan area. Employment in the engineering field will bring income to the area and will further boost the local economy.

Far-Reaching Effects

In the larger context, results of the study confirmed the need for PD that bridges the gap between engineering education and industry practice for the benefit of engineering graduates and the industry that employs them. The PD will be presented to other universities so that they can consider offering it to their own graduating classes. The PD will save money and time for local employers and graduates. It will contribute to safe engineering designs and minimize engineering accidents. Graduate engineers who participate in the PD will gain knowledge to seek the information that they need to perform engineering tasks safely and efficiently.

This case study contained the views of 15 working engineers regarding the gaps in engineering education and identified what engineers need to know when they graduate from university. The study offers a solution to the problem in the form of a PD project. Once implemented, tested, and evaluated, the project could be adopted nationwide.

Conclusion

Section 3 provided information relevant to the description of the PD, the rationale for implementation, the literature review, implementation procedures, and the evaluation protocol. The section on project implementation contained details about potential resources, barriers, timetable, and the roles and responsibilities of the stakeholders. The project fills a gap in engineering education and gives graduates a smooth transition to engineering practice. With the readily usable knowledge and skills gained in the PD, graduating engineers are likely to experience more successful interviews, quicker employment, and easier assimilation with working engineers than graduate engineers who did not take the PD.

Section 4: Reflections and Conclusions

Introduction

The early PD of engineers entering the workforce provides timely preparation for practice and increases their opportunities for employment and the potential to make immediate contributions to their new employers. In addition, project-based learning such as PD can be an extension of the capstone projects that they completed in their senior year and reinforce experience already gained. Project-based learning ensures active involvement in activities relevant to projects that require the use of industry design tools, vendor data, and calculation methods, all of which are routine in engineering jobs. Participants in the PD will be involved in process design, problem solving, equipment specifications, material selections, cost estimations, and implementation of the project. Participants will work in teams, communicate with each other and with members of the industry, and present final reports.

Project Strengths

A key strength of the project is that the PD addresses the study’s findings by implementing proven teaching and learning methods facilitated by experienced instructors. Because I found that integral workplace topics such as codes and standards were not covered in college, the project includes a component in which participants are required to look up the Texas Code and similar regulations. Because I also identified gaps in the practical application of the theoretical knowledge, PD will be implemented in a project-based format ensuring hands-on practice for the participants. The project includes a field trip to a refinery where participants can see live industrial equipment. I also found that engineering design is not adequately covered in college; therefore, project participants will engage in the designing of a real facility during the PD. Additionally, the PD will cover other deficiencies I found by including teamwork, problem solving, and communication.

The project covers topics largely ignored by university curricula such as health, environment, and safety, all of which are of importance in the workplace. Engineers are expected to apply safety in design and material selection, carry out hazard and operability analyses, and use safety systems to protect the workers' health and workplace environment. The PD also will include instructions on constructability and facility operations, as well as data collection, analysis, and interpretation.

The PD will use relevant research-based teaching methods such as project-based learning (Chua, Yang, & Leo, 2014; Velegol et al., 2015; Ward, 2013), flipped classroom (Schrlau et al., 2016), and active participation to prepare graduates for the workplace. Although professional practice will be emphasized in the PD, the PD will move reciprocally between hands-on activities and content, as suggested in the literature (Bass, 2012; Trevelyan, 2016). Participants will use engineering tools and industry data to execute the project in a team environment. Instructors with significant industrial experience will conduct the PD. Engineering practitioners also will help the participants complete the project within the 5-day PD period. With the help of these experienced engineers, the PD is expected to satisfy some of the knowledge and skills gaps identified in the study.

Recommendations for Remediation of Limitations

The first limitation of the project is that a 5-day PD might not be long enough for some of the participants. To cover the full content of the PD and complete the project, participants must work at a fast pace, which will be adequate for some but too cramped for others. The second limitation is that the PD will be implemented in one local university, even though many engineering colleges graduate engineers every year. My long-term objective for the PD is to expand it to other colleges based on its initial success. The third limitation stems from the diversity of engineering disciplines (Trevelyan, 2016) and the realization that the PD might not cater to the 17 major engineering disciplines stated in the engineering education research taxonomy (Finelli, Borrego, & Rasoulifar, 2016). The limitation regarding the duration of the PD could be minimized by establishing networking between the instructors and the participants and providing them with sufficient reference material.

