Perceived and valued professional roles of engineers among engineering students in Finland

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Introduction

Engineering as an endeavor is thousands of years old, and engineering as a profession is hundreds of years old. Yet, many engineering students lack a clear understanding of what engineers actually do. Descriptions of engineering practice tend to emphasize technical problem solving and design [1], and value creation in engineering is often perceived as resulting from technological innovation [2]. Interviews and field observations among practicing engineers show that some engineers "*tend to hide the social dimension of their work behind a technical facade*" [1]. Faulkner sees this as a manifestation of a broader cultural phenomenon, which she calls the technical/social dualism [3]. This dualism is characterized by the mutual exclusivity of technical and social, dictating that one cannot be interested in both at the same time. Especially the male engineers take pleasure in the technical, their professional identities specifically excluding the social, and they make a clear distinction between narrowly-specialist and more heterogenous professional roles [3]. Hence, both the ordinary engineering routines without significant elements of innovation and the social side of engineering practice are easily overlooked. In practice, however, most engineers have little or no involvement with technological innovation, and value is often created through ordinary routine engineering [2]. Moreover, although many engineers cling to the technicist engineering identity, the technical aspects and social content of engineering work are intertwined [4].

The perception of engineering work and its alignment with an individual's self-conception has an effect on their persistence in the field. Cech discovered four professional identity traits among engineering students: problem-solving prowess, technological leadership, managerial/communication skills, and social consciousness, three of which were related to students' intentions to persist in engineering [5]. Two of the traits exhibited gender differences as women were more likely than men to value social consciousness and less likely to value technological leadership. Social consciousness appeared not to have a connection with persistence in engineering, whereas the emphasis on technological leadership and problem-solving prowess seemed to increase and the emphasis on managerial/communication skills reduce the intentions to stay in the field [5]. Thus, the lesser emphasis of female students on the technological leadership may lead to greater attrition compared with men. In addition to traits, students' confidence in their ability to meet the professional expectations predicts persistence in engineering, with women's lower professional role confidence resulting in weaker behavioral and intentional persistence [6].

Professional roles in engineering

Literature on professional roles of early career engineers is scarce and characterized by undefined use of the concept and inconsistent use of terms [7]. Nevertheless, three broad focus areas are generally recognized: innovation, optimization, and customization [7]. This study employs the model of competency-based professional roles for early career engineers developed by Craps et al. [8] and validated in industry and higher education. The model

depicts three types of roles that engineers often take on in their working lives regardless of their discipline: Product Leadership, Operational Excellence, and Customer Intimacy. The three roles emphasize different aspects of engineering work and require partly different competencies for success [7], [8].

The role of Product Leadership is probably the one that best mimics the common view of engineering as creating value through technological innovation. It focuses on radical innovation and creation of state-of-the-art artifacts with competencies such as innovation, vision, persuasiveness, perseverance, initiative, creativity, and client focus, considered particularly important in the role of Product Leadership [8]. The role of Operational Excellence emphasizes design and implementation of operational processes, which require competencies such as a positive critical attitude, planning and organization capabilities, a holistic view, teamwork skills, and stress resistance [8]. In the professional role of Operational Excellence, engineering work creates value through incremental improvements in efficiency, reduction of technical uncertainties, quality assurance, and compliance with standards rather than through radical intensive R&D [2]. In the third role, Customer Intimacy, engineers work in close collaboration with customers to find and meet their needs [8]. Although customers are often perceived as commercial clients, this role could also be extended to situations where engineering creates value through gaining and maintaining a "social license to operate," e.g., through comprehensive safety and environmental monitoring practices [2]. An engineer in the role of Customer Intimacy with the goal of ensuring customer or stakeholder satisfaction through tailored solutions benefits from competencies such as communication and negotiation skills, capacity for empathy, and networking and relation building capabilities [8].

