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Industry Assessment of Multidisciplinary Teamwork Skills

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ABSTRACT

Background
Technology and globalization have created a world of complex problems that require complex solutions. Consequently, engineering students are inheriting a future that will require them to work on teams with other engineers from different disciplines, scientists, and other non-engineers.

Purpose
Our research explores whether, in addition to traditional teamwork skills, there are skills specific to working effectively on multidisciplinary engineering teams that can better prepare students to enter the modern workforce and accelerate their ability to deliver meaningful impacts.

Method
To determine whether there are skills specific to working effectively on multidisciplinary engineering teams, we employed three stages of research: a literature review, stakeholder interviews, and a survey. The literature review produced questions used to conduct interviews of working engineers. In turn, the interviews provided content for a survey that was completed by 156 industry professionals to evaluate skills specific to working on multidisciplinary engineering teams.

Results
The interviews with practicing engineers revealed the existence of seven key skills specific to working on effective multidisciplinary engineering teams. The importance of these skills was confirmed by the subsequent survey, which further revealed that respondents believe that the majority of entry-level engineering hires are not proficient in these core multidisciplinary skills at the date of hire.

Conclusions
The results suggest several opportunities for future research, including analyzing the findings in light of key demographics, skill development, and hiring practices. As engineering educators, we hope to uncover and design approaches that will better prepare our students to enter the modern workforce and develop meaningful solutions through multidisciplinary collaboration.

Keywords: Multidisciplinary, professional skills, teamwork, engineering profession, industry perspective

1. INTRODUCTION AND BACKGROUND

Technology and globalization have created a world of complex problems that require complex solutions. Consequently, engineering students are inheriting a future that

will require them to work on teams with engineers from a range of disciplines, scientists, and other non-engineers. As the US National Academy of Engineering asserted in their report *The Engineer of 2020*, while engineering has always engaged multiple stakeholders, it will "increasingly involve interdisciplinary teams, globally diverse team members, public officials, and a global customer base" (National Academy of Engineering U. S., 2004, p. 55; Handford, Van Maele, Matuous, & Maemura, 2019, p. 162). Our research explores whether, in addition to traditional teamwork skills, there are skills specific to working effectively on multidisciplinary engineering teams that can better prepare students to enter the modern workforce and accelerate their ability to deliver meaningful impacts.

For the purposes of this paper, we define multidisciplinary teams as teams composed of members with specialized understanding, training, or experience in different disciplines who must work together to achieve a common goal. A multidisciplinary engineering team may be composed of different engineering disciplines alone, such as a device development team that includes mechanical, electrical, and computer engineers. A multidisciplinary engineering team may also include non-engineers, such as medical professionals, marketers, and financial managers. The distinction we are drawing between multidisciplinary and interdisciplinary for this paper is that "multidisciplinary" implies a team of individuals with discrete skill sets or knowledge areas whereas "interdisciplinary" refers to programs, problems, and projects that integrate or require skill sets, knowledge, or both from different disciplines.

Undergraduate engineering programs have long recognized the importance of preparing students with teamwork skills (Adair & Jaeger, 2014; Chang, 2006; Gilbert, Held, Ellzey, Bailey, & Young, 2015; Lundy & Aceros, 2016; Nugent & Kulkarni, 2013). More recently, many schools have begun offering courses and programs to engage engineering students in interdisciplinary and multidisciplinary teamwork experiences to meet the demands of industry, research, and accreditation. The Accreditation Board for Engineering and Technology (ABET), European Network for Accreditation of Engineering Education (ENAEE), and Federation of Engineering Institutions in Asia and the Pacific (FEIAP) have together called for engineering professionals who "have the skills and attributes to communicate and work in teams with professionals in wide ranging fields" (Handford et al., 2019, p. 162; FEIAP, 2010, p. 12).

Industry journals reinforce this demand for engineers who can function on multidisciplinary teams and deliver interdisciplinary outcomes by emphasizing their role in "[translating] bench discovery to bedside" (Von Roth, Canny, Volk, Noble, Prober, Perka, & Duda, 2011, p. 1145) and "[meeting] workforce demands within life sciences" (Nugent & Kulkarni, 2013, p. 854). Specific demands include the need to improve methods for imaging chemical systems (Cordes & Blum, 2013), "develop clinically relevant biomaterials" (Fong, Watson, Kasper, & Mikos, 2012), and build and expand genome-scale network reconstructions (Monk, Nogales, & Palsson, 2014). Industry journals expand on the need for multidisciplinary teams through calls to "solve problems with energy storage and conversion" (Yang & Tarascon, 2012, p. 560) and create new materials and systems that are more sophisticated, "recyclable, reliable, and consume less energy" (Sanchez, Arribart, & Guille, 2005), and more.

