AC 2009-230: UNDERSTANDING THE CURRENT WORK AND VALUES OF PROFESSIONAL ENGINEERS: IMPLICATIONS FOR ENGINEERING EDUCATION

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Understanding the Current Work and Values of Professional Engineers: Implications for Engineering Education

Key Words: engineering practice, values, identity; education implications

Abstract

To better meet the needs of this century's workplace, engineering educators must better understand the current work and values of professional engineers. However, formal research in this area is limited. In this portion of our study we interviewed practicing engineers (n=45), surveyed engineers, engineering managers and individuals with engineering backgrounds (n=280), and conducted a case study of one engineering firm. In order to better understand the epistemic frame of engineering, or what makes an engineer an engineer, this study used a grounded theory approach. This approach used the viewpoint of engineers to uncover implications for engineering education. We gained insights on (1) what engineers see as notable and as exemplifying engineering in their work, (2) what aspects of their work they value most, and (3) what they would like to be different in their work. Specifically, we found that engineers see their work as using specialized knowledge to solve problems in a constantly evolving, local and/or global, business context. Engineers value (1) solving problems for clients, (2) creatively applying their knowledge, and (3) learning new skills and concepts. Engineers also expressed that their work often involves a greater focus on managerial and business processes than the tangible engineering of solutions, and that there is insufficient emphasis on developing new skills. These findings indicate that engineering education should ensure that students work to creatively apply their knowledge to actual clients' problems and develop significant business and communication skills. Engineers also substantiated these implications in responding to what they would have liked to have had as part of their formal undergraduate education.

Problem

Engineering practice in the United States is constantly evolving due to new technology and a changing global context. Arguably, educational practice needs to keep pace with those changes. According to the *Engineer of 2020* report, unless engineering education practice change to meet the demands of the workplace, the United States will not sustain its global leadership and share of jobs in high-tech professions[1]. Statistics from the American Society for Engineering Education also indicate that U.S. engineering programs "are not keeping up with the country's increasing demand for engineering talent"[2]. Not only is enrollment insufficient, retention of engineering students needs to improve as an estimated one third of college students who start in engineering drop out [3].

Enrollment and retention could be improved by better aligning educational practices with workplace realities. Current studies indicate that "there is a clear need for more effective integration between education and working life"[4]. Before that can be done, it is essential to have a firm picture of the work that engineers do today. Unfortunately, that picture is limited. "There are few reliable reports of research on engineering practice"[5].

In response to this need, this study will provide insights into the questions, "What do engineers describe as the key aspects of their work, what do engineers most value within that work, and how can we use a better understanding of this work and set of values to improve undergraduate engineering education?"

Literature Review—Engineering Practice

While a great deal of literature describes specific skills and practices of engineers, fewer studies painting a broad picture exist. Few people have attempted to understand the engineering profession as a whole[6,7]. There are three easily identifiable books and a few articles which attempt to address the practice of engineering, or a portion thereof. Other important articles attempt to not only describe an element of engineering work, but also to connect it to improvements in engineering education.

Books: Vincenti, Davis and Vinck

In his 1990 book titled, *What Engineers Know and How They Know It*, Walter Vincenti provides a frequently referenced look at engineering work[8]. An aeronautical engineer and professor, Vincenti is arguably one of the premier engineering historians in the United States. In his book, he uses examples from the history of aeronautical engineering to detail how engineers approach their work and learn through doing it.

Vincenti argues that most engineers practice "normal design;" they simply modify something that already exists. Radical design, starting a project from scratch, happens much less frequently. Vincenti describes "normal" engineering as inherently practical and as a social interaction. It is intended to serve humans in some way, and is thus constrained by the public realm. There are trade-offs determined by what the client wants and what safety dictates; making innovative changes is often not a priority.

In describing this work, he also says engineering involves a great deal of uncertainty. As engineers learn in their work, that learning is not logical and efficiently coordinated, but is "messy, repetitious, and uneconomical"[9]. He observes that the work done is also not necessarily theoretically based, but instead it may involve a lot of trial and error combined with practically educated judgment. The full effect of a design change can rarely be understood by theory; it must be implemented and tested. For the profession, he describes an evolutionary creation of knowledge and artifacts, largely taking a historical perspective of knowledge developing gradually through time (not in leaps and bounds). So, as a corollary to this gradual change process, much of engineering work is "not very important" [10]. When innovation happens, it's often just part of a slow and steady industrial refining of a product, not necessarily "derived from formal research and development" [11].

Nevertheless, he says engineering is artful. He highlights a quote from an 1892 description of engineering: "There is a gap between scientific research and the engineering product which has to be bridged by the art of the engineer" [12]. He goes on to say that, "The creative, constructive knowledge of the engineer is the knowledge needed to implement that art"[13].

Connecting with education, Vincenti emphasizes the importance of "practical learning"[14]. Engineering judgment and problem solving is learned through *doing*, and such hands-on experience in not typical for many undergraduate courses.

