AC 2010-1740: BENEFITS TO NON-ENGINEERS OF LEARNING AN ENGINEERING WAY OF THINKING

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Benefits to Non-Engineers of Learning an Engineering Way of Thinking

Abstract

In this study we seek to describe the benefits of an engineering way of thinking, as gained through an engineering degree program, for individuals who choose non-engineering careers. There is limited literature on this topic. Arguably, this understanding should influence the future of engineering education as fewer than half of engineering graduates remain in "traditional" engineering roles. We surveyed individuals with engineering degrees, but who described themselves as not being an engineer or in an engineering management role (n=112). We also interviewed a few such individuals (n=7). We found that the majority of these individuals still considered themselves engineers, even with a different career focus; it was part of their identity. Most of the respondents who did not consider themselves engineers still greatly valued their engineering training. These individuals described how the systematic and analytical thinking of engineering applied to solving problems in their current work contexts. They also found practical value in their technical competence.

Introduction

Research indicates a continuing need to better align engineering education with engineering practice[1,2]. However, many engineering program graduates do not end up in "traditional" engineering positions, or if they do initially, they often move into engineering management or other careers[3]. Is the only aim of engineering education to prepare students for traditional engineering careers? Arguably, it is not. In this paper, we seek to describe what individuals who do not stay in engineering-related fields see as the key aspects of their engineering education. How do they continue to use the skills and ways of thinking that they learned? We found no research, either empirical or theoretical, that directly addressed these questions.

Arguably, a vast range of factors influences why individuals begin a degree in engineering, finish it, and go into an engineering career. Despite this complexity, we hypothesize that if high-school and college students understood the vast range of professionals who use and value the learning from their engineering degrees, more would enter engineering majors. A first step before testing this hypothesis is to understand how these non-engineering professionals use their engineering education. This hypothesis of improved recruitment is supported by research showing that even first-year engineering students are often unaware of the wide range of careers open to individuals with engineering degrees[4].

Literature Review

To understand the benefits of an engineering education, we will first review the literature on the ways of thinking of engineers. This literature relates to the question because, while the specific technical skills learned in engineering often do not apply in other professions, the way of thinking learned in engineering does apply quite widely. After looking at that literature, we will look at literature on connections between engineering education and non-engineers.

One recurrent theme within the literature on engineering work and thinking is the nature of the problem solving done in engineering. Many articles and books on engineering discuss the complexity of engineering problem solving and the analytic thinking required to tackle those problems. Robinson describes engineering thinking as explaining why a particular solution is the best given the problem and the constraints[5]. He notes that this typically requires analogical reasoning—which may incorporate theory, but primarily connects with previous problems and experience. Vincenti also describes engineers' thinking as not necessarily relying on theory, but likely involving a lot of trial and error combined with practically educated judgment[6]. He notes that engineers largely learn through doing in a manner that is not logical and efficiently coordinated, but is "messy, repetitious, and uneconomical"[7]. Bailey and Gainsburg also describe the messiness of engineering work, finding that it requires thinking about a multitude of competing variables and a careful balancing of priorities[8].

A great deal of the messiness of this engineering approach to problems comes from the social nature of the problem solving. Research on engineering practice and thinking also describes this social element of how an engineer approaches his/her work. Vincenti describes "normal" engineering as a social interaction that serves practical needs[9]. Public safety standards and client desires must factor into the thinking of the engineer. Similarly, Davis finds that engineering work is rooted in ethics[10]. Engineers have to weigh options, give reasons to pick one option and explain the reasoning for that option. Ethical questions critically factor into this analysis. Will this be safe? Will it be of high enough quality? Does it meet standards? But, as mentioned above, it's not a simple analysis as organization factors of budgets and time constraints come into play. It's an interplay of technical, organizational and public constraints. Furthermore, Bucciarelli notes that design engineers have their own way of thinking, and they must interact with individuals from other subcultures of engineering and business to "negotiate their differences"[11]. Vinck highlights the importance of careful collaboration and notes problems that can occur in engineering due to poor communication[12].