Ameliorative actions for the second and third limitations would depend on the extent of adoption of this PD. Based on a survey of awareness and adoption rates of engineering innovations, Borrego et al. (2010) reported high awareness of 82% and low adoption rates of only 47% for active learning methods. However, these adoption rates might be realistic for this PD only for the local university. In this case, the PD will be expanded to the local engineering colleges. At the same time, each engineering college will modify the PD based on the engineering disciplines in its own program.

The problem also might be addressed in several other ways. For example, PD topics might be incorporated into the senior-year curriculum, with engineering practitioners invited to teach industry-related topics. Alternatively, the university might arrange with a partner to allow the PD to take place at an industrial facility. The participants can work on real projects while interacting with experienced engineers as they work. Another option is to convert the PD into a semester-long seminar for the senior class, where subject experts from the industry are invited to teach portions of the PD. It is also possible to collaborate with the industry to teach the PD either as one of the public training courses or as an in-house training to new engineers. However, the PD is intended to benefit all graduates and help them find jobs or succeed in their jobs. The industry serves their workers only.

On Qualitative Scholarship

Qualitative research data on engineering practice have been scarce (Trevelyan, 2016) because quantitative methods of data collection and analysis dominated engineering research in the past. However, many researchers have called for the use of qualitative methods to expand engineering enquiry and provide in-depth answers (e.g., Borrego et al., 2009; Case & Light, 2011; Koro-Ljunberg & Douglas, 2008). Although engineers who are accustomed to using the quantitative method believe that qualitative data collection, coding, and analysis are difficult, engaging in qualitative research has been a learning experience for me. My objective in conducting this study was to identify, study, and resolve the local problem with honesty and integrity. The qualitative method proved to be suitable to meet these objectives.

I developed an appreciation for the qualitative case method as I interviewed the participants and found the process of data recording, transcribing, coding, and analyzing to be a time-consuming and sometimes difficult task. Throughout the journey, I reflected not only on the change in my scholarly thoughts but also on the learning progression from the literature search to the development of the methods, data collection, and final PD project. Regarding my personal scholarly development, I believe that the transformation from my starting position to the present has been remarkable. The skills that I gained throughout the process have been and will continue to be invaluable to me.

Project Development and Evaluation

The project development has been a learning experience for me. Given that the criterion for selecting the project was to provide a solution to the problem, the PD project should be implemented with existing resources. In the process of developing the project, I learned to identify resources, obstacles, and possible objections during implementation. I gained an appreciation of the importance of reviewing the literature to confirm the selection of a suitable project as a solution to the research problem. I learned to prepare the curriculum, the schedule, and the resources. However, the long-term success of the PD will depend on the arrangements made for its execution and the level of involvement of the stakeholders. This part of the process was a learning exercise and will prepare me for educational practice. Despite the thoroughness of the plan, the success of the PD is not guaranteed, nor will all tasks run smoothly (Caffarella & Vella, 2010). The success of the PD should be assessed at the end of the 5 days of training. I included a summative evaluation survey to compare the objectives and outcomes of the initial offering of the PD.

Leadership and Change

Leadership requires the inclusion of all stakeholders who have an interest in the project. No single leader can carry the burden of change alone (Hallinger, 2003). I have learned that leadership requires not only the support of institutions and individuals but also collaboration with other professionals. The PD project will require the support of educators, employers, and professional societies. The project calls for 5 days of PD, which represents change from the university's regular class schedule. The request to change the university work process, as well as the provision of resources, will cause resistance. This is where leadership becomes important because persistence is required to gain support from others.

Analysis of Self as Scholar

Before enrolling at Walden University to pursue my doctoral degree, my scholarly research experience had been limited to an experimental thesis study completed during my master's degree in chemical engineering. Following graduation, I entered the workforce and had some opportunities to perform work-related research that did not require scholarly writing. Completion of this study expanded my research and writing abilities.

In regard to the literature review, the search for relevant scholarly and peer-reviewed articles was initially challenging but eventually rewarding. Even more demanding was the exercise of selecting, summarizing, and citing peer-reviewed articles. In the process, I gained respect for the work of others and learned how to give credit when borrowing the ideas or words of other researchers. I gained writing skills to avoid plagiarism. I also developed an appreciation for the qualitative case study methodology, which taught me how to conduct individual interviews and collect, analyze, and interpret interview data for the first time in my professional life. Writing the study was the most time-consuming and sometimes most frustrating experience in this journey, particularly because English is neither my native language nor my first foreign language.