The next key book to be reviewed on engineering practice is *Thinking Like an Engineer,* by Michael Davis, published in 1998[15]. In his book he begins by wrestling with existing definitions of engineering, and he generally finds them all lacking. Many groups define engineering circuitously, by using technology or engineering within the definition itself. He then works to define engineering through the ethical considerations of the profession. Additionally, to define engineering, he differentiates it from science. In a workshop given to scientists and engineers, he asked whether they would rather "invent something useful" or "discover new knowledge" [16]. The scientists had a hard time answering and ended up split in their decision, while *all* of the engineers chose something useful. Therefore, he claims, "The primary commitment of engineers is not to knowledge, theoretical or applied, as one would expect of scientists, but to human welfare" [17]. He concludes that engineers believe they are involved in a process of improving connections between people and things. And, Davis sees an intimate connection between knowledge and action.

Moving to the next book, in his 2003 work, *Everyday Engineering: An Ethnography of Design and Innovation*, Dominique Vinck, as the chief author and editor, uses an ethnographic method to provide a picture of engineering design[18]. He and the other authors contributing to this collection of research document the work of several engineering teams at Grenoble Labs, looking particularly at how they collaboratively work through the design process and what artifacts they use to facilitate that work. His collection of articles emphasizes the social nature of engineering and the complexity of it, noting communication problems and some complicated business logistics.

Articles on Engineering Practice

The work of Diane Bailey and Julie Gainsberg (2003) also uses direct observations of engineers at work, looking at what types of knowledge engineers have, and how to categorize that knowledge[19]. They further consider how this knowledge is used and learned, arguing that while some knowledge is historical and learned through typical education, other knowledge is contextually based and learned through doing. This focus on "practice-generated knowledge" goes against the conventional wisdom of engineering knowledge being "mainly established" [20]. Engineering work is different from other scientific work because the knowledge to do it is so intimately tied to practice. Further, as found by Vincenti, they describe the messiness of these often uncertain and distinctive work environments. Their methodology was to observe engineers at work in three firms, ask them a few questions about their work at the end of these observations, and gather artifacts from their work processes. They then went through and coded these observations according to the type of knowledge employed. These types of knowledge included technical, social, visual (which is largely understanding constraints and determining how to present information), and financial.

The 2005 work of Kaija Collin reviews the learning of design engineers in their workplace[21]. Like the work of Bailey and Gainsberg, Collin looks at the situated learning of engineers and focuses on observation and interview. However, she does much more to directly bring in the engineers' voices and use them to tell the story. Collin paints a picture of designers' "work and learning as practical and social rather than that of linear problem-solving" [22]. She notes that traditional conceptions of design work as solitary, with little interdisciplinary cooperation, are largely incorrect. In today's engineering work, technical design and product development is "multi-professional team work which aims to solve ill-defined and short-term problems" [23]. Like Vincenti, Collin shows engineering work to be "messy" [24].

Schrage's look at "Serious Play" in engineering is one of many books and articles focusing on innovation in work environments[25]. He describes prototypes, models and simulations (toys) bringing multi-disciplinary groups together and bridging the gaps between them. He documents that using these "toys" to engage and "play" with ideas and products nurtures the possibility of radical design, which is an arena largely left out by the aforementioned authors.

Literature Review—Connecting Engineering Practice to Engineering Education

As James Trevelyan posits, in order to better align education with the evolving work of engineers, it is essential to have a firm picture of that work[26]. As mentioned previously, that picture is limited, and should be expanded. Specifically, "An accurate account of engineering practice could help educators explain the relevance of coursework to students, helping to provide appropriate motivation for learning. Such an account may also reveal opportunities to improve curriculum design" [27]. In his article, Trevelyan also emphasizes the important engineering skill of coordinating the work of other people, and suggests improving engineering education through projects where that skill can be practiced.

Jonassen, Strobel and Lee describe workplace problems of engineers and suggest that engineering education should include problems that look more like those of the workplace[28]. In the workplace, engineers struggle through much more complex and changing problems that have both engineering and non-engineering constraints.

Korte, Sheppard and Jordan describe the early work experiences of engineers and how well their education prepared them for this transition to a work environment[29]. In so doing they describe the work environment. Like Jonassen, et al., Korte et al. point out that educators should improve engineering education by working on more real-world problems that also require navigating social interaction. Social and organizational contexts of the work environment impact "the problems and processes [new engineers] experience—often introducing greater complexity, ambiguity, and subjectivity than expected" [30]. Korte et al. also point out that in surveys employers rated new graduates highly in areas of technical preparation, but they were much more likely to rate new graduates as inadequate in communication skills and understanding of business contexts and constraints—another note for education improvement. Finally, these researchers emphasized that the quality of work relationships had a large effect on the learning of new engineers, highlighting another complexity and constraint of engineering work.

Looking specifically at how engineering is taught versus how it is practiced, Sheppard, Colby, Macatangay and Sullivan build a picture of engineering practice[31]. Their methodology included reviewing other literature on the engineering profession and interviewing engineering professors. Their study describes three main components of engineering work: problem solving, including defining problem; specialized engineering knowledge used to solve these problems; and, integrating knowledge with the processes of doing engineering.

