Which skills are more important in the engineering world? Perceptions of college students, recent graduates, and employers

Dimitra Michalaka and Emanuele Giogli
The Citadel, Volvo Car US Operations, Inc.

Abstract

In today's world, engineering problems are very complex, often multi-disciplinary and require a variety of skills to be solved. Engineers needs to be competent in technical matters, able to work in teams, communicate effectively, understand management and leadership concepts, have strong work ethic, and apply critical and analytical skills. But how are the aforementioned skills ranked in terms of importance in the engineering world? This paper examines the perceptions of engineering college students, recent graduates, and employers on the importance of the skills engineers should have. Surveys were administered at The Citadel, and several companies in the southeast U.S. Results are analyzed and presented to better inform and prepare college students for a successful engineering career.

Keywords

Engineering Skills, Student, Recent Graduate, Employer Perceptions

Introduction

Engineering education targets to prepare students for a successful career in engineering. The Accreditation Board for Engineering and Technology (ABET) accredits programs that ensure that students are prepared in 11 areas including ability to apply knowledge of mathematics, science, and engineering, ability to design and conduct experiments, analyze and interpret data, design systems, work in teams, formulate and solve engineering problems, be professionally and ethically responsible, have good communication skills, understand the impact of engineering solutions in the world, engage in lifelong-learning, know contemporary issues, and use techniques and modern tools in engineering practice[1]. The American Society of Civil Engineers (ASCE) Body of knowledge (BOK) identifies 24 learning outcomes in three categories (foundational outcomes, technical outcomes, and professional outcomes) that should be attained to prepare students for successful careers as practicing engineers[2]. Criteria identified in the BOK suggests students should be able to solve problems, formulate documents, assess newly created knowledge, communicate effectively, function in multidisciplinary teams, justify solutions, assess personal professional and ethical development, and others[2]. In the literature there are a lot of studies on how to develop student technical, critical skills, and professional skills[3,4,5] because of how important they are to the engineers.

The undergraduate civil engineering and construction engineering curriculums at a teaching institution emphasize preparation of graduates to serve as principled leaders in design, construction, maintenance and operation of the built-environment. In support of this vision, department faculty have adopted a series of outcomes focusing on technical and professional skills needed to prepare graduates for successful engineering careers.

This paper examines which skills from the following: competent in technical matters, able to work in teams, able to communicate effectively, understand management and leadership concepts, have strong work ethic, and apply critical and analytical skills, engineering college students, recent graduates, and employers/ managers are considering the most important in the engineering world. This paper also studies how prepared engineering students, engineers, and employers/managers feel for an engineering career based on the college education they have received or receiving.

Survey and Data Collection

To answer the question of this research, data was collected through an anonymous survey administered in SurveyMonkey[6]. A questionnaire including 10 questions was created and distributed among about 200 professional engineers working in different positions at different companies, and engineering students of a teaching college in the civil and construction engineering department. The first three questions of the survey were directed to determine the composition of the survey poll, asking the respondents to pick among different career stages:

- Manager/Employer
- Engineer/Researcher (Engineer, Post Doctorate, Graduate)
- Undergraduate Student (Senior, Junior, Sophomore, Freshman)

The professionals were also asked to select their experience level on 5-year increments (1-5, 5-10, etc.) and indicate their current position and company. A total of 13 companies in various

industry fields, including but not limited to transportation, construction, automotive, silicon manufacturing and power generation were contacted.

Questions 4 and 9 are the key questions of the survey, asking to rank, from 1 to 8, a set of skills predetermined based on existing literature. The skills selected are:

- Technical knowledge
- Teamwork
- Communication skills
- Leadership concepts
- Strong work ethics
- Critical skills
- Analytical skills
- Creativity

For clarification, the analytical skills were defined as the ability to collect and analyze information[7] and the critical skills are defined as the ability to intelligently assess information, recognize useful facts, and exercise common sense[8].

Participants were asked to rank the above competences twice, once based on the importance in the career of an engineer and second based on the level of preparation received through education and academic background.

The other questions gave the possibility to participants to justify their top and bottom ranked choices, indicate skills important to them that were not already mentioned, and also give examples of how these skills helped their career.