Personal strengths gained as a scholar included becoming a persistent, goal-oriented, and critical thinker. The doctoral program also confirmed that adults can learn throughout the lifespan. I have been engaged in lifelong learning for more than 30 years. Equipped with the fundamentals in education and skills in educational research, I am now prepared to take a leadership role in adult education or engineering education and contribute to experiential learning opportunities that can prepare engineering students for professional practice.

In the future, as an educator, I plan to educate adults in my area of expertise, mainly in the engineering field and specifically in chemical engineering. Chemical engineers participate in the design, construction, and operation of petrochemical facilities, and without proper training, engineers can expose field workers and members of the community to the dangers of fire, explosion, toxins, and environmental pollution. Therefore, it is imperative that engineers develop sound practices and not be rushed from university to the industry without having the requisite skills of engineering practice. Long before enrolling in this program, I mentored, trained, and supervised recent engineering graduates, and I spent time improving their abilities to learn and assimilate into the workforce. Engagement in this project gave me the time, the background, and the tools to develop a structured PD that meets the requirements of new engineers entering the workforce.

Analysis of Self as Practitioner

As an adult, I joined the doctoral program at Walden University after having practiced successfully in engineering for more than 2 decades. As a result, I brought with me the basic scientific and engineering knowledge, professional skills, and attitudes necessary for problem solving. I am pleased to add educational research practitioner title to my experience.

As a research practitioner, I became aware of the opportunity to effect social change and solve some of the problems in the areas of teaching and learning. Schön (1984) described professional practice as the process of problem solving. As a research practitioner, I also have taken the first steps in this project to propose a solution to a local problem and hope to solve more problems that face my communities. Practitioners confront problems arising from the situations in front of them and reflect on actions to work toward solutions (Schön, 1984). Thus, I became a reflective practitioner who used critical thinking and reflection to solve a problem.

The engineering profession lent me the ability to execute work, solve real-world problems, and lead multidisciplinary teams in several large companies. As a member of teams implementing large projects that benefit communities, my job was professionally and financially satisfying. However, my dream was to earn a doctoral degree so that I could teach later in life; thus, it made sense to me to pursue a doctorate in education instead of engineering research. I wanted to continue earning while learning, a desire met by Walden University's online programs.

Even though I practiced engineering successfully in various capacities in the past, receiving a degree in education has taught me what I need to be an effective educator. I learned about teaching and learning methods and theories, along with educational research methods, and I engaged in research that produced a project ready for implementation. I am still a novice in this field, but I have developed an appreciation for my ability to design learning programs, write curriculum content, specify learning objectives and outcomes, and conduct evaluation research. I am prepared to use best practices in research and use proven learning and teaching methods after graduation. My plan is to put this knowledge into practice to engage in research and teach at the university, community college, public school, or industry level.

Analysis of Self as Project Developer

I developed a 5-day PD for the project. I learned to conceive a project, develop a detailed plan for execution, prepare PD objectives and outcomes, and prepare implementation and evaluation plans. The PD will require resources, support, and the sponsorship of individuals and organizations. As the developer of the PD, I understood the challenges and obstacles to overcome for the project to succeed. It is important to seek project support from the stakeholders as well as understand the needs of the audience and the willingness of the supporters to sponsor the PD. Above all, the project should add value to the local community and advance education.

Project's Potential Impact on Social Change

I confirmed the gap identified in the literature between engineering education and practice. The 15 working engineers identified deficiencies in their skills after graduation. Based on the findings, I developed this PD project to increase the skills that new engineering graduates need as they enter the workforce. The results will contribute to the current educational literature, and the efforts put into completing this study will be reaped upon implementation of the project.

The graduating class will be prepared to add value to the success of their employers and the community in their first jobs. Knowledge and skills gained will improve the local economy for two reasons: the high salaries of employed engineers will boost the local economy, and skilled engineers will increase the production of economically and safely manufactured goods and services. In addition, the university will have a convenient PD available to implement for its graduates every year.

Implications, Applications, and Directions for Future Research

The gap between engineering education and practice has been widening for decades, and efforts to narrow the gap have been unsuccessful (ASEE, 2012; Duderstadt, 2010). However, progress has been made, and such efforts should continue to add practical skills to engineering education. This PD project makes a contribution toward the inclusion of practice in engineering education.