Work by Trevelyan and Tilli and by Collin note that traditional conceptions of engineering work do not match these findings of the social nature of the work. In surveys of new engineers, Trevelyan and Tilli found that up to 60% of their work is communication with others in some way—writing, emailing, direct meetings, etc.[13] Collin further notes that problem solving is not linear and solitary as typically perceived, but interdisciplinary and ill-defined[14].

Within this literature on the work and thinking of engineers, we found no discussion of how this way of thinking connects to and benefits individuals in other professions. It could be that literature specific to other professions describes a similar mode of thinking without referring to it as an engineering approach. But, the literature within and outside of engineering appears to neglect the connection of an engineering degree with performance in other fields. Two strands of literature, however, touch on the idea indirectly: one segment describes the importance of technical education for non-STEM majors; another body of literature describes longitudinal studies of engineering students.

First, a broad range of literature covers STEM education for non-STEM majors, with a subset of that including technical or engineering knowledge. One such study is from Krupczak and Green who described what non-engineers were interested in learning about within a technological literacy course[15]. Students frequently mentioned wanting to gain practical information to help consumers and users of technology, such as understanding what to do when technology breaks down. Understanding the actual thinking processes of scientists or engineers did not come up. However, some educators do emphasize the need to make engineering education more flexible so that non-engineering majors who want more technical background have a means for getting it[16].

Second, as noted by Tilli and Trevelyan there are few longitudinal studies of engineering graduates[17]. They are conducting one such study. In their study they plan to look at the work of engineering graduates who went into other fields and what they say about that work. But, because they are in the early stages, they do not yet have published details on those findings. As part of their study, they reviewed other longitudinal studies that have been done of engineering graduates; none of these other studies looked at how individuals that are not engineers are using their engineering background.

Therefore, with this understanding of engineering thinking and work, we endeavor to fill this gap in the literature and look at what non-engineers with an engineering degree say about how it impacts their work.

Theoretical framework

This paper includes data gathered as part of a larger National Science Foundation funded study on describing engineering practice. The theoretical underpinning of this broad study is an epistemological look at professions that focuses on gaining a better understanding of the values, knowledge, skills, and ways of thinking (or "epistemic frame) of that profession[18,19]. It also tries to determine how engineering education can be better aligned with this epistemic frame of engineering.

We used a grounded theory approach within this project[20,21]. In this method, as data is gathered, it is categorized into broad themes and possible directions to look to find answers to the research questions (in this case, what non-engineers say about applying their engineering education to their current 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

Our broader study includes three online surveys, case studies of 6 engineering firms and interviews either in person or through email contact with 91 additional engineers or individuals with engineering backgrounds. For this paper, we use a portion of the survey and interview data—those which questioned individuals who describe themselves as not currently holding positions as practicing engineers or engineering managers.

We originally surveyed 2500 alumni of a large, public university's college of engineering. We received 93 responses from individuals who selected their current professional positions as being, "Engineering background, but not in an engineering field." We asked the following open-ended questions of these individuals:

1) Even though you are working in a different field, do you still consider yourself an engineer? Why or why not?

2) If applicable, describe a notable work event (or experience) from your current job where you used engineering skills.

3) What were these skills?

4) Why would you consider them engineering skills?

Our second survey consisted of follow-up questions asked of engineers, so it did not include non-engineers. Our third online survey is still being administered. To data, it has been sent out to 800 individuals who have been involved in professional development courses related to engineering through this same large, public university. Of the responses, 19 are from individuals who selected their current position as being, "Engineering background, but not in an engineering field (not in an engineering company)." We asked these individuals one unique question related to the topic at hand: "How, if at all, do you still use the skills you learned in your engineering education?"