Overall, 73 answers were received: 6 Managers, 18 Engineers and 49 students. Out of those, 4 student answers were not included in the analysis due to them being incomplete. In the sections below, the data analysis, results and conclusions are discussed. Due to the difference in the numbers of answers received in each group, the data is presented both as the sum of the answers and as the "average" answer per person when comparing the answers by groups. The average is calculated dividing the sum of group answers by the number of participants in that group. Doing so, the influence of the group size is eliminated, and direct comparisons can be done. Also, the survey margin of error is 12% and 10%, assuming a 95% and a 90% confidence interval, respectively.

Data Analysis

Collective Answers

This section highlights the results of survey question 4:

"Which competences are the most important in the engineering field? Please rank them from the most important to least important, based on your personal opinion and experiences (1 = Most important; 8 = Least)."

The comprehensive data for all answers received combined, disregarding categories are presented in Table 1 with the total sum of the answers, the average per person, and the final ranking. Since the question is asking to rank the most important from 1 to 8, smaller sums are equivalent to higher rank.

Table 1: Which skills are the most important in the engineering world?

OVERALL ENGINEER SKILLSET			
Skills	**Sum**	**Average**	**Rank**
Critical Skills	237	3.4	1
Communication Skills	242	3.5	2
Strong Work Ethics	270	3.9	3
Analytical Skills	291	4.2	4
Teamwork	311	4.4	5
Technical Knowledge	314	4.5	6
Leadership Concepts	408	5.8	7
Creativity	447	6.4	8

Figure 1 shows how participants exactly ranked the top 3 (3 highest ranked) skills. Remember, number 1 indicates most important and number 8 indicates list important. For example, 15 participants ranked communication (green in Figure 1) as the most important (#1), other 15 participants ranked ethics (blue in Figure 1) as the most important, and 13 participants ranked critical skills (yellow in Figure 1) as the most important.

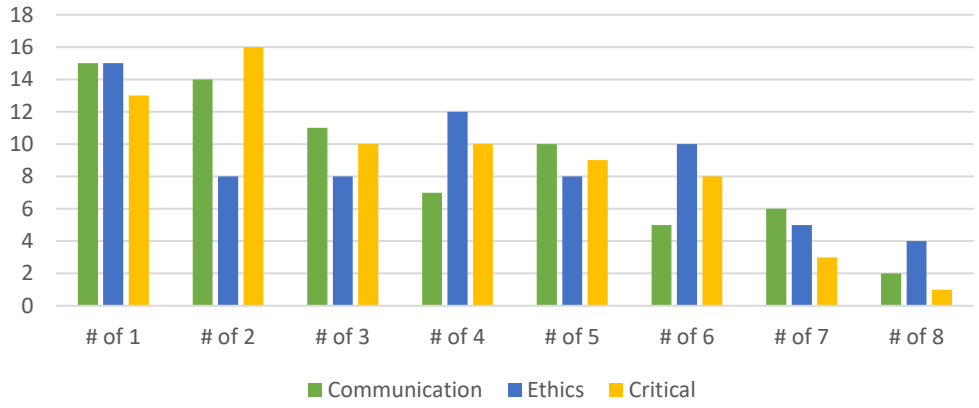

Figure 1: Top Ranking of Skills Distribution

Critical skills are the most valued, ranked among the top 3 in 56% of the respondents. In Figure 1, it can be seen that the number of lower ranking votes progressively decreases, indicating the general consensus about critical skills being very important. Both professionals and students recognize the top priority of being able to take rational decisions in a timely manner, collecting useful information and applying common sense. To use some of the respondents' words:

- "Need to have a mindset of what is important in data collection, how to gather, and what the data is saying using analytical, theoretical, and common sense."

- "Many decisions are needed to be made in a quick concise manor. It is necessary to be able to collect all necessary information and have the critical thinking skills to be able to come up with suitable solutions when problems arise."

Communication skills are the second overall highest ranked with 21% of people ranking it number one and about 57% ranking it either number 2 or 3. Reasoning behind this is that even the most skilled engineer will not reach his full potential without being able to communicate with the people around him/her. Effective communication is the key for advertising oneself, building reputation and networking successfully. Excellent communications extend the reach of the engineer beyond his own competences, allowing him to tap into the vast shared knowledge of the entire group. Quote from the survey:

- "You may not be able to answer all questions yourself, but someone has the answer and communicating to them is vital to solving complicated problems".