Research shows that positive multidisciplinary team outcomes are more likely when each individual team member has prior experience demonstrating interdisciplinary thinking and

working in teams with interdisciplinary goals (Spelt, Luning, van Boekel, & Mulder, 2017; Turner, Benessaiah, Warren, & Iwaniec, 2015). To meet the Grand Challenges laid out by the National Academy of Engineering in 2013 of addressing challenges ranging from preventing nuclear terror to providing clean access to water, "engineers must possess not only deep technical expertise, but also… the ability to collaborate on interdisciplinary teams" (Walther, Miller, & Sochacka, 2017). Many universities have responded to this research on the importance of interdisciplinary thinking and the need for multidisciplinary teamwork skills by creating new capstone and other projects along with new courses and curricula (Adair & Jaeger, 2014; Gilbert et al., 2015; Lundy & Aceros, 2016).

While much has been written about the importance of preparing engineering students to work effectively on multidisciplinary teams, very little has been published identifying the skills needed to do so from the perspective of engineers currently practicing within industry and others who work with or supervise them. As engineering educators, we wanted to know if there are skills specific to the success of multidisciplinary teams, as differentiated from general teamwork skills, with the ultimate goal of incorporating the skills into our course learning objectives and activities. Further, we were unable to find research focused specifically on the importance of multidisciplinary teamwork skills and their prevalence among newly graduated engineers from the perspective of industry. Thus, our research reflects a desire to gain this industry perspective and identify a list of multidisciplinary teamwork skills that working engineers agreed were important to the success of their organizations and projects.

In this paper, we have built on existing literature and interviews with industry professionals to construct and carry out a survey to answer the following primary research questions:

1. Are there skills specific to working effectively on multidisciplinary teams?
2. How competent are newly hired engineering employees (i.e. entry-level hires) with these skills?
3. How long does it take a newly hired engineering employee unequipped in these skills to become proficient in their execution?

Regarding question 1, we hypothesized that industry professionals would confirm the existence of skills specific to working effectively on multidisciplinary engineering teams. We did not know what to expect from the responses to questions 2 and 3 and therefore did not venture hypotheses for these questions. This work has the potential to help engineering educators develop curricula to better prepare students to meet the needs of the modern workforce and accelerate students' ability to meaningfully impact their future projects and organizations.

2. APPROACH

In order to determine whether there are skills specific to working effectively on multidisciplinary engineering teams from an industry perspective, we employed three stages of research: a literature review, stakeholder interviews, and a survey. The literature review established a foundation for the research while suggesting a new area of inquiry. We then formulated open-ended questions based on the findings from the literature review in order to interview working engineers with the goal of both testing our hypothesis and generating content for a more robust

survey. Finally, we designed and distributed a survey to industry professionals to further test and evaluate skills specific to working on multidisciplinary engineering teams.

2.1 Literature Review

Literature searches were conducted using PubMed, Academic Search Ultimate, Web of Science, and Engineering Village. We sought articles published between 2000 and 2019 using various combinations of key terms such as *interdisciplinary* and *multidisciplinary engineering teams, teaching, education, competencies, skills, workforce, activities, programs,* and *training*. The goal of our search was to support the review with evidence from both high impact technical engineering journals and engineering education journals, as well as evidence from both academia and industry stakeholders. We also reviewed references from the assembled articles, and the search strategy yielded more than 30 articles.

2.2 Interviews

Following the literature review, we conducted one-on-one interviews with 18 practicing engineers to investigate whether or not they perceived any skills that are specific to working effectively on multidisciplinary teams. The first interviewees were professionals known by the authors. We then used snowball sampling to acquire additional interviewees.

We interviewed only people who were supervisors and/or members of a multidisciplinary team that included engineers. Beyond those requirements, we were open to a range of perspectives, and received feedback representing early stage, mid-stage, and late-stage careers, and professionals who work in a variety of industries and government institutions, including automotive, engineering consulting, and product development. Interviewees also represented a variety of engineering disciplines, including mechanical, civil, and materials science. Sixteen of the initial interviewees were male and two were female.

We asked each interviewee a series of questions about their professional experience working on and supervising teams. At the start of our conversations, we were careful not to use terms such as “multidisciplinary” and “interdisciplinary” so as not to influence answers, and we transcribed the responses of each individual as they were interviewed. The complete list of interview questions is available in Appendix 1.

Once we completed the interviews, we identified the various teamwork skills mentioned by each interviewee. We then further identified the skills as either “general” teamwork skills or skills particular to working on a multidisciplinary team. For example, oral communication was considered a “general” teamwork skill, whereas the ability to communicate with others outside of one’s own discipline was considered a skill specific to multidisciplinary teams. We further refined the skills specific to multidisciplinary teams by using keywords and context to group similar, but differently expressed, skills together.

Finally, based on the frequency of the various skills mentioned by the interviewees, we identified an initial set of seven key skills specific to effective multidisciplinary teamwork. These skills, along with individual and organizational demographics, became the foundation for the survey.