We were assisted in the design of these surveys by the engineers and engineering managers of the college's technical communication advisory board, faculty within the Engineering Professional Development department, our NSF grant advisory board, and faculty and graduate students from the School of Education. We also 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 referenced, we also used the work of David Shaffer to guide us in asking questions to uncover the "epistemic frame" of engineers, a picture of the epistemology of engineering, or what makes an engineer, an engineer[18,19]. Engineers from different backgrounds piloted each of the surveys. Their responses were used to refine the questions, making sure they were understandable and similarly interpreted across individuals. Answers from the first survey were also used to formulate and refine the second and third surveys.

We allowed for open-ended responses to gain a more authentic understanding of these individuals' viewpoints, as use of grounded theory suggests. We then used a thematic analysis approach to find themes within these answers[22]. At least two researchers reviewed the data in generating each theme to add to the validity of the findings.

Because surveys were only sent out to alumni of one large, public research university, or individuals involved in professional development at this university, there will be some measure of selection bias to the survey responses. However, because of the variety of non-engineering disciplines represented by the individuals and their differing backgrounds, they do provide a useful picture of how engineering applies to a wide range of practice. Statistically, they are not representative of all non-engineering disciplines, but they provide an informative cross-section.

Through the course of our case studies and other interviews we also connected with a number of individuals who have engineering degrees, but no longer work in a position which they consider engineering, such as marketing or business management (n=7). These interviews were conducted by the authors and by engineering students in their first year technical communications course. Interviews were guided by an interview protocol consisting of 15 open ended questions. The questions ask about the individual's current job, notable events in their work, values in relation to their work, continuing education, and advice to new engineers. With individuals no longer in engineering, we also asked them how they use their engineering background in their current position and worked to elicit specific examples of that. Most of these individuals were not graduates of the same large, public university, so they provide a basic means to examine the possible bias of other respondents. Qualitatively, we could see no clear differences between the themes of their responses and those of other interview and survey subjects.

Data and Findings

In the initial survey, we first asked non-engineers, "Even though you are working in a different field, do you still consider yourself an engineer? Why or why not?" As shown in Figure 1, a substantial majority (73%) of the 93 respondents said that they did still consider themselves engineers.

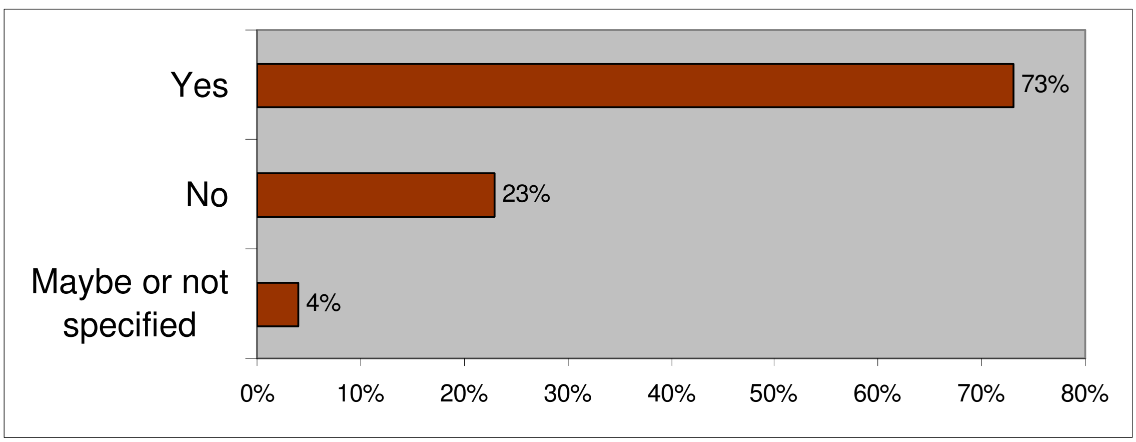

Figure 1: Survey responses of individuals with an engineering background but no longer working in an engineering field to question of whether they still consider themselves engineers (n=93).

For those selecting yes, four major themes arose as to why they still consider themselves engineers. These themes were the following: 1) they still used the problem solving skills they learned in engineering schooling or work; 2) in their current work they applied technical knowledge or skills they learned in their engineering education; 3) they feel that they still think about their work and their life like an engineer; and 4) they have to communicate and often translate technical information to various audiences as part of their work. The frequencies of these themes are listed in Figure 2; in some responses more than one theme appeared.