Work ethics are third in rank. Even though this skill shares the same number of rank 1 as communication skills, there is also almost 30% of respondents ranking it among the last 3 skills. Although nobody is openly against ethics, some people think that strong ethics are easily confused with working as much as possible, which is not the number one requirement for a top performer per se. An example response includes:

- "A strong work ethic is typically viewed as someone that puts in the hours; however, this is not always related to how efficient an employee is."

On the other hand, several people state that having strong work ethics show commitment and loyalty which are among the most valued characteristics for a company, and also allows to quickly recover from any shortcoming in the other skills.

- "Work ethics, showing you care and you are committed to the company is valued the most. Work ethics with technical skills make you stand out."
- "Having a strong work ethic is invaluable as you may have other short comings, like a technical background, but if you're willing to put the work in then that shows to your employer more than anything else."

Figure 2 illustrates how participants exactly ranked the bottom 3 skills. Again, number 1 indicates most important and number 8 indicates list important. For example, only 6 participants ranked technical skills (green in Figure 2) as the most important (#1), 2 participants ranked leadership (blue in Figure 2) as the most important, and 4 participants ranked creativity (yellow in Figure 2) as the most important.

The survey results show an across the board accord for the skills that are deemed the least essential. More than 55% of the responses list Leadership skills in the last three spots. The number raises even higher for creativity, with 80% of the respondents ranking it 6th or below. The most common justification is that leadership could be developed with time and experience.

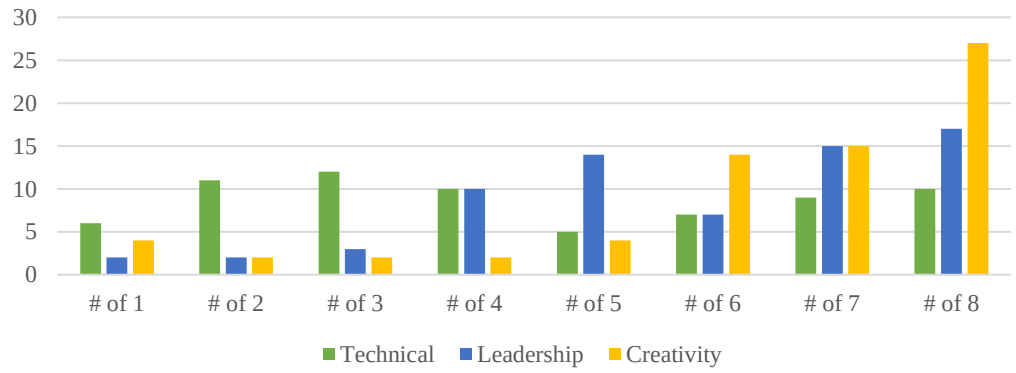

Figure 2: Bottom Ranking of Skills Distribution

As per creativity, it is something nice to have, but not essential for engineers that are not heavily involved in new designs or high-tech solutions. Many people report that the current industry, manufacturing in particular, is more striving for standardization than innovation, see below.

- "Most engineers will not end up in a leadership position. Similarly, engineers often are required to follow standards and not be creative, for better or worse."
- "Creativity is due to the fact that fossil power industry has well developed and does not require as much creativity as newer high-tech industry."

Another interesting observation is the possibility to achieve creativity through communication and teamwork.

- "Being creative is important but not the most important because you are surrounded by people around you that can give ideas and you can add onto it.

Preparation

Question 9 asked participants to rank the same skills on how prepared they felt from their background and education. Table 2 shows the answers.

Question 9: "Now let's see how prepared you feel for a career in the engineering world. Please rank the competences below from best to worst, based on how your education and background prepared/are preparing you for them (1 = Best prepared; 8 = Worst prepared)."

Table 2: On which skills do you feel more prepared?

OVERALL ENGINEER SKILLSET			
Skills	**Sum**	**Average**	**Rank**
Teamwork	261	3.7	1
Communication Skills	265	3.8	2
Critical Skills	275	3.9	3
Strong Work Ethics	297	4.2	4
Analytical Skills	316	4.5	5
Technical Knowledge	327	4.7	6
Leadership Concepts	358	5.1	7
Creativity	421	6.0	8

Switching to the analysis of the results from question 9, there is substantial accordance of the skillset required and the level of preparation offered by the academic institutions, although with a few twists. The overall opinion is that teamwork is the skill education most prepares students for, followed closely by the communication skills. Critical skills come at the third place and strong work ethics at the fourth place. Figure 3 shows how participants exactly ranked the top 4 skills.