2.3 Survey

After identifying seven key skills related to multidisciplinary teamwork, we used an online survey platform to gather information from STEM industry professionals. Using a convenience sample, we initially contacted working engineers known to the authors through our personal and professional networks and university connections. We also asked participants to forward the survey link to their workplace colleagues and LinkedIn contacts. Finally, we made a general request for participants through LinkedIn with the following hashtags: #name of our university, #faculty, #engineering, #engineers, #engineeringeducation, and #department name. The survey was posted for 20 days in July 2019 and the full set of survey questions are presented in Appendix 2.

The survey elicited 191 responses and respondents were given the option to remain anonymous. To complete the survey, participants had to answer initial screening questions to indicate that they had experience as a member or supervisor of a multidisciplinary team that included at least one engineer. Of the 191 people who responded to the survey, 156 indicated that they met our screening criteria. For the remainder of this paper, the term "respondents" will refer only to these 156 participants.

Upon meeting the initial screening criteria, respondents were asked to rate each of the seven key multidisciplinary skills on the three metrics noted below (see Appendix 2 for survey presentation). Both Likert Scale and Fixed Alternative question formats were used.

1. The skill's importance to working effectively on a multi-disciplinary team.

   Rating options:
   Not at all important
   Not so important
   Somewhat important
   Very important
   Extremely important

2. Percentage of entry-level hires that are proficient in the skill at date of hire.

   Rating options:
   None
   1% to 25%
   26% to 50%
   51% to 75%
   76% to 100%

3. How long it takes for entry-level hires who are not already proficient in the skill to become proficient.

   Rating options:
   1 to 3 months
   3+ to 6 months
   6+ to 12 months
   12+ to 24 months
   24+ to 60 months

For each skill, we provided one or two examples to help the respondent understand its meaning. As an illustration, for Skill 1, the "ability to consistently communicate clearly and respectfully to others outside of one's own discipline," the example we provided was: "the engineer who patiently explains the technical challenges of a proposed idea to a marketing manager without sounding patronizing." All of the examples are included with the survey in Appendix 2.

After rating each of the seven skills on the three metrics, respondents were asked for information on their professional status, including title, employer size and industry, and years of professional experience. The survey also included optional questions about education and gender. They were invited to leave contact information; otherwise their results were anonymous.

3. RESULTS

As with the approach, the results of our research were associated with three distinct yet interconnected stages: a literature review, stakeholder interviews, and a survey. The literature review suggested a need to explore skills specific to multidisciplinary engineering teams from an industry perspective. Stakeholder interviews allowed us to identify and articulate seven key skills for further investigation. And, finally, the survey confirmed the importance of skills specific to working effectively on multidisciplinary engineering teams from an industry perspective while also suggesting several trends for future consideration.

3.1 Literature Review

Our literature review yielded several findings. First, universities and accreditation boards are already investing significant thought and action into preparing engineers to work on teams (Adair & Jaeger, 2014; Gilbert et al., 2015; Lundy & Aceros, 2016; Handford et al., 2019). Further, educators and professional engineering organizations (e.g. ASME, ASCE) recognize the importance of preparing engineering students to work effectively on *multidisciplinary* teams (ASCE, 2019; ASME, 2011; Mostafavi, Huff, Abraham, Oakes, & Zoltowski, 2016; Ravesteijn, Graaff, & Kroesen, 2006). However, while the phrase "multidisciplinary skills" (and "multidisciplinary education" and "multidisciplinary thinking," to a lesser extent) occurs frequently in the engineering education literature, we were unable to locate a reference in which this particular set of skills was clearly identified and articulated. Ravesteijn et al. (2006) come closest in this regard by citing the need for "communicative competence" and "a combination of critique and respect" among engineers working on multidisciplinary teams.

We also discovered a lack of input from industry practitioners concerning specific skills needed to succeed on multidisciplinary engineering teams. Publications such as the ASCE *Civil Engineering Body of Knowledge* (ASCE, 2019) and the ASME *Vision 2030* report (ASME, 2011) do promote the importance of multidisciplinary teamwork based on industry survey results. However, they do not identify specific multidisciplinary skills, nor do they mention the current proficiency of such skills in newly-graduated engineers.

3.2 Interviews

The interviews of 18 practicing engineers who work on and/or supervise multidisciplinary teams revealed a clear awareness by industry professionals of the importance of teamwork skills to the success of engineering projects. After filtering "general" teamwork skills, such as oral and written communication, conflict management, and time management from the results, we then took the remaining skills specific to multidisciplinary teamwork and grouped similar, but differently expressed, skills together.

For example, the following two comments, from two different interviewees, were grouped together:

1. "The challenge comes from lack of understanding or empathy from one discipline to the next."

2. "…a lack of 'work empathy' for the challenges and rigors that people from outside one's discipline face."

While both comments were framed around challenges, they can be understood as support for the importance of appreciating the contributions of teammates from outside one's own discipline.