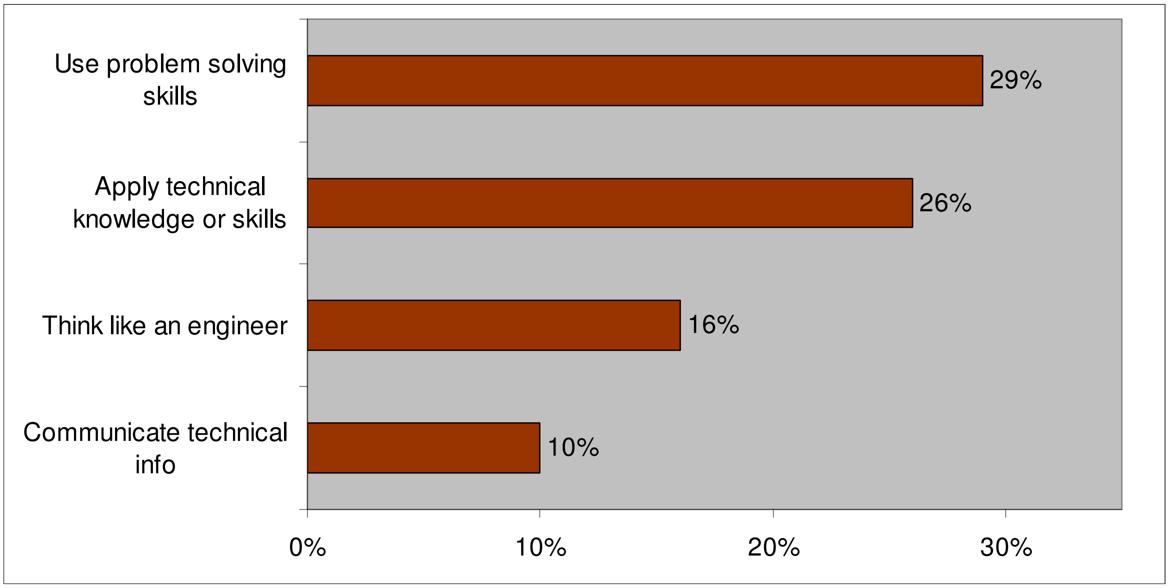

Figure 2: Reasons why individuals still consider themselves engineers even though they are no longer hold an engineering position (n=68).

When describing why they still think of themselves as engineers, many individuals shared arguably passionate answers. One engineer shared some common ideas in his strong response to whether he still considered himself an engineer:

> "Absolutely. My problem solving skills, my logic based approach to issues, my understanding of processes, my data-based research methods, my mathematical understanding & usage of statistical methods are all a basis of my engineering background and education. It is hard to find people with that skill set in the Finance & Human Resource world, so engineers are the best place to find the skill set. My boss specifically sought out an engineer to fill the role."

Another common saying among respondents was, "Once an engineer, always an engineer!" They felt that the work they put into their degree, and the mindset and skills it engendered, qualified them as engineers for life regardless of current title.

Of the 23% of respondents who no longer considered themselves engineers, many still noted the value they placed on their engineering degree and training. Twenty-four percent of this group talked about still using and valuing their engineering background. For example, one woman said, "As a stay at home mom, I implemented 'processes' in our home to help things run more smoothly. It drives my husband crazy, but I have a reason for the way I do just about everything, right down to placing a dish in the dishwasher." Another 24% felt like they were no longer engineers, because they did not use those skills in their current job. Obviously, much of the reasoning behind why they still considered themselves engineers or not depended on personal opinion. One individual stated, "When asked, I do not say I am an engineer... I believe I still think like an industrial engineer in that I am focused on process and how the data is used by those that want to use it." While this person does not consider him/herself an engineer, others expressing similar sentiments did.