Literature Gaps and Aims of this Study

On the whole, the literature on engineering practice provides a broad picture of what engineers do, how they work together and how they learn in their work. Nevertheless, there are some important limitations.

- The major limitation with Vincenti's work is obvious; it looks at engineering from an historical viewpoint. He does not collect any data of current engineering practice or discuss the current context of engineering.
- A limitation with Davis is that he occasionally backs up his assertions with other non-empirical research, historical accounts or with no research. He only did a limited amount of interviews of engineers (n = 29) and engineering managers (n = 31), and those interviews were almost exclusively focused on how decisions are made and the power dynamics of those decisions. Another problem is that while his work focuses on the creation of a definition of engineering, he does not use engineers' own voices, or the policies of companies, in providing that definition.
- As an ethnography of teamwork in design, Vinck's work is limited by that frame. It is qualitative in nature and primarily looks at how teams work together to design or re-design a product or process. Arguably, this process is a large part of engineering, but it's not the whole picture.
- Bailey and Gainsberg: One limitation of this study is that it does not encourage engineers to significantly reflect on their practice and why they do certain things, it is more objective. The voice of engineers does not significantly appear to factor in. The study does not aim to suggest improvements to the education of engineers; it simply reports that engineers learn some things in a university setting and some through practice. It does not question those norms.
- Collin's work is mainly limited in scope, just considering workplace learning in Finland.
- A limitation of the study of Korte, et al., is that it just focused on new engineers. It did use their voices extensively; however, it only looked at 17 engineers in one manufacturing firm.
- Sheppard, et al. use only the voice of engineering faculty and other literature on practice; it does not empirically bring in the voice of practicing engineers.

Therefore, many of these studies are limited in scale, looking only at one type of engineering work environment. Most studies do not include the voice of practicing engineers who have moved into project leadership and management roles. Also, these studies are all qualitative, and larger quantitative pictures of engineering work are not readily available. While some of these studies bring in the voices of engineers, they do not typically include the values of these engineers or their views on what needs improvement in education.

Accordingly, this study attempts to do more to let the engineers tell their own story, and uses their words to identify the characteristics of their work. This study also has the benefit of looking at the current picture of engineering, which is constantly changing. Next, this study includes both a case study of engineering in a particular firm and through surveys and interviews, the voice of engineers of many disciplines. It also utilizes both quantitative and qualitative data.

Theoretical Framework of the Study

The theoretical underpinning frame for this study begins with an epistemological look at professions that focuses on gaining a better understanding of the values, knowledge, skills, and ways of thinking of that profession[32,33]. It also tries to determine how education can use this "epistemic frame" to better align with practice.

The learning theories of Bransford, Brown and Cocking, also provided an impetus for this work, as they indicate that learning through doing is much more effective method than learning through lecture[34].

Finally, this research will be focused on understanding the research question through a grounded theory method[35,36]. In this method, as data is gathered, it is categorized into broad themes and possible directions to look for answers to the research questions (in this case, what engineers describe as notable and valuable in their work). These categories are then used to guide additional collection of data, to determine if these initial themes and directions point to certain theories. Researchers then posit initial theories on the answers to the research questions. Further data is then analyzed in order to validate these theories, grounding them in a variety of qualitative and quantitative data.

Methodology

To investigate engineering practice and values, we triangulated data from surveys, interviews and one case study.

The online survey consists of 37 questions. Some questions follow a Likert scale format, such as asking about the importance of a certain skill or how well one's education prepared them for their work. Other questions were open response, such as asking them to describe a notable work experience that exemplifies engineering, and then asking why it exemplifies it. Finally, other questions asked engineers to choose from a list of responses, such as what they value in choosing one project over another. At the beginning of the survey engineers are asked about their educational backgrounds (degrees and years of degrees) as well as the type of industry in which they work. Engineers select the type of work they now do from a list of 1) "traditional" practicing engineer, 2) engineering managers or project leader, and 3) engineering background but in a different field (which were not used in this study). Some of the questions they receive differ depending on what they select, with many fewer given to those no longer in engineering. In analyzing the data for this study, we chose to look at the responses of both practicing engineers and managers, considering both of these positions to be important aspects of the role of an engineer. While this study combines their responses, a future study will look at the differences among individuals in these self-selecting categories of engineer or manager.

The survey was created collaboratively by a group of engineering faculty within the technical communications department. They were assisted by the engineers and engineering managers of their advisory board, faculty within the Engineering Professional Development department, their NSF grant advisory board, and faculty and graduate students from the School of Education. This group used the National Academies reports, *The Engineer of 2020* and *Rising Above the Gathering Storm*, as a guide for what to look for in engineering practice and for what skills to ask engineers about. As previously described, this group also looked at the work of David Shaffer (2007) to guide them in asking questions to uncover the "epistemic frame" of engineers, a picture of the epistemology of engineering, or what makes an engineer, an engineer. Additionally, questions were guided by some of the literature cited above and other engineering education literature to determine what questions of engineering practice warranted further study. Engineers from different backgrounds (n =13) piloted the survey. Their responses were used to refine the questions, making sure they were understandable and similarly interpreted across individuals.