Future studies should include participation of more discipline-specific engineers in the study. The engineering taxonomy comprises 17 major disciplines (Finelli et al., 2016), and not all groups could be included in the study. Only four disciplines were represented; other disciplines such as bioengineering, aerospace, and marine engineering were not represented. Future scholars should expand the list of represented disciplines. Moreover, interviews with university faculty, graduating engineers, and local engineering managers will strengthen the findings and streamline or amend the content of the PD.

Future work also might mean other improvements or extensions of the PD to other institutions. Initially, the PD will be adopted by the local engineering college as a bridge between education and practice, but the PD could be offered to all engineers, including university graduates, newly hired engineers, and engineers who are either unemployed or are working for nonengineering positions and wish to refresh for new employment. The PD also could be added to the curriculum of any engineering college and could be offered before graduation. Training duration and content could be modified to suit university calendars and available resources. The training topics also could be assimilated into engineering programs. Finally, the PD could be adopted as it is or modified to fit the needs of other professional programs that might be interested in joining in the future.

Conclusion

The project fills a gap in engineering education because it provides educators and industry partners with a vehicle for helping graduate engineers to transition from theoretical education to the practical application of knowledge in the field. Engineers who participate in the PD project will have more opportunities for successful employment and early contributions to the industry and society. Implementation of the PD project at the local university is expected to demonstrate early successes that can be shared with other colleges in the United States. The development of the project has fulfilled my dream to contribute to the solution of a problem that has persisted for decades.

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Appendix A: The Project

Training Title: Preparing Engineering Graduates for Practice

Objective: The proposed training is project-based professional development course designed to bridge the gap between engineering education and engineering practice. The purpose of the project is to develop a program that prepares graduating engineers for work. The program contents may be modified in collaboration with university faculty, industrial partners, engineering practitioners, and graduating engineers.

Course Duration: 1 week (5 days of instruction). The course is equivalent to a 3-hr/week semester course at a regular university, covering 40 hours of practical training.

Learning Outcomes: Attendees will apply their knowledge and skills to engineer a real-world engineering project and be able to:

- Apply engineering principles on the design, implementation, and operation of facilities.
- Develop conceptual and detail engineering skills.
- Apply communication skills.
- Develop teamwork skills.
- Prepare project specification, schedule, and cost estimate.
- Use industry codes and standards.

- Understand the importance of ethical principles, safety, and environmental issues
- Use engineering tools such as simulation programs, spreadsheets, and other engineering software to solve complex problems.

Audience: Engineering graduates entering the workforce

Teaching & learning methods: The course is project-based learning using active learning methods, interactive team discussions, and flipped classroom.

Instructors: The training instructor is a practicing engineer with many years of practical experience in the design, implementation, and operation of industrial facilities. The instructor will invite discipline practitioners from chemical, civil, electrical, and mechanical engineering disciplines to lecture or guide students during the course.

Course delivery method: Project-based learning covering major areas of engineering. The project is described in this document. The instructor will arrange a visit to a local refinery or chemical plant to familiarize participants to live industrial equipment. The practitioners will be sourced from the local industry.

Course Venue: The program will be conducted at a suitable location such as conference room; a training room; lecture hall, or similar. The course will be taught on face-to-face basis.

Course Evaluation: Instructor will use summative evaluation based on the survey method after completing the course

Resources: Engineering reference books, short-cut references, Rules of thumb references, industry codes & standards, and software tools

Powerpoint presentations: First day powerpoint presentation slides are given in Appendix D.

General training instruction:

- The project will be fully explained on the first day of the course.
- The class format may follow the traditional method and start with 30-minute video presentation delivered before the project activities begin each day. Alternatively, a flipped classroom format may be adopted where the videos will be given as homework and the class time dedicated to PBL.
- Approximately 80% of the time will be spent on project
- Training instructors are facilitators but will present the topics listed in Table A1
- Additional project instructions will be delivered as needed basis
- Engineering software and other tools will be provided by instructor
- Lunch and coffee breaks will be announced by instructor

Table A1

Schedule of Lectures

Schedule	Section title	Topics covered
Day 1	Introduction	Course content, goals, and outcomes
		Daily activities plan
		Education versus engineering practice
	Engineering principles & ethics	Fundamentals in practice & ethical considerations
	Health, environment & process safety	Safety in design, construction & operation
	Material selection	Construction materials /corrosion considerations. Piping specifications, equipment specs, instrument & electrical specs
Day 2	Engineering standards Codes & regulatory standards	Codes & standards, piping specs, electrical specs, mechanical, etc. (Codes: NFA, API, NACE); Regulations: EPA, PSM, DOT, etc.