Although the literature on engineering students' perceptions of professional roles and work is not abundant, some interesting aspects and cultural differences have been identified. Saunders-Smits et al. discovered that first-year mechanical engineering students in Belgium, Ireland, and the Netherlands showed a clear preference for the professional role of Product Leadership regardless of their national origin [9]. Kövesi and Kálmán compared Hungarian and French graduate engineering students' perceptions of their employability and found that Hungarian students perceived strong technical skills to be necessary for finding a job and nontechnical skills to be developed while working, whereas French students saw nontechnical skills necessary for finding a job and technical skills for keeping it [10].

How engineering students conceptualize the "nontechnical" and its relationship to engineering work can also take interesting turns, as the study by Loweth et al. [11] shows. They discovered that even though students emphasize the importance of teamwork, collaboration, and communication in engineering, they see it primarily as related to the interactions between engineers, leaving the customers or other stakeholders out of the picture [11]. Students also considered collaboration and communication activities more important for engineering work than activities they described as more "social in nature," such as building personal relationships with peers. The authors interpreted this as a form of technical/social dualism, where the value of collaboration stems from achieving technical goals, which is considered the core of engineering work [11]. A similar phenomenon can be seen in Hatmaker's study [12] on the role configuration of practicing engineers, where men in

particular saw the role of communication solely in the context of responding to professional and instrumental needs and generally did not express an affinity for communicator roles. All this seems to point to the professional role of Customer Intimacy not being recognized or valued by either engineering students or practicing engineers.

This study aims to understand how engineering students in Finland perceive and value the different professional roles of engineers and the associated competencies. We also seek to determine whether there are gender differences in perceptions or valuations.

Data and Methods

The data were collected in September 2024 as part of an annual student survey conducted by a professional organization for academic engineers in Finland. In addition to professionals, the members of the organization include students of engineering/technology, computer science, and natural sciences. The purpose of the survey is to collect information on the students' well-being and employment as well as to gather data on timely and varied topics, the special topic of this year being perception of professional roles and competencies. The overall response rate was 11%, and after excluding the responses from the relatively few nonengineering students, we had 1934 respondents representing all the nine Finnish universities offering engineering education. 60% of the respondents were male, 38% female, 1% identified themselves as other, and 1% did not want to disclose their gender. Compared with the gender distribution of the student member population of the association, males were underrepresented (66% in population) and females overrepresented (33% in population) among the respondents. The survey was conducted online.

The survey included three questions related to the professional roles of engineers. The questions are shown in Appendix 1. In the first question, the respondents were asked to evaluate how well the presented nine statements matched with their perception of engineering. The responses were given on a five-point Likert scale (1=very poorly 5 very well). Each professional role was represented by three statements formulated from the descriptions in [8]. The second question followed the format of the PREFER Explore test developed in KU Leuven [13]. The respondents were presented with four scenarios and asked to rank the responses in order of preference. The questions contained four different scenarios in total. In the third question, the respondents were requested to rate the importance of the named nineteen competencies on a five-point Likert scale (1=not important at all, 5=very important). The competencies were those defined in [8] as required for successful performance in each of the three professional roles.

Statistical analyses were performed with the statistical software Stata (version 18.5). The differences between professional roles were assessed with the Wilcoxon matched-pairs signed-rank test and the gender differences with the Mann–Whitney U test. A significance level of $p<0.05$ was used for all tests. The internal consistency of the subscales was measured using Cronbach's alpha, and the correlations between items were measured using Pearson correlation coefficients.

Results

The results show that students recognize all the three roles to a somewhat similar extent. To compare the perceptions of the three roles, the nine statements were factorized into three factors according to the theory. The factors are presented in Table 1.