Surveys were sent out to engineering alumni of a large, public research university. Admittedly, because the responses all come from these alumni, there will be some measure of a selection bias to the responses. They are all engineers who were able and chose to go to such an institution, so they do not represent all engineers. However, because of the variety of engineering disciplines represented by the individuals and their differing backgrounds, they do provide a useful picture of engineering practice. Statistically, they are not representative of all engineers or disciplines, but they provide an informative cross-section. To date, 280 of the initial online surveys have been completed, and 35 follow-up surveys focused on engineering thinking have been completed.

Interviews of practicing engineers and engineering managers have been guided by an interview protocol consisting of 15 open ended questions. The questions ask the engineers about their current job, notable events in their work, values in relation to their work, continuing education, and advice to new engineers. These interviews were conducted by students in their first year technical communication course in the college of engineering. Engineers involved in professional development courses agreed to be interviewed by these students. Again, because these were engineers actively involved in professional development, their responses will not be generalizable to all engineers. However, the majority of these engineers did not attend the same research university as the survey participants, so they will add some balance to their responses.

Interviews using this protocol were also conducted as part of a case-study by one researcher within one engineering firm. Through university connections, we were able to gain access to the manufacturing firm, Porter & Young Technologies (P&Y Tech—pseudonym used). In the broader range of our research we are working with six different engineering firms of varying sizes and industries. P&Y Tech was chosen because it is a very large, international, manufacturing corporation. The case study consisted of the following: observations of three engineering meetings, two hours of observing four engineers at work along with questioning these engineers about their work activities, one focus group of three engineering managers (with an in depth interview of one of them), one focus group of three other engineering managers and three engineers, a tour and basic history of the facility, a presentation on the mission and policies of the firm, interviews of five other engineers, interviews of two technicians, an interview of a marketing person, an informal discussion with the HR director, and an interview of one other engineering manager. Only a small fraction of these individuals attended the large, research university of the survey participants, adding further balance to our picture of engineering.

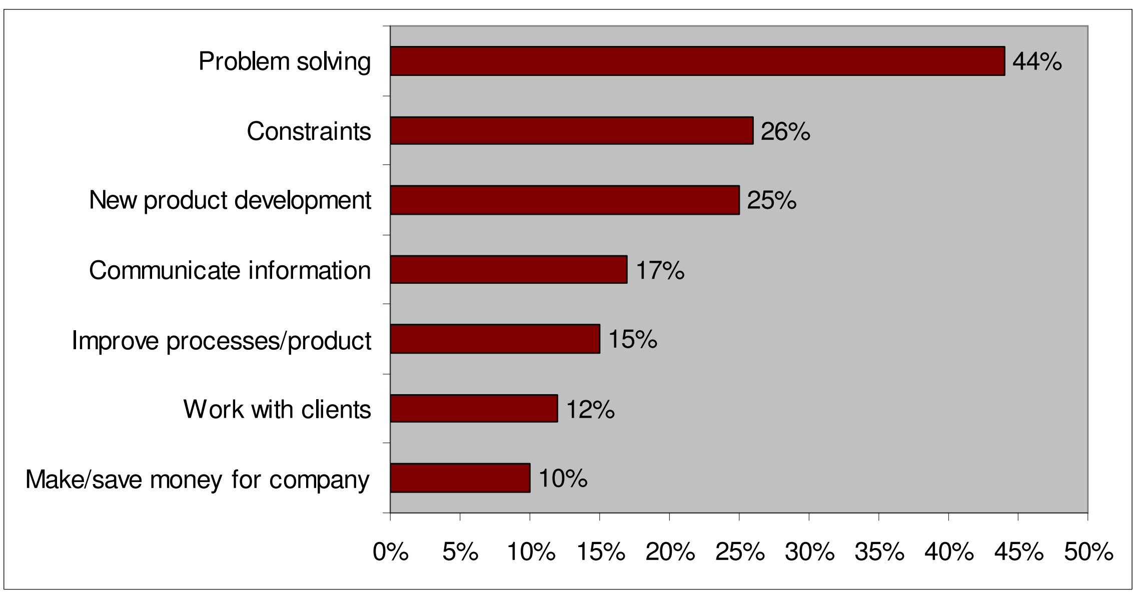
Data from the surveys, interviews and case study were placed into a qualitative research database (NVivo). Within that database researchers coded this data based on themes found within it relating to what engineers felt was important within their work. Researchers were also able to search the database to find relevant quotes and information to support these themes.

Initial Findings

What is Notable in an Engineer's Work?