Finally, based on the frequency of the various skills mentioned by the interviewees, we identified an initial set of seven key skills specific to effective multidisciplinary teamwork. These seven skills are presented in table 1 in the order in which we presented them in the survey.

Table 1 – Seven key skills specific to effective multidisciplinary teamwork

Skill No.	Skill Description
1	Ability to consistently communicate clearly and respectfully to others outside of one's own discipline.
2	Ability to acclimate quickly to a different industry- or discipline-specific vocabulary.
3	Ability to adapt quickly to different work and communication styles.
4	Ability to recognize and understand quickly how one's work supports the work of teammates from outside one's own discipline.
5	Ability to quickly recognize and understand how the work of teammates from outside one's discipline supports one's own work.
6	Awareness of, and comfort with, one's own lack of knowledge around the challenges faced by teammates from outside one's own discipline.
7	Respect for the chosen profession of teammates from outside of one's own discipline.

Among the seven key multidisciplinary teamwork skills we identified, we noticed several themes. For example, skills 1-3 are all related to communication. Skills 1, 4, and 7 relate to respect. Skills 4 and 5 relate to the appreciation of the contributions of each team member. And, skills 2 and 3 are related to the ability to learn and adapt quickly.

Taken together, the seven skills might be considered illustrations of "Multidisciplinary Emotional Intelligence" or MEQ. For reference, emotional intelligence (EQ) "includes the ability to engage in sophisticated information processing about one's own and others' emotions and the ability to use this information as a guide to thinking and behavior" (Mayer, Salovey, & Caruso, 2008). MEQ combines work empathy skills with the skills of communication, learning, and adaptation as they relate specifically to the various disciplines on the team (see Appendix 3 for links between skills specific to multidisciplinary teamwork and specific EQ skills).

When we asked the interviewees if new engineers possessed the skills they mentioned upon entering the workforce, seven of the interviewees responded with an absolute "no." The other responses to this question included variations of "most do not" or "some do." And one interviewee remarked, "the good ones do." These answers suggest a potential need in current engineering curricula.

We also discussed how long it takes new employees to develop teamwork skills on the job and received inconsistent answers. Some claimed that the skills could be learned "quickly," while others stated that it takes "a long time." One interviewee referenced co-worker consensus that "it

takes two years to train [a newly graduated engineer] how to work on a [multidisciplinary] team." This variation suggested the need for more investigation across a larger sample. More broadly, these answers along with the seven skills identified from the interviews provided the basis for the survey.

3.3 Survey

The 156 survey respondents represented a wide range of demographic perspectives. In terms of identified industry, "Engineering Services (not including IT)" made up the biggest allocation, representing 37% of respondents. The next two allocations went to "Manufacturing" with 14% and "Other Consulting (neither engineering nor IT)" with 13%. "Information Technology," "Government," and "Health, Medicine, or Social Care," clustered around 10%, 9%, and 8% respectively. "Education" with 4% and "Finance" with 3% completed the distribution (see Table 2).

Table 2 – Percent of survey respondents per industry

Industry	Percent of Respondents
Engineering Services (not including IT)	37%
Manufacturing	14%
Other Consulting (neither engineering nor IT)	13%
Information Technology	10%
Government	9%
Health, Medicine, or Social Care	8%
Education	4%
Finance or Insurance	3%

The respondents also worked in a wide range of organization sizes, with 37% working in organizations with more than 5,000 employees down to 9% working in organizations with fewer than 10 employees (see Figure 1).

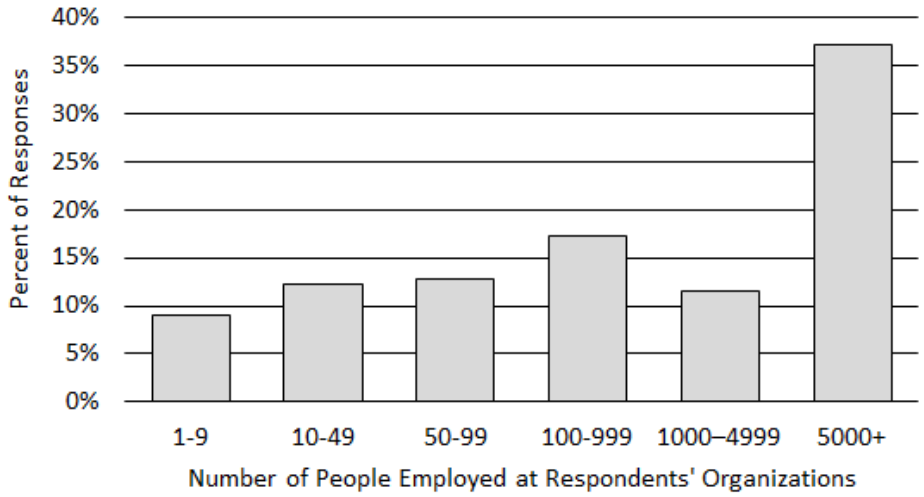

Figure 1 – Distribution of organization sizes among respondents

The majority of respondents had more than three years of professional work experience, with 44% of respondents reporting more than 10 years of experience (see Figure 2).