The results of the answers distribution on question 9 are slightly more uniform than the previous. Teamwork and communication skills were rated top 3 by roughly 48% of people. Once again, there are mixed opinions about the focus on work ethics, rated 1st by 24% of people but also among the last three in 41% of the answers.

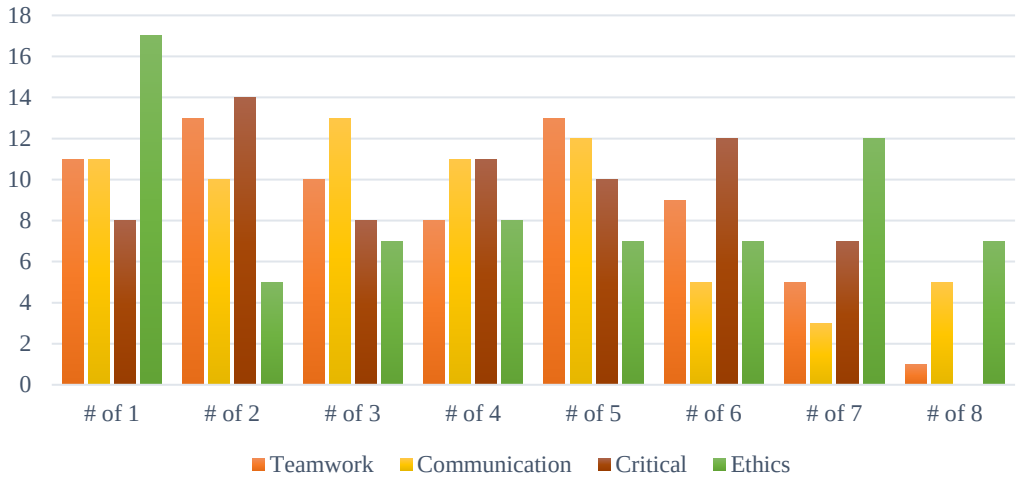

Figure 3: Top Ranking Distribution for Most Prepared Skills

As in the previous question, technical skills leadership and creativity are voted the least in the exact same order. Leadership was ranked among the last 3 by roughly 48% and creativity is down to 63%, which are less drastic than the results of question 4. Figure 4 presents how participants exactly ranked the bottom 3 skills.

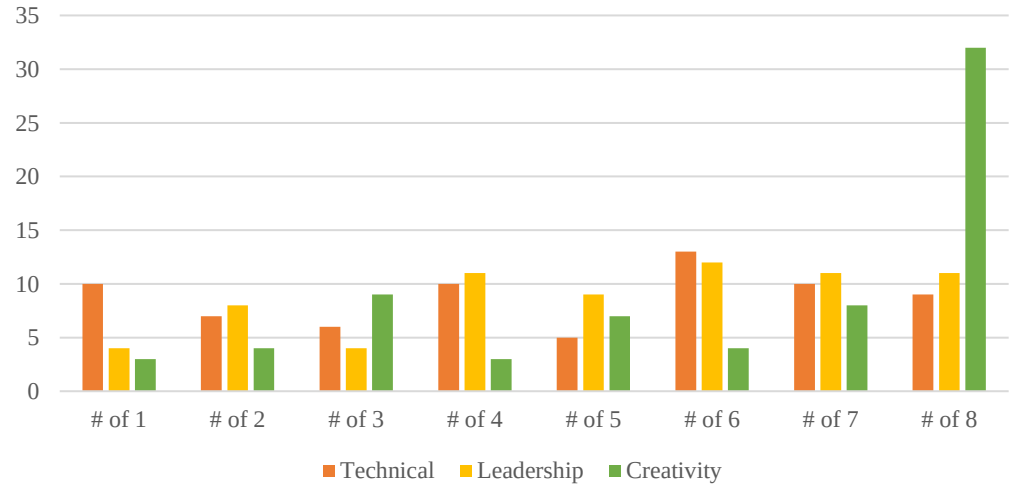

Figure 4: Least Prepared Skills

Gap Analysis

The purpose of this section is to give an idea of the discrepancy in between the importance assigned to a skill in the engineering career and the actual level of preparation received in engineering education.