Table 1. Factorization of the perceptions of the professional roles in engineering work

Professional role	**Statements (see App. 1)**	**Cronbach's alpha**	**Mean**	**Standard deviation**
Product Leadership (PL)	1.1–1.3	0.649	3.88	0.64
Operational Excellence (OE)	1.4–1.6	0.572	3.94	0.61
Customer Intimacy (CI)	1.7–1.9	0.712	3.72	0.73

The correlation between all the nine statements (α=0.776) was better than for any of the three subscales, and the pairwise correlations showed similar levels of correlation between all the statements, suggesting that all the presented aspects of engineering work were perceived to be part of the engineering work to the same degree. Although the differences between the means of the three roles were statistically significant (Product Leadership vs. Operational Excellence, p=0.0183; Product Leadership vs. Customer Intimacy, p=0.0000; Operational Excellence vs. Customer Intimacy, p=0.0000), it could not be stated that any of the roles were perceived remarkably better or worse than the others.

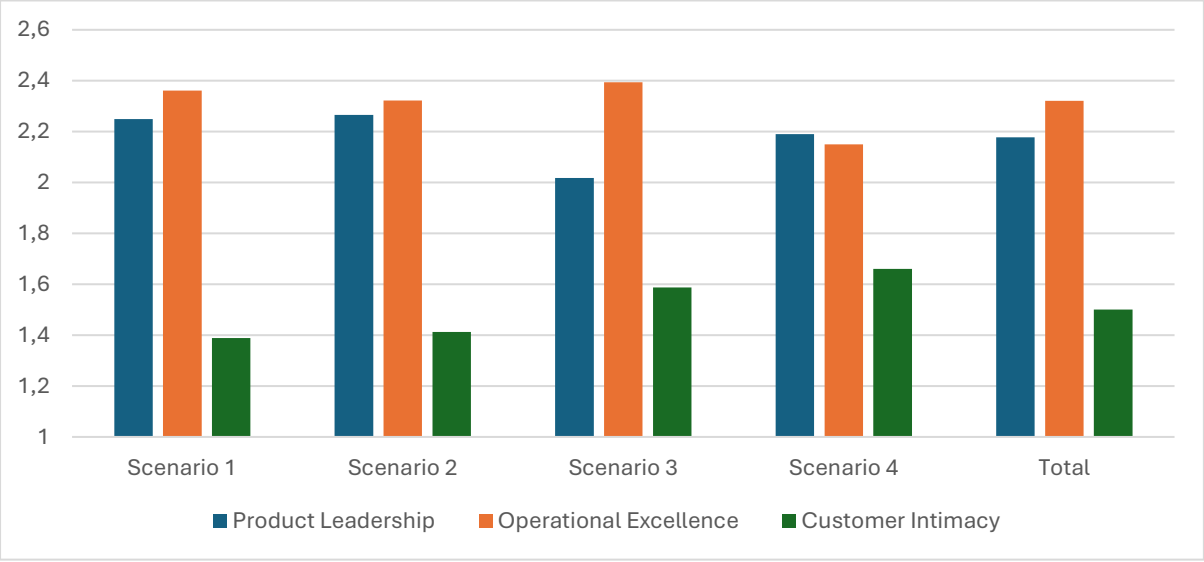

Figure 1. Respondents' preferences for tasks representing the three professional roles in different scenarios and overall

In the second question, the participants were presented scenarios and asked to rank their responses in order of preference. For each respondent and scenario, the most preferred answer was assigned a value of 3, the second a value of 2, and the least preferred option a value of 1. A total role preference for a respondent was calculated as the average of the respective role preferences in all four scenarios. The preference for a specific role for each scenario was calculated as the mean of all responses, and finally, the general preference for

each role was calculated as the average of respondents' total role preferences. The results are presented in Figure 1.

When respondents were asked to prioritize specific work tasks, the tasks related to Operational Excellence were rated as most compelling and the tasks related to Customer Intimacy as least compelling, with the difference between the role of Customer Intimacy and the other roles being particularly clear. All the differences except the difference between Product Leadership and Operational Excellence in Scenario 4 (p=0.8839) were statistically significant with a confidence level of 95%.

The order of the professional roles remained the same when the respondents rated the importance of the specific competencies in engineering work. Table 2 presents the means and standard deviations of perceived importance for all the named competencies as well as the summation of the competencies related to each of the three roles.