Figure 2 – Distribution of years of professional work experience among respondents

Other demographic information of note reported by the respondents includes:

- 90% have at least one degree in engineering
- 63% are in managerial or supervisory positions
- 54% are involved in the hiring process of entry-level engineers
- 77% work directly with their organizations' clients

Also, of the 147 respondents who chose to indicate their gender, the ratio of male:female respondents was 65:35%.

3.3.1 Unconditioned Results

The following three figures use segmented bar charts to present the ratings for each of the seven MEQ skills based on the complete set of respondents unfiltered by demographic information. For reference, see Table 1 for a description of the skills as they appeared in the survey.

Figure 3 presents the rating for our first metric: "Rank the skill's importance to working effectively on a multi-disciplinary team." It is clear that most of the respondents perceive all seven skills to be "very" or "extremely" important.

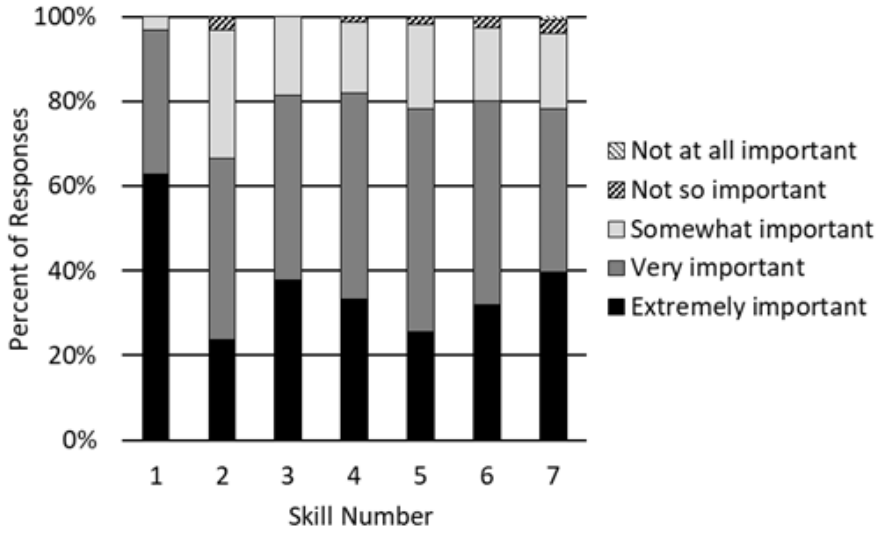

Figure 3 – Distribution of respondents' ratings to metric 1 (importance of skill) for each of the seven key multidisciplinary skills.

Figure 4 presents the ratings for metric 2: "What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?" Note that most of the respondents believe that the majority of entry-level hires are not proficient in the seven key multidisciplinary teamwork skills when they are first hired.

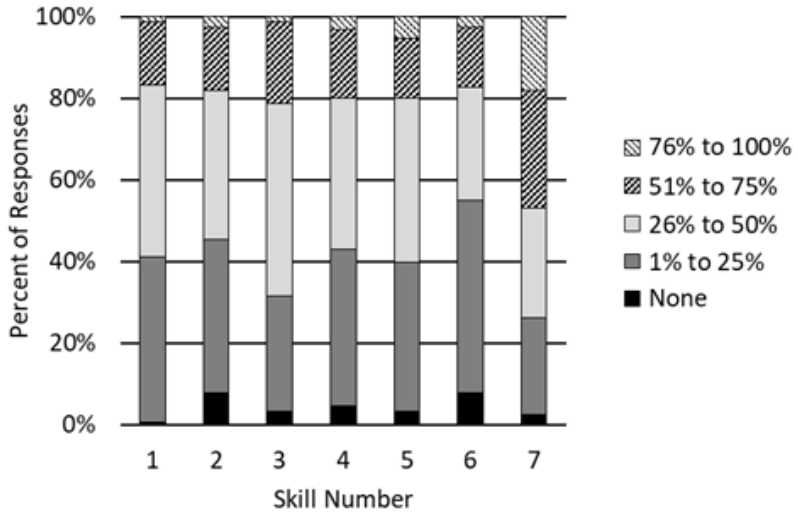

Figure 4 – Distribution of respondents' ratings to metric 2 (proficiency of skill in entry-level hires) for each of the seven key multidisciplinary skills.

Figure 5 presents the ratings for metric 3: "About how long does it take entry-level hires who are not already proficient in the skill to become proficient?" Contrary to the response of one of the initial 18 interviewees who referenced co-worker consensus that "it takes two years to train someone how to work on a team," most of the survey respondents believe that the seven skills can be acquired to proficiency within one year.