	Conceptual design	Feasibility studies & front end engineering design (FEED)
	Economic evaluation	Engineering economics overview/cost estimates
Day 3	Detail engineering design	Systems engineering
	Design criteria	Systems engineering
Day 4	Control Systems	Control & Instrumentation
	Engineering drawings	(PFDS/P&IDs/elect line diagrams / blue prints / mechanical details/3-D model
	Specific topics to each engineering discipline	Chemical: Process
		Mechanical: Piping & Rotating equipment
		Civil: surveying, site development
		Electrical: Power / distribution
Day 5	Project management	Project schedule & budget management
	Project implementation	Constructability studies / construction activities
	Facility operation	Operation, Maintenance, & Inspection

Project Vignette

A local company decided to build a 10,000-barrel/day refinery to supply sufficient quantities of gasoline, diesel and liquid petroleum gas (LPG) - propane and butane. A project manager was appointed to estimate project cost & schedule, and upon quick approval from authorities, build the refinery. The project manager selected a team of chemical, civil, mechanical, and electric engineers to design the facility. Preliminary drawings and cost estimates have to be completed within a week to ensure that the project is included in next year's budget. The team must organize themselves into several small groups, each working in certain area, to complete the preliminary design within a week.

A final report and presentations from each group are scheduled at the end of the week. The project manager and his team will present the project report in the last week. A simplified flow-sheet will be provided before the start date. The project execution plan is given in Table A2. The main project steps are shown below:

- Develop detailed drawings of the facility showing the crude storage tank, crude pumps, crude heater, crude distillation unit, product lines, product pumps, and product storage tanks. The refinery products are light fuel gas from crude unit overhead, LPG products at the top, and gasoline, kerosene, diesel, gas oil side-draws, and heavy products from the bottom of the crude oil. The fuel gas will be compressed to 750 pounds per square inch. Each liquid product will be pumped to its respective storage tank.
- Develop the plot plan and locate equipment on the plot

- Develop preliminary designs, and size major equipment such as the crude storage tanks, crude pumps, crude heater, the crude unit, product pumps, overhead compressor, and product storage tanks.
- Size main piping runs and pipe racks
- Develop electrical loads, and size electrical equipment
- Develop site paving, and equipment foundations
- Show, and size the main control valves
- Use the appropriate engineering tools such AutoCAD or Visio for drawing, Hysys for process simulation, hydraulic or hand calculation program for pipe sizing, and xx for electrical loads, etc.
- Develop cost estimate for the facility. Call equipment vendors for major equipment to get current cost estimates.
- Discuss any problems or challenges among yourselves and come to a consensus on disagreements.
- Prepare progress reports each day
- Submit final preliminary engineering package.
- Make final presentations (by group) on the last day of the training

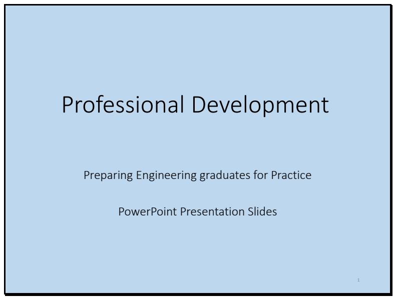
Table A2

Project Execution Plan

	Plan of the day	Planned activities	Work completed
Day 1	Present detailed course program	-Introduction to course -Overall course plan -Form project groups -Explain and discuss project parts	Thorough understanding of course, project work, basic engineering & documentation
	Project definition, equipment, and engineering tools & documents	Plant layout, site preparation, list of documents to be prepared	Layout drawings, engineering documents catalog
	Develop process flow diagrams and material balances	Development of initial Project drawings; Major equipment identification	Process Flow Diagrams, and equipment layout
Day 2	Major process equipment design	Start the design of major equipment	Start major process, and electrical equipment sizing as well as site civil and pipe rack work
	Electrical design and electrical loads		
	Civil & structural development		
Day 3	Finish up equipment design		Finish up remaining equipment sizing
	Material selection; Control systems	Select materials of construction and size control valves	Select materials of construction and control systems
	Preliminary drawings; pipe sizing	Prepare detailed P&ID drawings showing pipe diameters & lengths	Complete detailed drawings and size all major piping systems
Day 4	Final plot plan & equipment location	Final drawings and final cost estimates	Prepare cost estimate tables
	Material take off; cost data		
	Cost estimates		
Day 5	Develop preliminary engineering & construction schedule	Project implementation schedule	Complete project schedule