Due to the fact that the smaller the sum of the answers for a skill, the higher the skill is ranked, when analyzing the difference, negative gaps are an indicator of a perceived deficiency of the education system respect to the perceived importance of the competence. Similarly, a positive gap means that the respondents perceive a stronger focus of the education system than the actual need in the engineering career. Both sum and average per person are reported in Table 3. The skills in Table 3 are in order of how skills were ranked overall, please refer to Table 1.

The common opinion is that the biggest negative gaps are for the same top skills considered top 3 in the importance ranking. In the following order: strong work ethics, critical skills and communication skills. This means that there is an overall feeling that work ethics, critical skills and communication are not sufficiently stressed during the years of education, respect to their importance for a successful career in the field of engineering. Conversely, teamwork and leadership have the biggest positive gap, which translate in an excessive stress of these two competences from the education side, not matched by the actual professional needs.

Table 3: Gap Analysis

GAP ANALYSIS		
Skills	**Sum**	**Average**
Technical knowledge	-13	-0.2
Teamwork	50	0.7
Communication skills	-23	-0.3
Leadership concepts	50	0.7
Strong work ethics	-27	-0.4
Critical skills	-38	-0.5
Analytical skills	-25	-0.4
Creativity	26	0.4

The radar Figure 5 presents a good summary of the results mentioned above with blue showing the importance and orange the preparation. For the sake of the representation, in this and the following radar charts, the answers have been inverted (ranking best 8 and worst 1 instead of vice versa), to have higher numbers representing bigger importance and better preparation.

In radar chart, the axis grows radially from the center. The skills are at the vertices of the octagonal frame, and the closest the colored line goes to the vertex, the highest is the score for that skill.

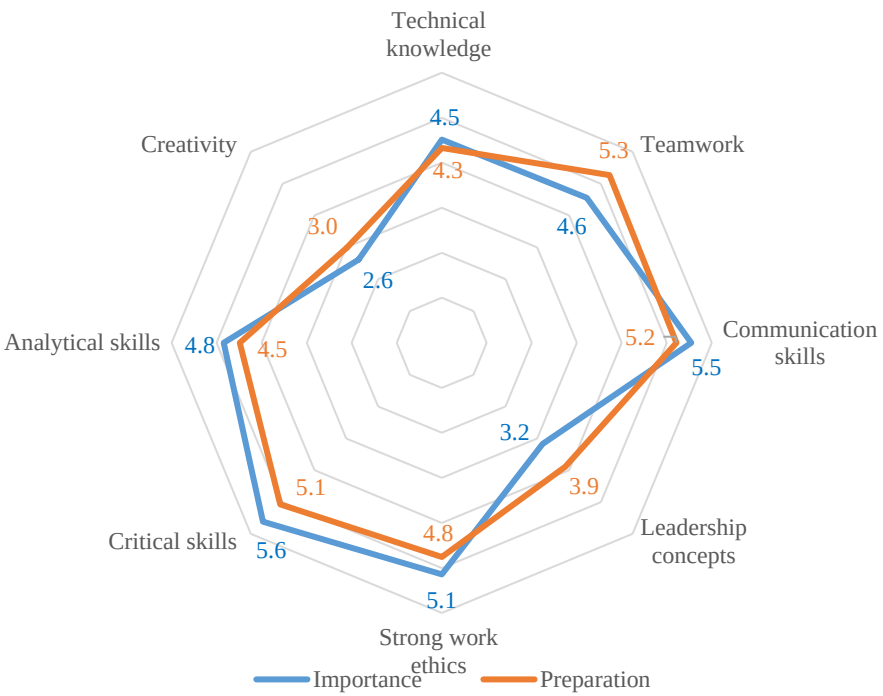

Figure 5: Overall Engineer's skillset

Answers by group

In this section, the survey is split in 3 subgroups based on the current professional level of the respondent. The intent is to identify similarities and differences in the opinions of engineers at different points in their academic and professional career in different stages.