To investigate what engineers describe as notable in their work, they were asked to describe a notable work event that gave a good picture of engineering. Researchers asked this question in both surveys and interviews. We then reviewed these responses for themes. We found the following main themes brought up in responses: solving problems, working with constraints, developing new products, communicating information, improving processes or products, working with clients, and making or saving money for the firm. We then counted the number of times these themes came up in the responses and divided by the total number of responses (n = 104) to find their prevalence. That data is found in figure 1. We also reviewed survey and interview data for quotes that provide representative examples of key themes found.

Figure 1: Themes of engineers' responses to a request to describe a notable work event (n = 104).

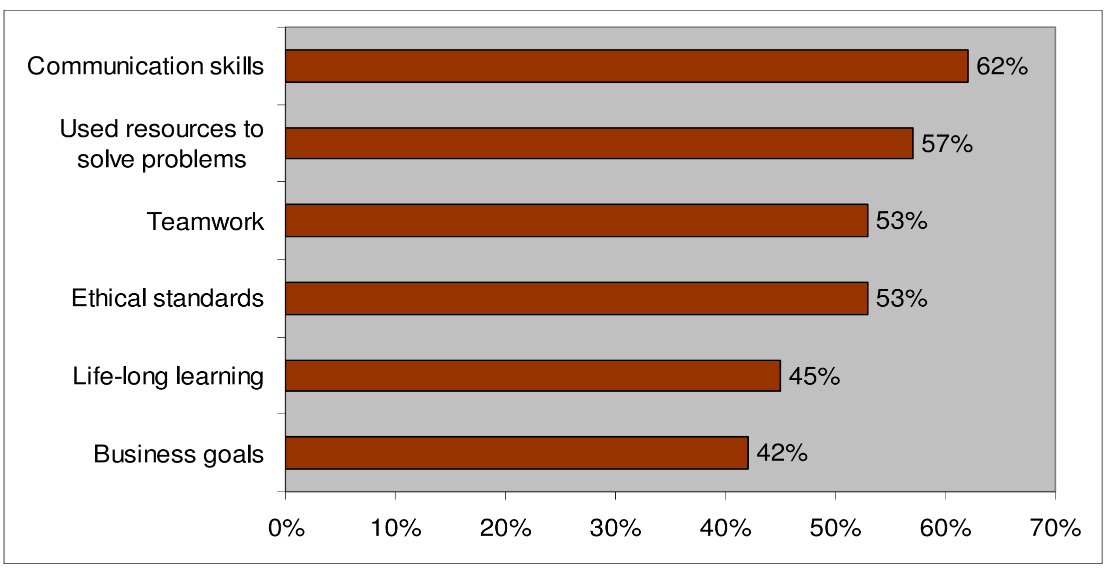


After they described this notable work event, we asked engineers why that event gives a good description of engineering (n = 102). Many engineers talked about problem solving as the key component of their work. For example, one engineer said, "I think an engineer is really just a problem solver. Someone who can look at a situation objectively and use their knowledge and skills to brainstorm solutions." Other engineers emphasized that this problem solving is done under constraints such as "being compliant" and needing a "low cost solution." Another theme that arose focused on the business and people side: "Engineering is not about numbers and formulas. Engineering is more about interacting with your customers." Finally, some engineers talked about the skills needed in the process of their work event. As one engineer said, "It required creativity, subject matter knowledge, good experimental skills, communication, inter-disciplinary cooperation, and a whole lot of persistence."

What are essential engineering skills?

Engineers were specifically asked what skills were essential to their job in the survey. They ranked a list of skills from "essential" to "not important" (see appendix 1, question 13 for the full list of skills). Sixty-two percent of engineers selected communication skills as essential, more than any other skill. Interview data also supports communication being the most important skill to have. However, it should be noted that open-ended responses in interviews and surveys indicated that many engineers assumed a level of technical competence in their co-workers when answering this question. Further research will be necessary to tease out the extent of that assumption as engineers answered this question; it could be that technical skills are more important than the rankings indicate. The second rank skill most frequently selected in the survey was using resources such as other people and technology to solve problems, which connects with what engineers see as their most notable work. The skill least often chosen as essential was using a broad intellectual background, such as social sciences, humanities, history, etc., which 7% of engineers selected as essential. Figure 2 identifies the frequency of the top 6 skills chosen by engineers as essential.

Figure 2: On the survey, frequency with which skills were selected as essential by engineers for their work (n = 162).