Table 2. Perceived importance of the different competencies for engineering work

Competence	**Related role**	**Mean**	**Standard deviation**
Holistic view	OE	4.592	0.658
Clear communication	CI	4.508	0.674
Planning and organization	OE	4.502	0.659
Solution-oriented	OE, CI	4.419	0.774
Focus on results	CI	4.395	0.743
Positive critical attitude	OE	4.379	0.759
Teamworking	OE	4.372	0.724
Perseverance	PL	4.233	0.771
Initiative	PL, OE	4.230	0.829
Organizing skills	OE	4.229	0.751
Ability to vision	PL	4.199	0.761
Innovativeness	PL	4.192	0.779
Stress resistance	OE	4.051	0.845
Persuasiveness	PL	4.032	0.876
Creativity	PL, CI	3.938	0.881
Networking and relation building	CI	3.928	0.954
Negotiation skills	CI	3.877	0.905
Client focus	PL, CI	3.674	0.980
Capacity for empathy	CI	3.474	1.068
	Cronbach's alpha	**Mean**	**Standard deviation**
Competencies for Product Leadership	0.7407	4.071	0.527
Competencies for Operational Excellence	0.7761	4.347	0.466
Competencies for Customer Intimacy	0.7699	4.026	0.546

Again, the differences between the three roles were statistically significant (p=0.000), but especially the difference between the perceived importance of the competencies related to the

roles of Product Leadership and Customer Intimacy was not very large. However, the two competencies rated as least necessary were client focus and empathy, both of which are central to the role of Customer Intimacy, and all of the five competencies deemed least important (and with the average less than 4) are related to Customer Intimacy.
The observed trends applied similarly to both male and female respondents (there were too few nonbinary respondents in the data to conduct an analysis), and in general, the gender differences were very small. The differences between the perceptions of men and women are presented in Table 3, and the perception differences within gender in Table 4.

There were no statistically significant differences between male and female respondents' role perceptions or preferences. Females rated the importance of competencies related to Operational Excellence and Customer Intimacy significantly higher than males, but women have been noted to rate engineering competencies generally more important than men also in previous studies [14].

Table 3. Differences between the perceptions of male and female respondents; statistically significant differences ($p<0.05$) bolded

	Role perception			**Role preference**			**Importance of competencies**		
	PL	**OE**	**CI**	**PL**	**OE**	**CI**	**PL**	**OE**	**CI**
mean, male	3.884	3.944	3.734	2.182	2.322	1.496	4.057	4..316	3.977
std, male	0.659	0.621	0.747	0.421	0.484	0.488	0.549	0.484	0.566
mean, female	3.872	3.939	3.694	2.166	2.314	1.520	4.095	4.402	4.109
std, female	0.603	0.584	0.697	0.415	0.468	0.494	0.485	0.429	0.499
diff (mean)	0.012	0.005	0.040	0.016	0.008	-0.024	-0.038	-0.086	-0.132
Mann-Whitney Z	0.884	0.551	1.487	0.515	0.646	-1.116	-1.683	-3.936	-5.417
prob>|Z|	0.3766	0.5813	0.1370	0.6067	0.5186	0.2644	0.0924	**0.0001**	**0.0000**

Both men's and women's perceptions of the professional role of engineers were best aligned with the role of Operational Excellence and least with Customer Intimacy. However, for men, the differences between the roles were statistically significant, whereas for women, only the difference between the most and least aligned roles was statistically significant. There were no differences in the role preferences of men and women; the order of the preferred roles was the same for both genders and all the differences between the roles were statistically significant. Men and women alike perceived the importance of competencies related to the role of Operational Excellence the greatest. For men, the importance of Product Leadership competencies was clearly the second, and the importance of Customer Intimacy competencies was the smallest with all the differences being statistically significant. Interestingly, the story was slightly different for women, with the importance of Customer Intimacy competencies slightly outweighing the importance of Product Leadership competencies, although the difference was not statistically significant.