Table 4: Skill Ranking by Group

GROUPED IMPORTANCE RANKING			
Rank	Managers	Engineers	Students
1	Communication skills	Critical skills	Critical skills
2	Critical skills	Communication skills	Communication skills
3	Strong work ethics	Analytical skills	Strong work ethics
4	Analytical skills	Technical knowledge	Teamwork
5	Technical knowledge	Strong work ethics	Analytical skills
6	Creativity	Teamwork	Technical knowledge
7	Leadership concepts	Creativity	Leadership concepts
8	Teamwork	Leadership concepts	Creativity

The single groups recognize more or less the same priorities. Critical and communication skills are at first and second place for all the groups, although in mixed order. Managers and students are in accordance on work ethics having the third place while engineers privilege analytical skills.

For the bottom 3, teamwork, creativity and leadership are repeating in mixed order, with the exception of the students that value teamwork more than technical and analytical skills.

From table 4, one interesting trend to highlight is the shift of the teamwork with the career progression. While students are probably used to study groups and group projects, engineers do not really recognize teamwork as a key aspect of success, and managers seem more focused on individual performances.

- "Before teamworking or leading people, an engineer needs to be able to prove himself through keen technical skills." (Manager)
- "Teamwork is used to check behind and talk through solutions, but low ranked because ultimately my projects are my responsibility." (Manager)

Judging the rankings as a whole, both technical and analytical skills jump two positions from students to engineering, suggesting that the perception of the importance of a technical formation increases once people start doing practical work.

- "Solid technical background and excellent problem solving abilities are essential to engineering consultants. The engineering problems from our client vary in large scale and a lot of time are time sensitive. To make the optimum solution in limited time would require the two skills along with others on the list." (Engineer)
- "The importance of technical knowledge is highly dependent on the field and specific job requirements. The more technical something gets, the more likely it is to be driven by software which reduces the importance." (Undergraduate – Junior)

The radar chart 6 provides a good summary of how the rankings are defining the skillset required for a successful engineering career.

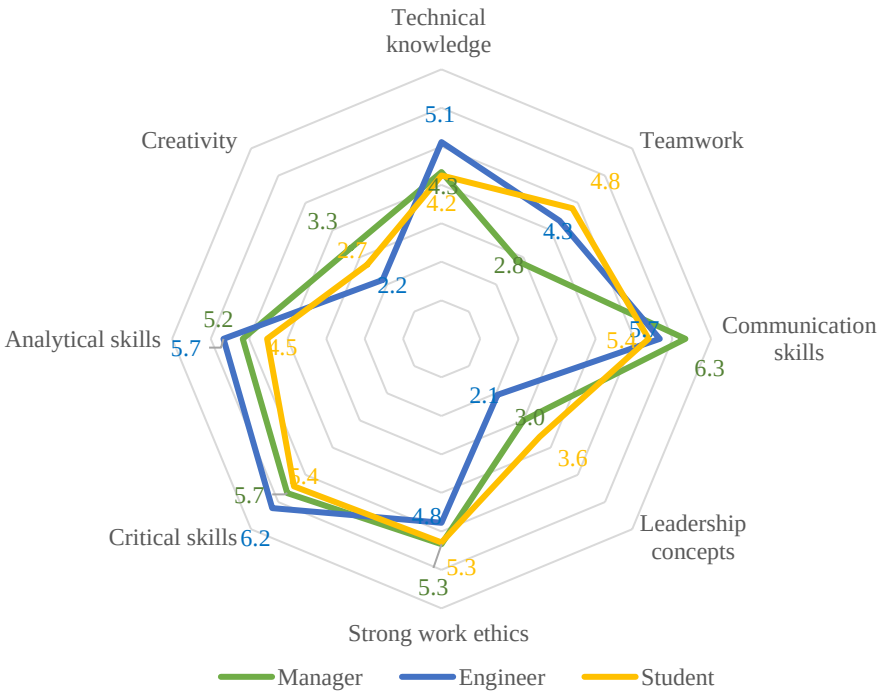

Figure 6: Engineer's Skillset by Group

Preparation

In this section, some variation in the answers pattern started to be visible.