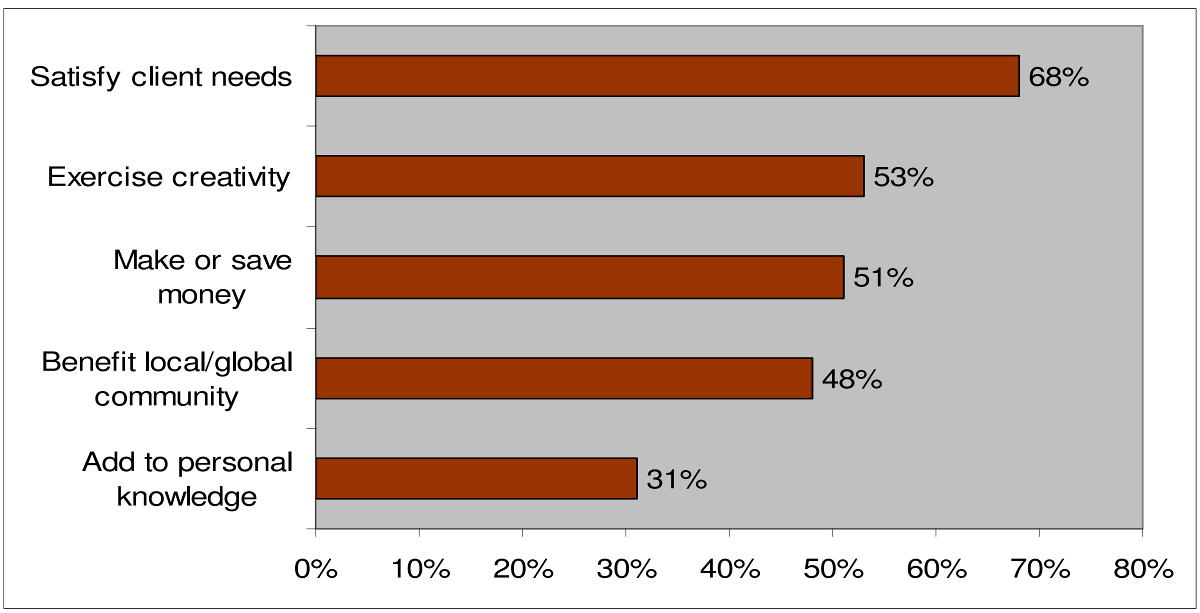
Within interviews, engineers were also asked what skills were important in their work. Communication and working with customers also came up more than any other skill. Specific technical skills and problem solving skills were the next most abundant responses.

To get a different perspective on what skills engineers used in their work, we also asked them in surveys to describe which skills were most important for the notable work event that we asked them to describe. The top four selections were the following: 56% of engineers choose understanding business goals, 52% choose communication skills, and 51% choose teamwork or using available resources to solve a problem (they were able to choose more than one skill). So, understanding business goals became much more important when engineers connected skills to actual work situations. Interestingly, within the interviews engineers did not mention business skills nearly as much; they were more likely to cite communication or certain technical skills. Solving problems and working with people/teams also came up.

<u>What do engineers value in their projects?</u>

In both surveys and interviews we asked engineers why they would choose one project over another if given a choice. In the case study, where engineers did not have the list of options as given in figure 3, they generally cited learning something new or doing something different as the primary reason for choosing a project. Responses such as "learning different things" and "the interest factor" were the most common among the engineers interviewed by students. However, in the survey, satisfying clients and making or saving money came out as much larger priorities. Interestingly, these reasons were virtually non-existent within case-study interviews. When asked if money was a consideration, engineers at the case-study site said that they were more interested in something personally satisfying and engaging than in making money. However, they did acknowledge that they often had to deal with profit as a constraint for their work.

Figure 3: When given a choice among projects, what factors do engineers primarily consider? In a survey, engineers were asked to select their top 2 or 3 reasons. (n = 130)