PowerPoint Presentation Slides for Day 1 of the PD

Slide 1



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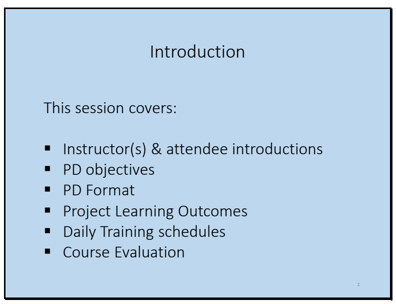

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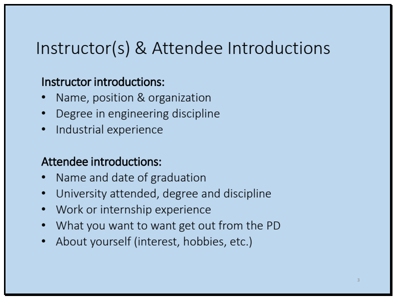

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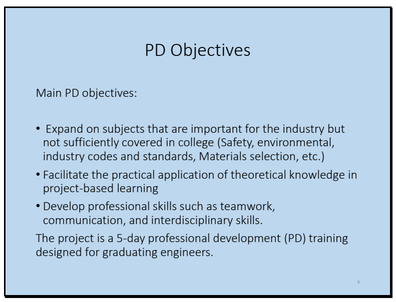

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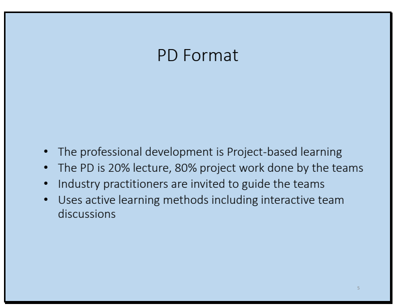

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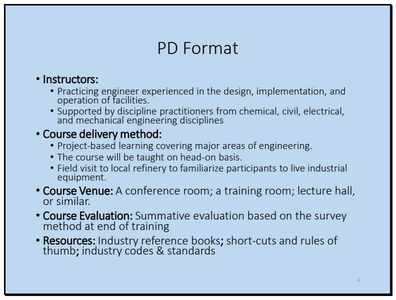

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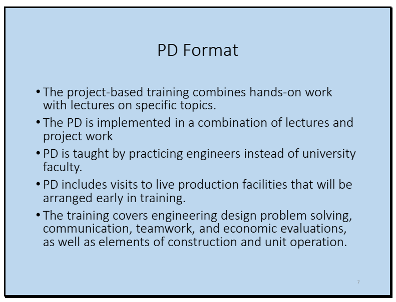

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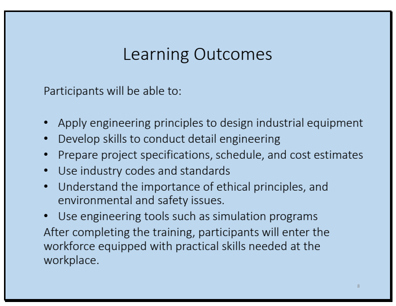

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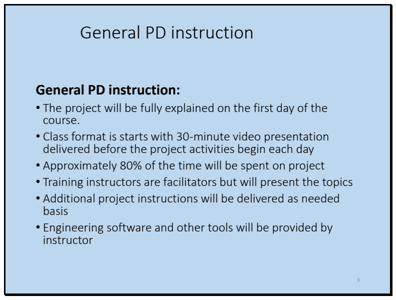

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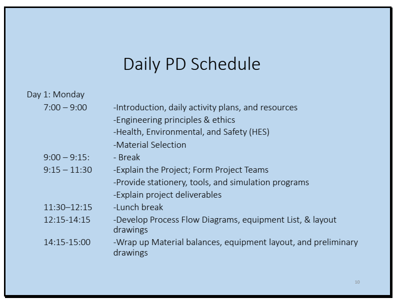

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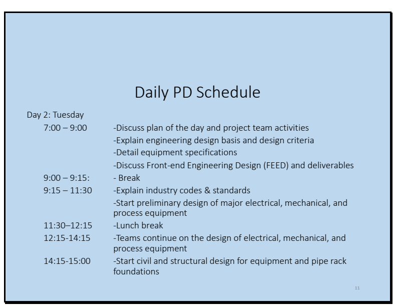