Table 5: Preparation Ranking by Group

PREPARATION RANKING BY GROUP			
Rank	Managers	Engineers	Students
1	Analytical skills	Technical knowledge	Teamwork
2	Critical skills	Communication skills	Communication skills
3	Technical knowledge	Critical skills	Strong work ethics
4	Communication skills	Analytical skills	Critical skills
5	Creativity	Strong work ethics	Leadership concepts
6	Teamwork	Teamwork	Analytical skills
7	Strong work ethics	Leadership concepts	Technical knowledge
8	Leadership concepts	Creativity	Creativity

Manager and engineers rank analytical, technical, critical and communication skills at the top, in varying order. Students agree on communication skills being an important part of their education, but differently from the other groups, have the teamwork at the highest rank.

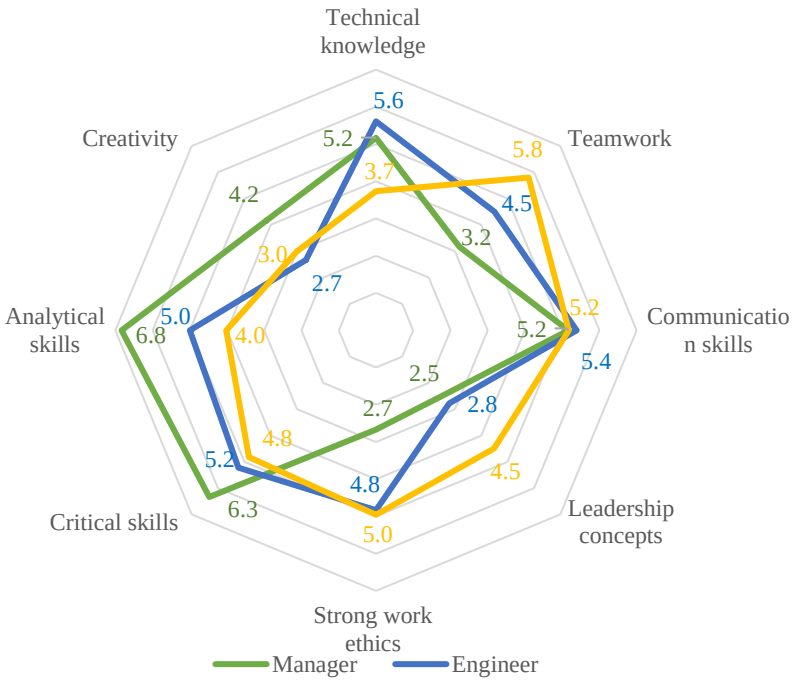

Figure 7: Engineer's Preparation Skillset by Group

A quite interesting trend is the progressive sinking of the preparation in strong work ethics and leadership. These suggest a possible illusion in the early career phases of being adequately educated in these two areas, which progressively evolves in the realization of not being prepared

enough, as they grow professional into a leadership position. It is possible that the impact and frequency of ethical decisions in the work environment grow with the increased responsibility of the higher positions, making younger engineers unaware. For what concerns leadership, it is important to remember that many people were justifying low ranks in the importance scale with the fact that leadership skills are acquired in time with experience. Judging from the answers of the people that currently are in a leadership positions, it looks like the position came earlier than the experience.

In radar chart 7, it is possible to observe the summary of the perceived preparation level for the different groups. As previously remarked, there is a noticeable unbalance of the green line (managers), towards the critical/analytical skills.

Gap Analysis

Once more, due to the nature of the data, negative gaps indicate a deficit of the education system, while positive gaps suggest exceptional (up to the excess) focus on a specific skill. The first thing to notice is that the sum of the absolute value of the average scores for managers is much higher than the one for students and engineers. In practice, this means that most of the managers voted alike, while the other two categories are more inconsistent. The biggest negative gaps are reported by managers for the work ethics and communication skills, while they feel they have an adequate preparation on the technical side.

Both engineers and students find deficiencies in their preparation in critical, analytical and communication skills, while they feel confident in leadership concepts and teamwork (especially students.