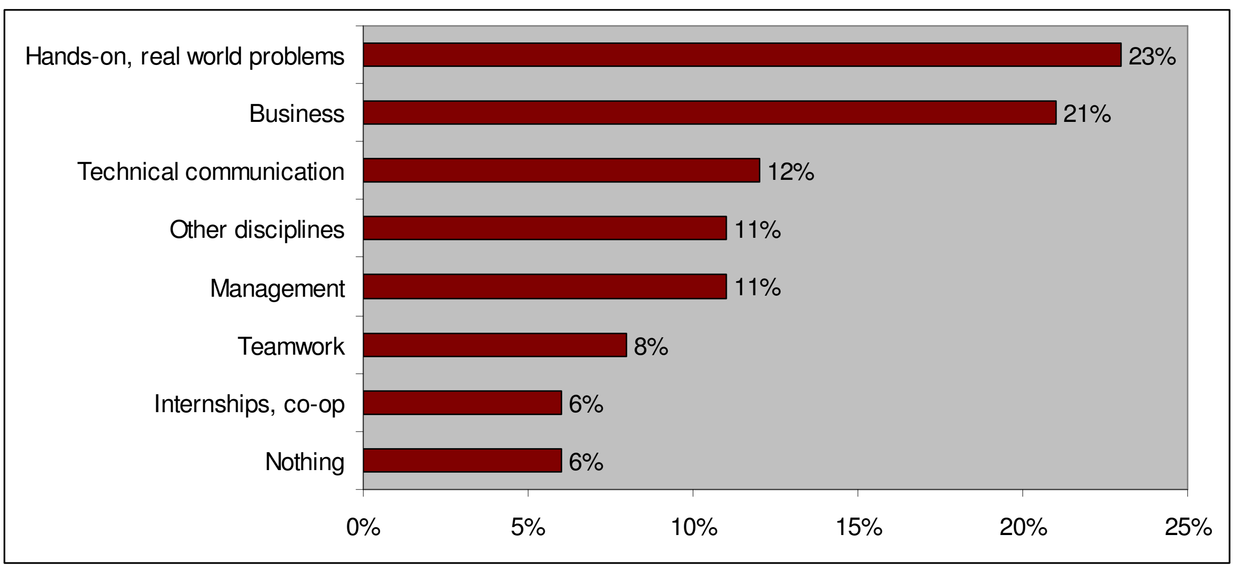


After selecting these reasons for choosing a project in the survey, we asked engineers why that was their reason. Engineers frequently brought up the importance of the customer. One engineer said, "Engineering is less about technical knowledge and more about satisfying your customers." Another said, "Honorable goals such as 'benefiting communities' is great and important, but at the end of the day you still need to feed and clothe your family, which will not be possible if you do not take care of your customer and create products that succeed in the marketplace." Other engineers talked about personal satisfaction criteria: "Exercising creativity and inventing are why I became an engineer." In interviews, responses were more apt to be choosing whatever project is the "most fun or interesting" or "something that I have never done before."

What did engineers feel their education lacked?

When asked, "What would you like to have had as part of your education to better prepare you for your current work?" engineers most frequently mentioned hands-on and real-world problem solving. They felt they needed less book learning and memorization and "more fundamental hands on problem solving skills." The second most common theme that arose was a desire to have more focus on "business acumen." Considering that about half of the 113 survey respondents were managers of some sort, this theme is perhaps not surprising. While some themes came up repeatedly, there was definitely no consensus, with only 23% of engineers mentioning practical problem solving in some way and 21% discussing business. Quite a few had their own unique request of engineering education; for example, one female engineer had hoped for more specific preparation for females to enter a male dominated work environment. Notably, there were no strong common themes from the interviews in response to this question. Most of the same responses came up at least once or twice, but not enough to consider them significant commonalities. Figure 4 gives an overview of the eight most common areas that were missing in their education according to the survey responses.

Figure 4: Common themes of engineers' responses to question on what education lacked (n = 113)



Case Study – Porter and Young Technologies

We had the privilege of studying Porter & Young Technologies (P&Y Tech). P&Y Tech is a very large, international manufacturing firm, with over 18,000 employees in more than 35 different countries. Much of their basic manufacturing is done out of the U.S., while their testing, development and small scale manufacturing is typically done within the U.S. Within one division of P&Y Tech, we talked with seven managers, twelve engineers, one human resources (HR) director, two technicians, and one person in marketing; one of the managers, seven of the engineers, the two technicians and the marketing representative were all part of one R&D group, which we studied in more depth. This group was preparing a new product for market launch. One of the engineering managers was female, all other interviewees were male. Two of the engineers were Asian and one was African-American. The HR director was African-American.

Data from our interviews and observations emphasized the importance of the extended history that participants had together and their enjoyment of their work. The majority had been at P&Y Tech for over 10 years, some for over 30, and nobody expressed plans to move elsewhere. They knew each other well and knew where they could go for assistance on a project, for another viewpoint on a problem, or for an answer to a question. The participants we interviewed and observed were clearly focused on doing good work and putting out quality products.

The engineers talked about a few key things that they valued in their work. One value that came up repeatedly was the people with whom they work. They valued learning from and working with the many competent engineers around them. One manager expressed his feeling that they were all part of a "culture of a team." Beyond learning from other engineers, they talked about their interest in learning new things in general. As one engineer said, "It's important to keep learning everywhere. You can't let the learning process slow down." When asked about why they might choose one project over another, most described a desire to do something new. Three engineers talked about going through the patent process and appreciating P&Y Tech's support in that. They also valued the company's support of them publishing articles and sharing their knowledge.

Much of the work of these engineers and managers was in meetings or in front of a computer screen. In the observations of individual engineers at work, two were working with CAD, one was running computer simulations of a redesigned product and another was reviewing a computer database. When these and other engineers described what important events came up in their work, many referred to solving problems. Most of the engineers in the smaller R&D group talked about their new product launch and the testing and revisions going along with that. In their weekly meeting each member of the group talked about their current progress and any problems they were having. Their typical meeting included not only mechanical and process engineers, but a person from marketing, a couple technicians and some administrative support. They felt that this interdisciplinary group made clear communication and problem solving easier.

When engineers expressed frustrations with their work, they usually described constraints on what they valued—learning and other people. Many expressed the desire to have more opportunities for and support in learning. While they felt they had some chances for learning, and appreciated programs like tuition reimbursement, they wanted more. For example, a couple felt that the company could do more to encourage and enable retiring or senior engineers to share their knowledge; there is no organized mentor program, just informal connections made individually or by managers. Two of the engineers and four of the managers specifically felt that the company is too concerned about the bottom-line to make professional development or mentoring a priority. A couple of them further felt that this bottom line focus limited innovation. While they had some opportunity for creative endeavors, it was constrained more than they wanted. One manager said the environment has become "less tolerant of mistakes" and others agreed. He felt that because everything is so much about the bottom line that mistakes are seen more as lost revenue than as learning opportunities.