In the first survey, we next asked these individuals to "describe a notable work event (or experience) from your current job where you used engineering skills" if it is applicable. Among the 62 responses, almost all discussed problem solving activities or analytical thinking in some form. The most common six themes in their responses can be found in Figure 3; again some responses contained more than one theme.

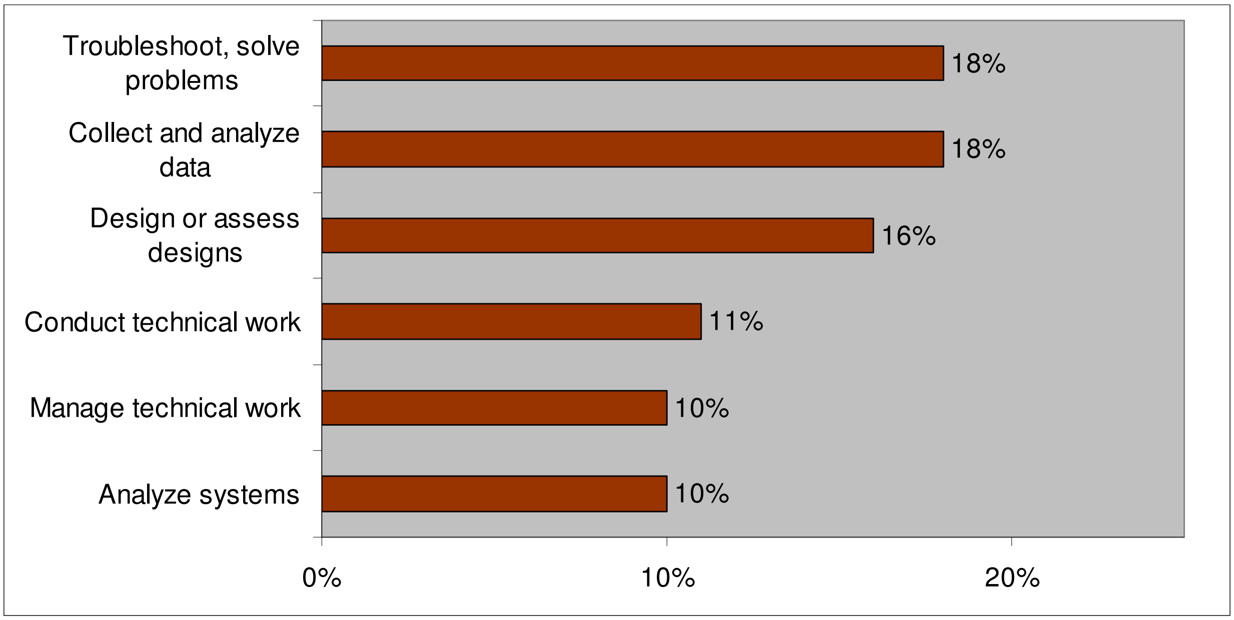

Figure 3: Themes to survey responses describing a notable work event that used engineering skills (n=62).

Interviewees, like survey respondents, typically described how the careful analytical problem solving of engineering applied in their current work contexts. As one interviewee said, when "engineers approach problems, they bring a certain approach, a process based, scientifically based, logic based approach to problem solve." One survey respondent also shared some common ideas on the value of engineering problem solving skills:

> "In some respects I use problem solving skills everyday. You would be surprised how many people have very limited capacity to solve problems. The ability to define a problem, layout a set of principles to apply, agree on constraints, apply math and or logic to arrive at conclusions, is something few people do well. My engineering training enables me to separate the facts from the emotion better than many of my peers."

Individuals also described applying their analytical thinking skills used in problem solving to collecting data and using statistical analysis to make sense of this data. Some described having a project to analyze business practices or current organizational systems where they collected significant data, analyzed that data, and then had to suggest recommendations or make changes based on what they found. Within both interviews and surveys these individuals also described either personally using technical skills or needing to be familiar with them as they managed other engineers using these skills.