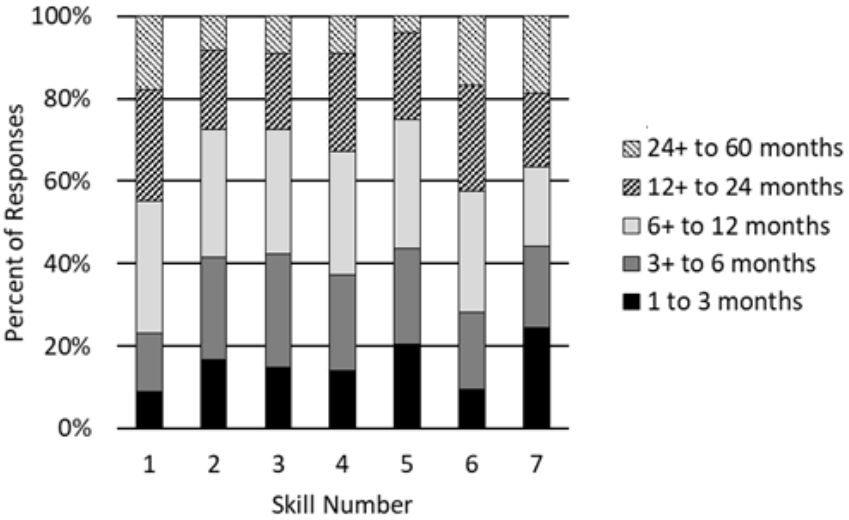

Figure 5 – Distribution of respondents' ratings to metric 3 (time to proficiency) for each of the seven key multidisciplinary skills.

In summary, respondents confirmed the importance of the seven key MEQ skills from an industry perspective, indicated that the majority of entry-level hires are not proficient in the skills when they are first hired, and mostly believed that the skills could be taught to proficiency within the first year of employment.

3.3.2 Analysis of Unconditioned Results

Each of the seven key MEQ skills we coded from our initial interviews were rated to be "very" or "extremely" important for effective multidisciplinary teamwork by at least two thirds of the respondents. This rating suggests that the seven skills we identified are indeed perceived by the survey participants as important to effective multidisciplinary teamwork for teams that include at least one engineer.

The highest rated skill in terms of importance, with 97% of respondents indicating that it is either "very" or "extremely" important, is Skill 1: the "ability to consistently communicate clearly and respectfully to others outside of one's own discipline." Skill 2, the "ability to acclimate quickly to a different industry- or discipline-specific vocabulary," was rated lowest of the seven skills in terms of importance, still with 67% of respondents indicating that it is either "very" or "extremely" important. The percentages for the other skills are presented in Table 3, along with additional percentages reflecting whether new employees have the skill at date of hire and whether respondents believe new hires can learn the skill to proficiency within 1 year.

Table 3 – Significant findings supported by respondents' ratings of seven key multidisciplinary skills

Skill	Very or Extremely Important	New Hires Lacking Skill at Date of Hire		Can be Learned in ≤ 1 year
		≥ 50%	≥ 25%	
1. Consistently communicate clearly and respectfully to others outside of one's own discipline	97%	83%	99%	55%
2. Acclimate quickly to a different industry- or discipline-specific vocabulary	67%	82%	97%	72%
3. Adapt quickly to different work and communication styles	81%	79%	99%	72%
4. Recognize and understand quickly how one's work supports the work of teammates from outside one's own discipline	82%	80%	97%	67%
5. Quickly recognize and understand how the work of teammates from outside one's discipline supports one's own work	78%	80%	95%	75%
6. Aware of, and comfortable with, one's own lack of knowledge around the challenges faced by teammates from outside one's own discipline	80%	83%	97%	58%
7. Respect for the chosen profession of teammates from outside of one's own discipline	78%	53%	82%	63%

Regarding our second metric of proficiency at date of hire, we found the perception among most respondents to be that more than half of new hires are not sufficiently proficient in any of the seven skills. For Skills 1-6:

- 79-83% of respondents reported that at least half of their new hires do not possess these skills on their first day of work.
- 95-99% of respondents reported that at least one-quarter of their new hires do not possess these skills on their first day of work.

For Skill 7:

- 53% of respondents reported that at least half of their new hires do not possess this skill on their first day of work.
- 82% of respondents reported that at least one-quarter of their new hires do not possess this skill on their first day of work.

There may be many reasons why engineering graduates do not sufficiently possess these multidisciplinary skills at hire. For example, current engineering programs may not be aware of the importance of these multidisciplinary teamwork skills or may not have designed programs to teach them. Other possibilities include: current hiring practices may be ill-equipped to select for these skills, there is a perception that teamwork skills can be more easily taught whereas select technical proficiencies are considered mandatory, or perhaps these skills are not conducive to being developed adequately in an academic environment and instead have to be learned on the job.