When asked about what they would have wanted in their own education, answers varied. However, all seemed to focus on wanting more workplace related skills. None expressed a feeling that technical education lacked. The most frequent response was a desire for more hands-on work, such as internships, co-ops, and creative problem solving. A couple mentioned interpersonal and technical communication. One felt that his professors understood academia, but not industry, and he wished they had had more real-world experience.

Overall, the engineers we worked with seemed satisfied with their work lives at P&Y Tech. They were motivated to do their jobs well with a high level of accountability and integrity. They were personally driven to continue to learn more and improve themselves. A key theme that came out is their appreciation for collaboration with and learning from other engineers.

Conclusion

In conclusion, our research validated much of the findings in the literature and supports continued revision of undergraduate engineering education. As suggested in the literature, engineers see problem solving using their unique skill set as the key part of their work. Our research also suggests that engineers feel that education needs continued revisions to include more hands-on problem solving and connect with real-world communication and business skills; in essence, it needs a greater connection to practice. Through our grounded theory approach, we have used the voices of engineers to develop a theory of how engineering education needs to change. It should involve more business skills, more hands-on problem solving, work with actual clients, internships or co-ops, and practice communicating and coordinating technical work. While these recommendations are not new, bringing in the voice of a wide range of engineers continues to emphasize that reform in engineering education is far from complete. In the following section we expand on these education recommendations and provide examples of programs that we think are moving the field toward an improved connection to engineering practice.

Implications for undergraduate education

Engineers emphasize business skills within their work, and the need for improvement in these areas of education. Programs could and should be created that develop these skills. Simoneau, Magenau and Ford discussed one such program where a school of engineering and a school of business create a systemic partnership[37]. Faculty from both schools collaborated to identify core business knowledge that engineering students should have. In this program a business faculty member began teaching a project management course for engineers, where they developed a product and a business plan for it. The plan for this program is to develop "graduates who can see the big picture and integrate solid technical skill and real business understanding early in their professional careers" [38].

In addition to real-world business skills, engineers also need more real-world problem solving in their education. As described in the literature above, much of engineering education is still fact and memorization based[39]. An example of a program which is making engineering more hands-on is the relatively new Franklin W. Olin College of Engineering, founded to reform the way engineering is taught. Based on reforms espoused by professionals, NSF and others, Olin College focuses on interdisciplinary learning, hands-on projects, and teamwork instead of the usual theory-laden lecture format[40,41]. Students' learning at Olin also concludes with a rich, year-long project for a client.

As is the case at Olin and other colleges of engineering, having students working with clients on an actual project connects well with the type of work that engineers do and the type of education engineers wish they had given. Students can also benefit from more hands-on projects early in their engineering programs; studies have shown that these types of programs increase retention[42]. With careful effort this type of project in either the first or last year can apply knowledge students learn in the classroom in an environment where constraints such as cost and practicality of production must be considered. As emphasized in the literature, this type of problem will be more like real-world engineering problems[43].

Many of the skills and values of engineers are going to be learned on the job, which leads to the next suggestion for engineering education, that of having students get involved in internships or co-ops. A number of engineers felt that these experiences should be mandatory. Many engineers also felt that a great deal of what they have learned has been on-the-job. However, it is very rare for engineering schools to require such internships or co-op experiences. Some engineering programs, such as that at Rowan University, are working on extensive industry and career center partnerships to ensure internship possibilities for all students[44]. Currently, 94% of their junior class has had such an experience, and they hope to maintain or improve that level of success.

Another arena for improvement for engineering education is communication within and coordination of technical work. Communication is seen as a key skill of engineers, and as was seen in the case study, engineers report that interdisciplinary meetings and teamwork are a frequent and important part of their job. Because globalization is also a continuing factor in engineering work, combining these skills makes sense. Stephen Silliman of the University of Notre Dame is working on programs where students in the U.S. work on international projects and collaborate with students in other countries[45]. These programs exemplify the type of work of engineers in the field and a positive direction for education.

Limitations and Future Directions

While this study adds to the evidence about important changes needed in engineering education, it does have limitations. It looks largely at engineers in one Midwestern state, or individuals having graduated from one Midwestern university. It doesn't have a statistically significant number of engineers from some engineering industries. It did not include the voices of a significant number of minority or female engineers. Finally, it only included about seven hours of observations of engineers at work; the remaining data is engineers describing their work, which is problematic as they likely describe and focus on the most interesting aspects, not the day to day activities.

One possible future direction for research would be to compare the effectiveness of new engineers that have had these types of educational experiences with those who have not, as measured by manager surveys, quality of work completed, peer surveys or some other instrument. An additional further study planned by this group will be comparing the engineering education feedback of recent graduates with less recent graduates to help determine whether or not current reforms in engineering education are making any headway. Further case studies and analysis data across all parts of the project are ongoing.

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