Table 4. Role differences within the perceptions of male and female respondents; statistically significant differences (p<0.05) bolded

signtest, 2-sided	Role perception		Role preference		Importance of competencies	
	male	female	male	female	male	female
PL vs. OE	**0.0051**	0.6576	**0.0000**	**0.0000**	**0.0000**	**0.0000**
PL vs. CI	**0.0000**	0.1934	**0.0000**	**0.0000**	**0.0000**	0.3491
OE vs. CI	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**

Upon closer examination of the gender differences in the importance of competencies, we can see that while women rate the importance of all but one of the competencies higher than men, not all of the differences are significant. The top three competencies that women rated more important than men—capacity for empathy, negotiations skills, and networking and relation building—are essential to the Customer Intimacy role. Similarly, many of the competencies required for Operational Excellence, but almost none of those required for Product Leadership, were rated statistically significantly more important by women than by men. The gender differences in the importance of competencies are shown in Table 5. The only competency that men rated more important than women in engineering was creativity.

Table 5. Gender differences in the perceived importance of competencies required in different professional roles; statistically significant differences (p<0.05) bolded

		Men		**Women**			
Competence	**Related role**	**Mean**	**Std.**	**Mean**	**Std.**	**Difference**	**p (M-W)**
Capacity for empathy	CI	3.33	1.09	3.71	0.97	-0.38	**0.000**
Negotiation skills	CI	3.76	0.94	4.07	0.82	-0.30	**0.000**
Networking and relation building	CI	3.85	0.98	4.07	0.88	-0.22	**0.000**
Planning and organization	OE	4.44	0.70	4.61	0.56	-0.18	**0.000**
Holistic view	OE	4.55	0.70	4.67	0.57	-0.13	**0.000**
Stress resistance	OE	4.01	0.86	4.12	0.81	-0.11	**0.005**
Persuasiveness	PL	4.00	0.89	4.10	0.84	-0.10	**0.027**
Clear communication	CI	4.47	0.70	4.57	0.62	-0.10	**0.004**
Ability to vision	PL	4.16	0.79	4.24	0.70	-0.08	0.065
Organizing skills	OE	4.20	0.77	4.28	0.71	-0.08	**0.047**
Perseverance	PL, OE	4.21	0.86	4.27	0.77	-0.07	0.153
Focus on results	CI	4.37	0.77	4.43	0.69	-0.06	0.218
Solution-oriented	OE, CI	4.40	0.80	4.45	0.73	-0.06	0.221
Teamworking	OE	4.35	0.74	4.41	0.70	-0.06	0.106
Innovativeness	PL	4.17	0.81	4.22	0.72	-0.05	0.417
Positive critical attitude	OE	4.37	0.79	4.41	0.71	-0.03	0.623
Initiative	PL	4.22	0.80	4.26	0.72	-0.03	0.601
Client focus	PL, CI	3.66	1.01	3.69	0.92	-0.03	0.476
Creativity	PL, CI	3.98	0.91	3.88	0.81	0.10	**0.003**

Discussion

The results indicate that the three professional roles in the model by Craps et al. [8] are distinguishable also in the perceptions of engineering work of the Finnish engineering students. However, Cronbach's alpha, which was greater for all statements regarding perceptions than Cronbach's alpha for any of the distinct three profiles, suggests that there is a notable overlap between the profiles. The model by Craps et al. [8], which is often illustrated using a Venn diagram with three overlapping circles, seems to imply the same. In our data, Cronbach's alpha for Customer Intimacy perception statements was the highest, whereas it was the lowest for the perception statements related to Operational Excellence. Similarly, when validating the model, Craps et al. [8] discovered that in the discussions among the industry representatives, the consensus was most easily reached for the profile of Customer Intimacy and most difficult to arrive at with the profile of Operational Excellence. This implies that it is better to view the profiles as a discursive set of norms than characterizations arising from the mere nature of work.