In the third online survey, which is still in progress, fifteen individuals no longer in engineering answered the question, "How, if at all, do you still use the skills you learned in your engineering education?" Their answers support the above findings of descriptions of notable work events. Many described applying engineering background knowledge to solve problems, evaluate work or make decisions. They also described how having a technical background made them better at management within a technical environment.

In the initial survey, as a follow up to the question about a notable work event using engineering skills, we asked what those skills were. The top 6 themes that came up in these 60 responses are summarized in Figure 4. The percentages again total more than 100% as respondents gave answers that included multiple themes.

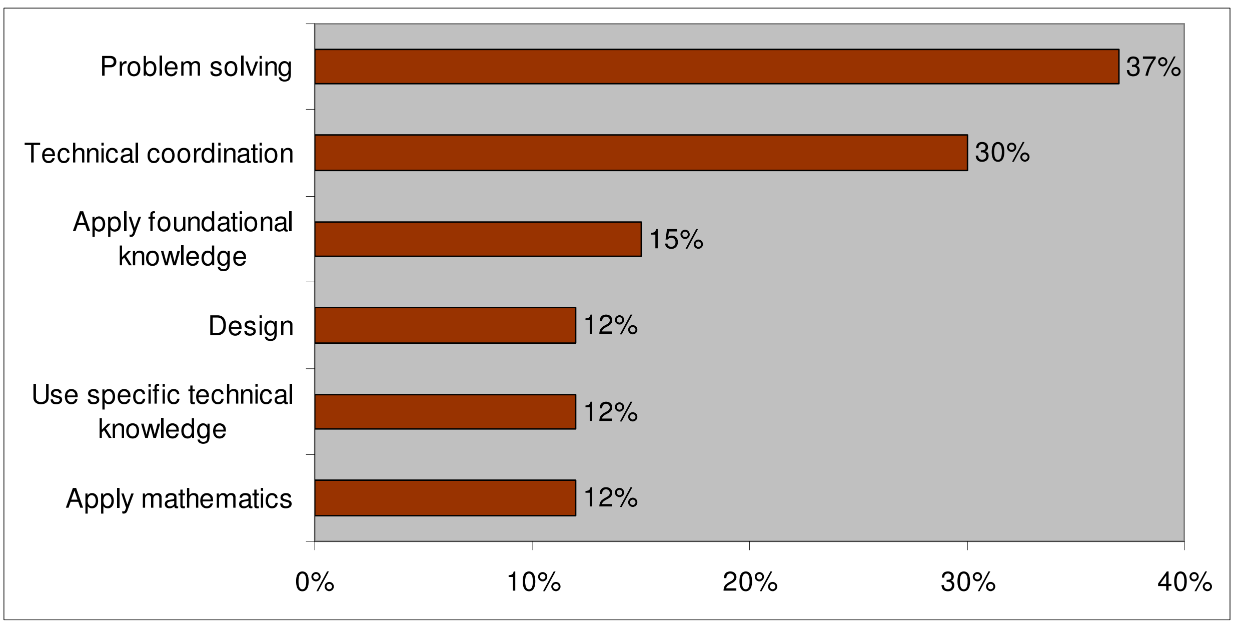

Figure 4: Survey responses on engineering skills that were used in notable work events of individuals no longer in engineering positions (n=60).

Once more, elements of problem solving appeared most frequently in the survey and interview descriptions of skills used. Specific mentions of "problem solving" occurred in only 15% of surveys, but mention of analytical thinking or reasoning occurred in 25%, gathering and using data came up in 8%, and defining problems arose in 3%. Individuals cited using their ability to "think through problems," which they learned within engineering. One interviewee gave insights into using this problem solving. He said, "I guess that many people would say that I am not really an engineer anymore. But, I think that engineering taught me a systematic way to evaluate operations and solve problems that is applicable to many problems that all businesses face."