For our final metric, regarding the length of time it takes entry-level hires who are not already proficient to become proficient in the seven skills, most respondents believed that all seven skills could be learned on the job within one year or less. This indicates that it may be possible for universities to teach these skills to students within the time they are enrolled. It is of note that for each skill there are also some respondents who believe that more than two years are needed for an entry-level hire to achieve proficiency. The highest rated skill in terms of importance, Skill 1: the “ability to consistently communicate clearly and respectfully to others outside of one’s own discipline,” is also the skill that appears to take the longest time to develop.

4. FUTURE RESEARCH

The results of the survey suggest several opportunities for future research, starting with a more in-depth analysis of the information already collected and expanding to inquiries related to skill development and hiring practices. To surface additional skills, the survey included an option for respondents to write in a multidisciplinary teamwork skill they believed to be important but was not represented in the seven skills provided. If a respondent chose to do so, they were then asked to rate the additional skill according to the same three metrics as the seven skills. This data may reveal additional skills that are unique to multidisciplinary teams.

Beyond collecting demographic data from respondents in order to verify the diversity of the sample, the data may reveal trends specific to specific groups. A preliminary analysis suggests that factors such as company size, years of experience, gender, and managerial responsibilities

may in fact influence the responses of survey participants. More comprehensive analysis of this data could provide valuable insight into how to best prepare our students for their professional careers, while also suggesting additional lines of inquiry.

As engineering educators, we are particularly interested in continuing our research on multidisciplinary teamwork by investigating the means through which new hires develop the seven key skills on the job, so that we may evaluate whether those means can be better incorporated into engineering curricula. To this aim, we also wish to identify current academic engineering programs and curricula that are actively teaching multidisciplinary teamwork skills. From this work, we could both identify existing needs and compile a set of best practices for enabling engineers to develop these skills before they graduate, or at least for providing a foundation that accelerates the acquisition of these skills on the job.

Given the industry interest we have received in this research, there are a range of questions we could pursue regarding the relationship between multidisciplinary teamwork skills, hiring, and impact. For instance, we could explore the role, if any, the seven key multidisciplinary skills play in the hiring process of entry-level engineers. That is, are job candidates more likely to be hired if they demonstrate proficiency, or even awareness, of these skills? Additionally, we could look into the financial and organizational advantages of hiring engineers already proficient in multidisciplinary teamwork skills.

5. CONCLUSION

Based on our findings, it is clear there are teamwork skills that are unique to functioning on effective multidisciplinary teams. It is also clear that professionals who supervise or work on multidisciplinary teams with at least one engineer value these MEQ skills. In spite of this value, our results indicate that the majority of entry-level engineering hires are not proficient in core multidisciplinary skills at their date of hire.

Moving forward, it is important to assess the role of engineering programs in preparing students to work on teams with engineers from a range of disciplines, scientists, and other non-engineers. This includes additional research into how the skills are developed as well as an evaluation of current efforts within engineering programs. In doing so, we hope to uncover and develop approaches that will better prepare our students to enter the modern workforce and accelerate their ability to deliver meaningful impacts.

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APPENDIX 1**:** One-on-one interviews questions

What is your name, title, employer, engineering discipline?

How many years of full-time professional experience do you have?

1) Do you work in teams? Are those teams comprised of engineers from various disciplines or of at least one engineer and one non-engineer?

2) (If yes to the last question above) Are there challenges specific to these teams?

3) (If yes to #2) What are these challenges and how are they different from the challenges inherent in working on any team?

4) (If yes to #2) Are there skills/capabilities/competencies that new engineering graduates need that would facilitate overcoming these challenges? If yes, what are they?

5) (If yes to the last question above) Do new engineers have these coming out of college? Did you? If not, can they develop them on the job quickly enough that the lack of them is not a problem?

6) Is there anything I did not ask that you think I should know?

APPENDIX 2: Online multidisciplinary teamwork survey

The following survey is designed to gather information from professionals about multi-disciplinary teams, with the goal of uncovering how universities can better prepare students for their postcollegiate lives.

For this survey, "multi-disciplinary" refers to teams composed of individuals from different disciplines who work together to achieve a common goal.

All of your responses will be kept confidential, used only for statistical purposes, and will be reported only in aggregated form. The final report will be presented at the spring 2020 mid-Atlantic ASEE (American Society for Engineering Education) conference, assuming it is accepted. If you would like a copy, please write to (author's name and email were shown here).

*At work, are you a member or supervisor of a multidisciplinary team?

- ❑ Yes
- ❑ No

Does that team include at least one engineer?

- ❑ Yes
- ❑ No

Skill Feedback

For the following 7 skills, please indicate 1) the skill's importance to working effectively on a multi-disciplinary team, 2) the percentage of new hires who begin their career proficient in the skill, and 3) the average time it takes someone who is not proficient in the skill to develop it once hired.

Skill 1. Ability to consistently communicate clearly and respectfully to others outside of one's own discipline.

Example: the engineer who patiently explains the technical challenges of a proposed idea to a marketing manager without sounding patronizing.