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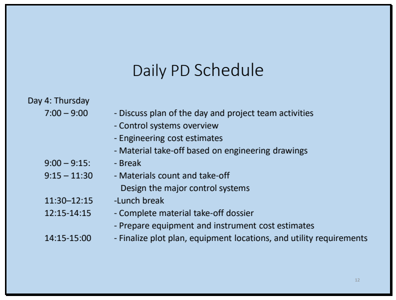

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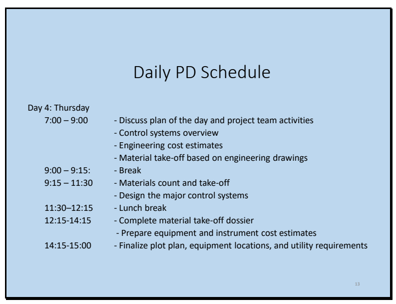

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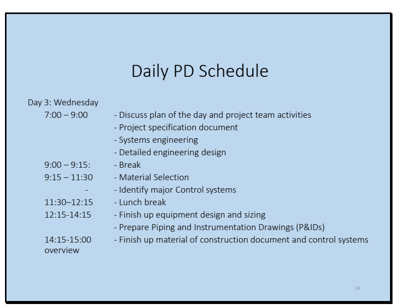

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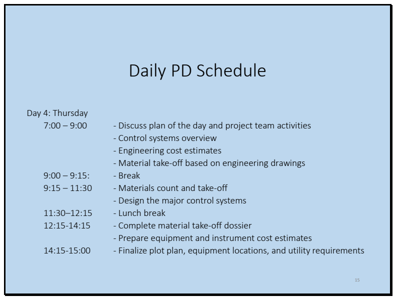

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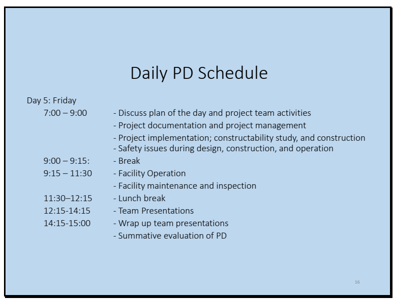

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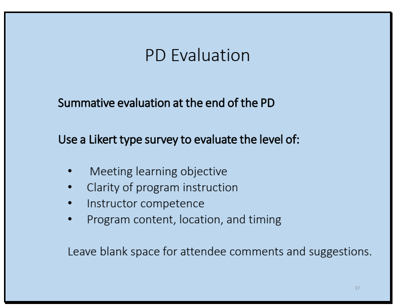

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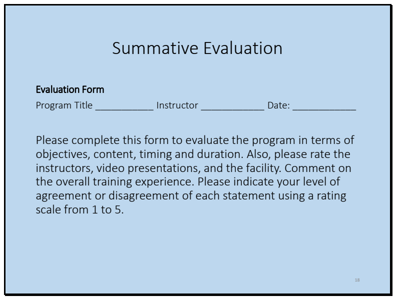

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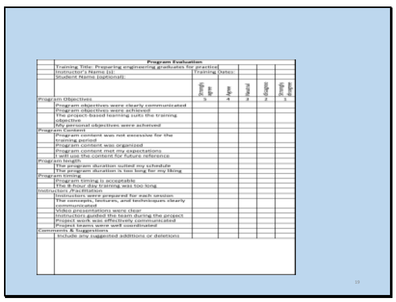
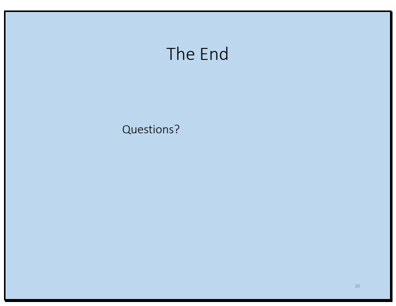


	Program Evaluation					
	Training Title: Preparing engineering graduates for practice					
	Instructor's Name (s):	Training Dates:				
	Student Name (optional):					
		Strongly agree	Agree	Neutral	disagree	Strongly disagree
Program Objectives		5	4	3	2	1
	Program objectives were clearly communicated					
	Program objectives were achieved					
	The project-based learning suits the training objective					
	My personal objectives were acheived					
Program Content						
	Program content was not excessive for the training period					
	Program content was organized					
	Program content met my expectations					
	I will use the content for future reference					
Program length						
	The program duration suited my schedule					
	The program duration is too long for my liking					
Program timing						
	Program timing is acceptable					
	The 8-hour day training was too long					
Instructors /Facilitation						
	Instructors were prepared for each session					
	The concepts, lectures, and techniques clearly communicated					
	Video presentations were clear					
	Instructors guided the team during the project					
	Project work was effectively communicated					
	Project teams were well coordinated					
Comments & Suggestions						
	Include any suggested additions or deletions					