Within the survey individuals also mentioned technical coordination as an important skill (see Trevelyan, 2007, for further detail on this skill[2]). We saw the technical coordination theme as encompassing project and process management, and improving organizational systems as done through Lean manufacturing or Six Sigma. Thirty percent of individuals in the survey talked about these skills of "project planning and monitoring" and "process improvement." Interviewees also discussed the importance of this skill. As one interviewee described, "We had this product that we were struggling making outside due to issues with the supplier, being consistent with delivery, quality, and cost. Much of the problem was our problem of having poor processes in managing that supplier." He then described how he helped manage the team which "insourced" this product—beginning to manufacture it in house.

Other themes of key engineering skills still used included applying foundational knowledge, applying math skills, designing products and processes, modeling, and using specific technical knowledge. However, interview data did not support all of these themes. Interviewees mentioned using their technical knowledge, particularly in negotiating between technical and non-technical groups. Perhaps the absence of the other themes is due to a smaller interview sample.

Finally, in the initial survey we asked why individuals would consider these skills engineering skills. The most common theme in the 58 responses surprised us. Thirty four percent of respondents said that these were engineering skills because they learned them within their formal engineering education. Because this explanation is circular reasoning, it is not particularly useful in describing what engineering is. One such response was, "They use engineering principles and concepts that are directly transferrable from my electrical engineering education." But, what are those principles and concepts? The top 6 themes of responses for why these skills are engineering are shown in Figure 5.

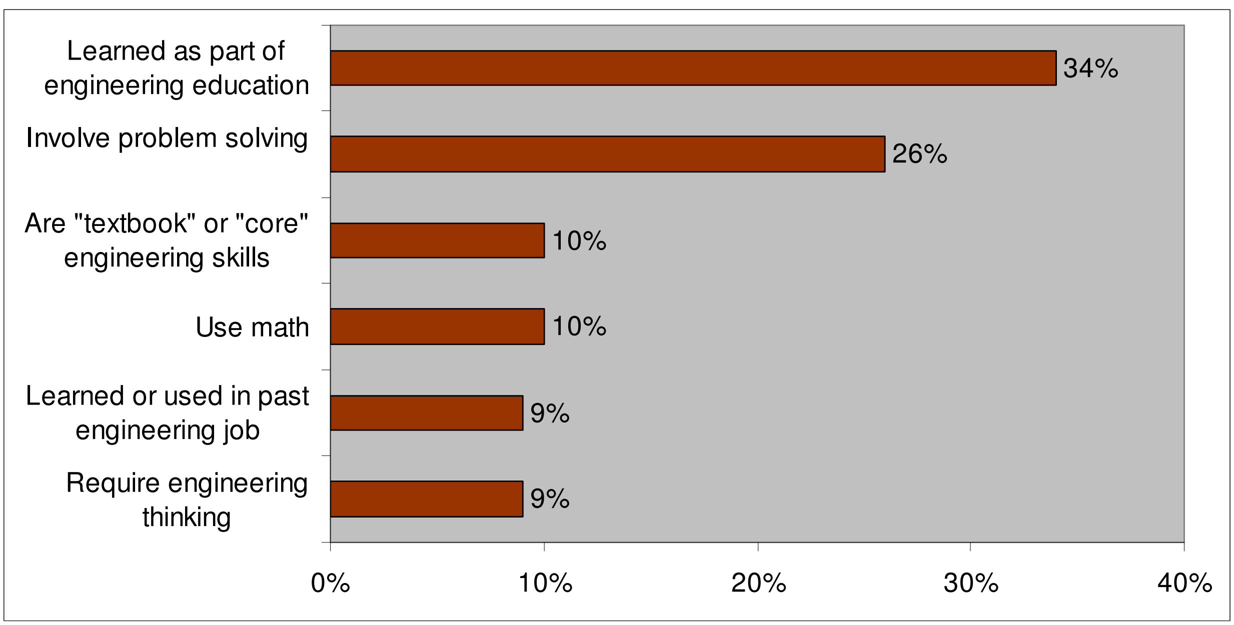

Figure 5: Survey responses on why the skills described by individuals not in engineering positions can be described as engineering skills (n=58).

The second most common response returns to the most common theme among the responses: the skill involved problem solving and addressing real world problems, which is what engineering is all about.