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important
- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None

- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months
- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

Skill 2. Ability to acclimate quickly to a different industry- or discipline-specific vocabulary.

Example: the design engineer who understands and re-articulates an artist-customer's vision for new product after listening carefully to the artist and then asking the artist a few astute questions.

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important
- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None
- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months
- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

Skill 3. Ability to adapt quickly to different work and communication styles.

Example: the newly-hired engineer who communicates effectively with a teammate from finance within a relatively short time of working together.

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important
- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None
- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months
- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

Skill 4: Ability to recognize and understand quickly how one's work supports the work of teammates from outside one's own discipline.

Example 1: the mechanical engineer who understands how and why the results of their energy calculations will be used by the electrical engineer.

Example 2: the chemical engineer who appreciates the importance of submitting quarterly reports on time because the business manager needs this information for quarterly projections.

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important
- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None
- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months
- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

Skill 5: Ability to quickly recognize and understand how the work of teammates from outside one's discipline supports one's own work.

Example: the software engineer who appreciates that a quality assurance teammate will be checking their code for errors to ensure they release a quality product.

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important
- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None
- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months

- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

Skill 6: Awareness of, and comfort with, one's own lack of knowledge around the challenges faced by teammates from outside one's own discipline.

Example 1: the bio-medical engineer who respects that the software engineer knows more about coding and accepts the software engineer's longer-than-expected timeline for completion.

Example 2: the civil engineer who recognizes that the construction engineer has to deal with union-related personnel issues that could affect the project schedule if not handled properly.

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important
- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None
- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months
- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

Skill 7: Respect for the chosen profession of teammates from outside of one's own discipline.

Example: the engineer who belittled non-engineering students while in college but now realizes that everyone on the team, regardless of title and discipline, is a colleague deserving of respect and professional courtesy.

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important
- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None
- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months
- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

* Is there another skill not listed that you believe is important to working on a multi-disciplinary team?

- ❑ Yes
- ❑ No

Skills not listed that you believe is important to working effectively on a multidisciplinary team

*Please state skill:

*Rank the skill's importance to working effectively on a multi-disciplinary team/

- ❑ Not at all important
- ❑ Not so important
- ❑ Somewhat important
- ❑ Very important

- ❑ Extremely important

*What percentage of entry-level hires do you estimate are proficient in the skill at date of hire?

- ❑ None
- ❑ 1% to 25%
- ❑ 26% to 50%
- ❑ 51% to 75%
- ❑ 76% to 100%

*About how long does it take entry-level hires who are not already proficient in the skill to become proficient?

- ❑ 1 to 3 months
- ❑ 3+ to 6 months
- ❑ 6+ to 12 months
- ❑ 12+ to 24 months
- ❑ 24+ to 60 months

Supervisory Questions

*Do you have a supervisory role on a multi-disciplinary team?

- ❑ Yes
- ❑ No

Demographic Information

*In which industry do you work?

Other (please specify)

*How many people are employed at your organization?

*What is/are your title?

*How many years of professional work experience do you have (in any capacity, job type or industry)?

If you are willing, please state if you have a degree in engineering.

- ❑ Yes, undergraduate
- ❑ Yes, graduate
- ❑ Yes, both undergraduate and graduate
- ❑ No

*Do you manage/supervise other employees?

- ❑ Yes
- ❑ No

*Are you involved in the hiring process for entry-level engineers?

*Do you work directly with your organization's clients?

- ❑ Yes
- ❑ No

If you are willing to be contacted for follow-up questions, please write your name and contact info.

Name:

Email Address:

Phone Number:

Thank you for your time.

APPENDIX 3: Multidisciplinary Emotional Intelligence

Skill in order of importance (top 4)	Related EQ skill
Ability to consistently **communicate** clearly and **respectfully** to others outside of one's own discipline.	Self-regulation: conscientiousness, adaptability, innovation Empathy: understanding others; developing others; service orientation; leveraging diversity; political awareness Social skills: influence, communication, leadership, building bonds, collaboration and cooperation, team capabilities
Ability to recognize and understand quickly how **one's work supports the work of teammates** from outside one's own discipline.	Self-awareness: accurate self-assessment, self-confidence Self-regulation: adaptability Motivation: commitment Social skills: collaboration and cooperation
Ability to **adapt** quickly to different work and communication styles.	Self-awareness: self-confidence Self-regulation: adaptability, innovation Motivation: initiative Empathy: understanding others, service orientation, leveraging diversity Social skills: influence, communication, change catalyst, building bonds, collaboration and cooperation, team capabilities
Awareness of, and comfort with, **one's own lack of knowledge** around the challenges faced by teammates from outside one's own discipline.	Self-awareness: accurate self-assessment, self-confidence Self-regulation: self-control, adaptability, innovation

EQ skills from Goleman, D. (1998) *Working with Emotional Intelligence*. New York: Bantam Books.