Previous research has shown that different stakeholders have different views on the competencies needed in engineering work. Pyrhönen at al. [15] discovered that professionals in industry, professionals in academia, and new graduates exhibit some disagreement of the competencies deemed most and least important. They also noticed that some of the competencies which students evaluated to be developed best during education were the same which academics perceived as most important, and some competencies regarded least developed by students were deemed the least important by academics. This poses interesting questions regarding the alignment of the model of industry-validated professional roles and the perception of engineering work conveyed through engineering education. Do they represent the same set of norms? Can students' lower interest in Customer Intimacy type of work be affected by academics' weak appreciation of the related competencies? Whose views and set of norms should form the basis of education?

In contrast to some other countries [9], Finnish engineering students do not seem to emphasize the role of radical technological innovation in engineering work but rather emphasize the operational side of engineering. Although the three professional roles, Product Leadership, Operational Excellence, and Customer Intimacy, were all perceived as part of engineers' work, the respondents' personal preferences lie most on the tasks related to Operational Excellence and least on the Customer Intimacy type of work. No gender differences could be identified in relation to the types of preferred tasks. The evaluation of the different competences required for engineering work tells a similar story, as the competencies needed in the role of Operational Excellence were deemed most important by both male and female respondents. Thus, the results suggest that even though the role of technological innovation is not overemphasized in the perception of engineering work among engineering students in Finland, the social side of engineering is, if not overlooked, at least undervalued or considered less attractive. This is in line with the literature and research findings on the technical/social dualism [1, 3, 4, 11].

However, a closer look at the valuation of the competencies required in different professional roles reveals some interesting gender differences, especially with respect to the professional role of Customer Intimacy and the aspects that are often considered to be the social side of engineering. Although women generally rated all the competencies except creativity as more important in engineering than men, the differences were greatest in the three competencies essential for Customer Intimacy, namely Capacity for empathy, Negotiation skills, and Networking and relation building. It also appears that the higher overall valuation of Product Leadership competencies over Customer Intimacy competencies was due to men's responses outnumbering women's responses, as women on average regarded Customer Intimacy competencies as more important than Product Leadership competencies, although the difference was not statistically significant. This suggests that the social side of engineering, especially when it comes to interacting and collaborating with customers and stakeholders outside the immediate work community, is more present in women's perceptions of engineering work. This is consistent with previous research [5, 12, 14]. In three out of four scenarios of question 2, the tasks related to the role of Customer Intimacy included communication or collaboration, yet the respondents, regardless of their gender, preferred other tasks over them. Hence, even if women perceive the social and communicative side of engineering work more readily than men, they appear not to be interested in them any more than men. Whether this little interest in the social side of engineering is caused by selection in the recruitment phase or something induced by the education, such as the diminishing concern for public welfare [16], is yet another issue that requires further research.

There are, of course, some limitations to this study. First, because the number of respondents who identified themselves as other than male or female was too small to allow for a reliable statistical analysis, the view of gender differences is limited to the dualistic conception of gender, which does not provide space for nonbinary voices. Similarly, the study does not take into account any intersections that undoubtedly affect the formation of professional identities and perceptions. Second, although the three professional roles used as the theoretical basis of this study are applicable across the subdisciplines in engineering [7, 8], it is also possible that, e.g., differences in the degree programs of the respondents may influence their perceptions of engineering work. Engineering education in Finland is generally male-dominated, but also internally segregated by gender, with, e.g., chemical engineering and civil engineering being more attractive to women than fields such as mechanical and electrical engineering [17]. Therefore, the disciplinary demographics of the respondents are likely to differ by gender. This was not considered in this study, but it is certainly an interesting direction for future research. Third, the study was conducted in the context of Finnish engineering education. However, the results seem to be very much in line with the international literature, and none of the results could be explained with a unique national feature related to Finnish society, engineering education or the engineering community, suggesting that the results may have relevance also beyond the national context.