One of the next most frequent responses also invokes circular reasoning. Ten percent of respondents said that these skills are engineering skills, because they are “textbook” or “core” engineering skills. As one said, “They are core to any engineers’ tool set.”

When a notable work event used math skills, these were described as engineering skills, because math-based problems were seen as engineering problems. As one respondent said, “Understanding engineering requires math but in a much more rigorous way in that it is applied to challenging problems” from the real world. Notably, while this emphasis on applying math skills could be seen as a core engineering skill, the respondents rarely described them in that way, so we kept them as a separate theme.

The final two themes connected with previous themes. Individuals felt that skills were engineering skills if they were learned in past engineering jobs or involved what they considered to be engineering thinking.

Conclusion

Through the perspective of individuals with engineering backgrounds who are no longer in engineering roles, we broaden the understanding of what it means to know engineering and think like an engineer. Even though these people are no longer practicing engineers in a traditional sense, we see that they typically still hold on to their identity as engineers, and almost always greatly value that background. They see that the careful problem solving and analytical thinking of engineers continues to usefully apply in their current positions, and thus reinforces their engineering identity. When individuals no longer considered themselves engineers, they often either described not feeling like they were using engineering skills any longer, or they seemed to connect engineering with an official title as engineer.

In the notable work events they described, engineering problem solving and ways of thinking came up as key components, but the process of data collection and analysis came up just as much. It seems that many individuals see a real-world example of engineering problem solving and thinking in this scientific process of figuring out what data to collect to solve a problem, collecting that data, analyzing it, and then applying it.

Not surprisingly, these individuals seemed to have more difficulty thinking about why certain skills are engineering skills. Describing skills as engineering simply because they are used in engineering jobs or learned in engineering programs does little to elucidate the underlying nature of engineering.

Where these respondents did more fully describe what they meant by engineering skills, their responses connected with ideas from the literature. In the literature review above, we focused on the themes of complex, messy problem solving and complex social interactions. Both of these ideas came up in responses, but with some elements missing. These individuals rarely discussed the messiness of the problem solving. Instead, they focused on the systematic and analytic nature of it. Additionally, while they discussed the complexity of program and process management, they did not often emphasize the underlying communication skills necessary. When they brought up communication, they often emphasized the skill of translating technical information for a non-technical audience. Engineers and engineering managers brought up communication much more directly and frequently in surveys and interviews than individuals no longer in engineering[3]. Why? Maybe engineering is still not generally perceived as a social enterprise with the key skill of communication, even though research consistently shows that it is.

We feel that this work implies some changes for engineering education. First, while problem solving receives significant attention in engineering, coordinating complex projects with a wide range of actors, usually does not. Some programs around the country use this type of pedagogy[23,24], but they should become more commonplace. Educators could also encourage students to be more metacognitive about what they are learning and doing, and what it means within engineering careers. Next, because so many graduates do not pursue or stay in engineering careers, it would be useful to broaden education pathways to allow students to gain some technical knowledge without completing a full engineering major. Perhaps, as has been suggested, more minors in engineering or combined engineering and business degrees could fill that role. Finally, these findings indicate definite benefits of an engineering education to non-engineers. Therefore, we feel that engineering degrees could be more effectively marketed to a wider group of students, perhaps increasing the number of students who pursue engineering degrees. Many engineering students and K-12 students not only have misperceptions about what traditional engineers do, but do not know how an engineering degree might benefit them in careers beyond engineering.

This study has some limitations. These individuals agreed to be participate in interviews or online surveys, which can indicate a bias. Most survey respondents were also graduates of one large, research institution (although the vast majority of interviewees and respondents to the other supporting survey were not). Survey responses did not allow for elaboration or follow up questioning, which may lead to some misinterpretation of answers. While interviews did allow for clarification, the interviewers did not always push for more details or examples about what interviewees meant. Finally, some of these individuals did practice engineering in the past, and some did not, but the data collection methods used to date do not allow us to differentiate between these groups. The third survey currently in progress will allow us to analyze differences between those two groups.

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