Table 6: Gap Analysis on Skill Preparation by Group

GAP ANALYSIS BY GROUP						
	Managers		Engineers		Students	
Skills	Sum	Average	Sum	Average	Sum	Average
Technical knowledge	5	0.8	9	0.5	-23	-0.5
Teamwork	2	0.3	3	0.2	45	1.0
Communication skills	-7	-1.2	-5	-0.3	-9	-0.2
Leadership concepts	-3	-0.5	13	0.7	40	0.9
Strong work ethics	-16	-2.7	1	0.1	-15	-0.3
Critical skills	4	0.7	-18	-1.0	-27	-0.6
Analytical skills	10	1.7	-12	-0.7	-23	-0.5
Creativity	5	0.8	9	0.5	12	0.3

Conclusions

This paper focused on the perception of managers/employers, engineers, and students on which skills are the most important in the engineering world and how well the education prepared those groups to succeed. In conclusion, the common opinion is that the most essential competences are critical skills, communication skills and strong work ethics, because those allow the engineers to

efficiently compensate for any deficiency in their knowledge and technical skills. However, according to the data, work ethics, critical skills and communication are not sufficiently covered during the years of education. Conversely, it is perceived that teamwork and leadership are overtaught at the education side, not matched by the actual professional needs. Across the board, every category is indicating leadership concepts and creativity as the least essential skills, asserting that most engineers will not have to cover a leadership position, and creativity is usually a prerogative of very specific positions, such as designers, while for many other sectors of the industry, the strive for standardization overpowers the necessity for innovation.

Future Work

The results of this study are very informative and can help improving the education programs that are preparing the future generations of engineers. In the future, the authors are planning to expand this research in other parts of the country and more universities to examine if the same perceptions hold true.

References

1. Criteria for Accrediting Engineering Programs, 2018 – 2019. Retrieved from: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/#GC2 Date accessed: 11/15/2019
2. American Society of Civil Engineers (ASCE), Civil Engineering Body of Knowledge: Preparing the Future Civil Engineer, Civil Engineering Body of Knowledge 3 Task Committee, Third Edition, ISBN (print): 9780784415221, ISBN (PDF): 9780784481974. Retrieved from: https://ascelibrary.org/doi/pdf/10.1061/9780784415221 Date accessed: 11/15/2019
3. Andersson, N. and Andersson, P.H., 2010. Teaching Professional Engineering Skills: Industry Participation in Realistic Role Play Simulation. Retrieved from: https://orbit.dtu.dk/en/publications/id(fe50a3dd-faeb-4c96-a1e0-ee170c3b481b).html Date accessed: 11/15/2019
4. Donald R. W., R. M. Felder, A. Rugarcia, J. E. Stice, The Future Of Engineering Education III. Developing Critical Skills*. Retrieved from: https://www.researchgate.net/profile/Richard_Felder/publication/2625823_The_future_of_engineering_education_III_Developing_critical_skills/links/54b7e5c00cf28faced60c57a/The-future-of-engineering-education-III-Developing-critical-skills.pdf Date accessed: 11/15/2019
5. Seat e., S. M. Lord, 2013. Enabling Effective Engineering Teams: A Program for Teaching Interaction Skills. Retrieved from: https://onlinelibrary.wiley.com/doi/abs/10.1002/j.2168-9830.1999.tb00463.x Date accessed: 11/15/2019
6. SurveyMonkey, https://www.surveymonkey.com
7. Doyle, A., 2019. Analytical Skills Definition, List, and Examples, The balance Careers.
8. Critical Thinking Skills, 2019. Lumen, College Success.

Dimitra Michalaka

Dimitra Michalaka is an Associate Professor at the department of civil and environmental engineering at The Citadel. Dimitra received her undergraduate diploma in civil engineering from National Technical University of Athens, after which she entered into the transportation engineering graduate program at University of Florida. Graduated with a Master of Science in 2009 and with a Ph.D. in 2012. Dimitra's research is primarily focused on traffic operations, congestion pricing, traffic simulation, and engineering education. Dimitra is a registered Professional Engineering in the state of South Carolina.

Emanuele Giogli

Emanuele Giogli is the Coordinate Measuring Machine (CMM) manager at Volvo Car US Operations, Inc. Emanuele received his undergraduate diploma in Mechanical Engineering from University of Bologna in 2012. Right before graduation, Emanuele completed a six months study abroad program at University of Florida on autonomous vehicles. After graduation, Emanuele worked at the Italian automotive company Tiberina Group as a project engineer. In 2015, he moved to United States, where he got his Master of Science in design and manufacturing at Clemson University in December 2016. In March 2017, he started his career in the American automotive industry as Geometry Engineer for Volvo Car US Operations, Inc. In 2018 he got promoted to Body In White Geometry Leader and in 2019 he was advanced to his current position**.**