Slide 20



Appendix B: Interview Protocol

Opening Statements:

Thank you for accepting to participate in the study and spending the time for the interview. I will try to complete the interview within the time limit but ensure that we cover the questions and collect as much data as possible.

My name is Abdulla Warsame. I am an Ed.D candidate at Walden University, College of education. I have a Master of Science degree in Chemical engineering and have been practicing engineering since 1987. I am currently employed as a Principal Process Engineer.

To start, I like to know the name & location of the university you have attended, your engineering degree & discipline, and the year of graduation.

Also, can you briefly describe your employment history since graduation, your main engineering activities, and some of the engineering practices undertaken during employment?

Interview Background

The topic of discussion and purpose and significance of the Study:

The topic of this study is: "The Gap between Engineering Education and Postgraduate Preparedness". The aim of the study is to explore the experiences of graduated engineers with respect to bridging the gap between education and engineering practice, overcoming educational deficiencies, through engagement in self-learning, mentoring, and professional development. Using the qualitative case study methodology, this research will answer the question: "What are the experiences of graduate engineers working in the industry regarding overcoming the deficiencies in their practical skills and bridging the gap between education and practice?" Interview data from participating chemical, civil, mechanical, and electrical engineers will be analyze, and interpreted.

The significance of the study is that it provides firsthand information of how a sample of graduate engineers engaged in self-learning and acquired the skills that they needed to become engineering practitioners. The outcome of the study will provide valuable feedback to engineering education stakeholders.

Purpose of the interview

The purpose of this interview is to capture your experiences as you reflect on your preparedness for engineering practice after graduation, and how you trained to bridge the gap between theoretical education and engineering practice.

Terms of Confidentiality

All information will remain confidential and will not be disclosed or discussed with others.

Interview Process

Format of interview: Structured & unstructured questions

Interview duration: 5 to 45 minutes

Interview date and time: February 10, 2016

Documents: None

Follow up contact information: (Insert participant contact information)

Interview Guide:

1. How effectively did engineering education prepare you for engineering practice? Describe areas where college education did not fully prepare you to apply your knowledge in the field.
    a. (Probing question: How well were you prepared to apply your technical, problem solving, and communication skills as graduated?)
2. What are some of the practical skills that you needed to perform engineering tasks? How did you develop these skills?
3. How did you train yourself to become a practicing engineer? Briefly explain any professional training, company training or personal training through public courses, workshops, seminars, or self-learning efforts that you have done to advance your professional competency.
4. What are the skills that you feel you need more development and how would you develop these skills?
5. What are some of the competency-related training efforts that you have taken since graduation? Which competencies should be part of the engineering education and which can be developed after graduation?

Thank you for taking the time to answer the interview questions. I will transcribe your response and send it to you by mail for your review and comment. I may also call you to clarify some of the points.

Appendix C: Summative Evaluation

Evaluation Form

Program Title ________________ Instructor ________________ Date: _____________

Please complete this form to evaluate the program in terms of objectives, content, timing and duration. Also, please rate the instructors, video presentations, and the facility. Comment on the overall training experience. Please indicate your level of agreement or disagreement of each statement using a rating scale from 1 to 5.

	Program Evaluation					
	Training Title: Preparing engineering graduates for practice					
	Instructor's Name (s):	Training Dates:				
	Student Name (optional):					
		Strongly agree	Agree	Neutral	disagree	Strongly disagree
Program Objectives		5	4	3	2	1
	Program objectives were clearly communicated					
	Program objectives were achieved					
	The project-based learning suits the training objective					
	My personal objectives were acheived					
Program Content						
	Program content was not excessive for the training period					
	Program content was organized					
	Program content met my expectations					
	I will use the content for future reference					
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	The program duration suited my schedule					
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	Video presentations were clear					
	Instructors guided the team during the project					
	Project work was effectively communicated					
	Project teams were well coordinated					
Comments & Suggestions						
	Include any suggested additions or deletions					