Conclusions and implications

The technical/social dualism is clearly evident in Finnish engineering students' perceptions of engineering work and professional roles. Whether this is due to self-selection into the field, enculturation during study, or other factors is beyond the scope of this study, but the

phenomenon must be recognized and seriously considered if the Finnish engineering education is to meet the needs of employers. Research shows that valuing management and communication skills reduces intentions to stay in engineering [5], and this study confirms previous findings that Finnish female engineering students and graduates value these skills more than men [14]. This poses a risk that people with Customer Intimacy type interests and competence profiles may not perceive their value to the field, which not only hinders their professional growth, but may also divert them away from engineering, leaving employers with an insufficient supply of people interested and able to fill these roles.

It has been widely noted that the technical/social binary is more present in the culture and image of engineering than in the actual engineering practice [2, 4, 12]. Thus, it is imperative that engineering education find ways to evolve the cultural image of engineering in a more heterogeneous direction, where the social and the technical are intertwined, much like in the reality of engineering work. Furthermore, it is highly important to convey this enhanced image in recruitment and educational processes. Although this is certainly easier said than done, a good starting point is to acknowledge the professional roles when carrying out curriculum design and pedagogical development, and explicitly present and discuss the different professional roles in teaching and career guidance, using tools such as those developed in the Prefer project [13].

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Appendix 1. Survey questions related to the professional roles of engineers

Question 1.

How well do the following statements match with your perception of engineering (1=very poorly 5=very well)?

1.1. Engineers translate theoretical ideas into marketable applications
1.2. Engineering emphasizes innovation and creativity
1.3. Engineers explore and identify radical alternative solutions to existing and future challenges
1.4. Engineering focuses on the design and implementation of operational processes
1.5. Engineers locate opportunities to create efficiency gains through continuous improvement
1.6. Engineers fix flaws and oversee operations
1.7. Engineers collaborate closely with clients in complex business environments
1.8. Engineers help customers to express their needs
1.9. Engineering provides technical tailored solutions to the needs of business

Question 2.

Scenario 1
Thinking of some projects you have been involved in, what part is typically your most and least favorite part of the project?

- Brainstorming and design in the start-up phase
- Execution and implementation of the project activities
- Presentation and communication of results to stakeholders

Scenario 2
All jobs include tasks that are not necessarily very pleasant. Which of the following tasks would you most and least prefer, despite their unpleasantness?

- One week of data cleaning after piloting a new piece of equipment
- One week of drafting a manual on how to log production failures in the relevant system
- One week of contacting potential clients by the phone to ask if they are interested in the services of your company

Scenario 3
Together with two colleagues, you are preparing a new project. Which of the following roles would you most and least prefer during this preparatory phase?

- Exploring technical reports to find the latest developments in the field
- Drafting the operational processes to reduce risk and maximize efficiency
- Analyze the market and set up a market segmentation strategy

Scenario 4
You are a member of a project team within your company that has been tasked with increasing customer satisfaction. How would you prefer to contribute the most and the least?

- Mapping the requests clients have and come up with original solutions to their needs
- Redesigning the processes to provide clients with a quicker response
- Meeting with the three biggest clients in order to gather their in-depth feedback on the service delivery of your company.

Question 3.

How important are the following competencies in engineering (1=not important at all, 5=very important)?

- Innovativeness / Innovatiivisuus
- Ability to vision / Visiointikyky
- Persuasiveness / Vakuuttavuus
- Perseverance / Sitkeys
- Initiative / Aloitekyky
- Creativity / Luovuus
- Client focus / Asiakaskeskeisyys
- Solution-oriented / Ongelmalähtöisyys
- Positive critical attitude / Positiivinen kriittinen asenne
- Planning and organization / Suunnitelmallisuus ja organisointikyky
- Holistic view / Kokonaisuuksien hahmottaminen
- Teamworking / Tiimityöskentely
- Organizing skills / Järjestelmällisyys
- Stress resistance / Stressinsietokyky
- Clear communication / Selkeä kommunikointi
- Capacity for empathy / Empatiakyky
- Negotiation skills / Neuvottelutaidot
- Networking and relation building / Verkostoituminen ja suhteiden luominen
- Focus on results / Ratkaisukeskeisyys