STEM: A help or a hinderance in attracting more girls to engineering?

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Abstract
Background: Research on gender differences and practical initiatives to attract girls to engineering are often carried out at the macro level where science, technology, engineering, and mathematics are aggregated into an entity called STEM.

Purpose/Hypothesis: This article challenges the aggregated approach, analyzes gender differences among science and engineering applicants in Finland, and discusses the implications of the findings for engineering education and intervention initiatives.

Design/Method: The data consist of the application choices of all applicants to Bachelor studies in Finland in 2016 (151,369 individuals), from which two groups were selected: persons whose first application choice was engineering/technology and persons whose first choice was natural sciences or mathematics. The application choices of these individuals (in total 9,104) are statistically described and analyzed.

Results: Engineering/technology (TECH) and natural sciences and mathematics (SCIMA) subjects are not perceived as alternative options by female applicants. Almost 60% of all female TECH applicants and more than 50% of the female SCIMA applicants apply only to their respective programs. Moreover, TECH applicants considering other options prefer other subjects to SCIMA and vice versa.

Conclusions: Encouraging more girls to study STEM is not a sufficient solution for attracting more women to engineering. Instead of or in addition to encouraging girls to study science and mathematics in K-12 education, it is necessary to open the black box of technology and help young people better understand what engineering is about.

Key words
gender diversity, higher education, identity, STEM
The underrepresentation of women studying Science, Technology, Engineering, and Mathematics (STEM) subjects and, consequently, the gender gap among professionals in these fields have attracted attention from educators, researchers, and policy makers since the 1970s. Over the last 10 years, scholars have started to question the validity of prevalent explanations for the gender gap (e.g., Mann & DiPrete, 2013; Stoet & Geary, 2018) and to highlight the importance of evaluating change over time (e.g., Kanny, Sax, & Riggers-Piehl, 2014). Furthermore, many researchers now acknowledge that conducting research on the gender gap at the aggregate level of STEM appears insufficient and even problematic. Even the main concept, STEM, is somewhat ambiguous and used inconsistently (Manly, Wells, & Kommers, 2018).

The gender gap in STEM has often been explained by differing cognitive abilities, girls’ lack of academic preparation, or their lack of interest in STEM subjects (Blickenstaff, 2005). According to several international studies measuring proficiency in natural sciences and mathematics, Finnish girls have been outperforming boys both in mathematics and natural sciences since 2015 (Vettenranta, Välijärvi, et al., 2016; Vettenranta, Hiltunen, Nissinen, Puhakka, & Rautopuro, 2016). On the other hand, Finnish girls are far less interested in engineering and technology as study fields than boys (Stoet & Geary, 2018; Teräsaho & Keski-Petäjä, 2016). Current intervention efforts and projects in Finland assume that enhancing girls’ interest in natural sciences and mathematics will also lead to an increasing interest in technology and engineering. However, these efforts have not had a significant impact on the underrepresentation of women in engineering/technology.

Although there are extensive data available on students and education in Finland, data on the application choices of individuals are not publicly available, and thus, we do not know whether engineering/technology or natural sciences and mathematics attract the same applicants or whether these fields appeal to different applicant pools. If distinct pools exist, this has important implications for engineering education and initiatives aimed at attracting more girls to study engineering.

There were approximately 51,000 students studying for STEM degrees in Finnish universities in 2018 when STEM is defined to include natural sciences (i.e., biological or physical sciences), mathematics, computer science, engineering, and technology. Thirty percent of these students were women although the percentage varies considerably depending on the discipline. For example, the percentage of female students was 69% in biology, 26% in physics, and 14% in electrical engineering and energy technology. The proportion of women among new students in engineering/technology fluctuated around 25% between 2005 and 2017 (Vipunen, n.d.).

In this article, we examine the choice patterns and identify gender differences in these patterns among STEM applicants in Finland based on data containing all applicants to university-level Bachelor studies in Finland in 2016. Along with increasing understanding of the applicants’ interests, we assess and challenge current recommendations for decreasing gender segregation in STEM, especially in engineering. We also discuss broader implications for engineering education and intervention initiatives.

The gender gap in technology and related fields has been studied extensively since the 1980s. The studies have employed a wide variety of theoretical approaches and focused on different levels of the gender gap (see, e.g., meta studies by Blickenstaff, 2005; Kanny et al., 2014). A considerable amount of this research is conducted at the macro level where science, technology, engineering, and mathematics are aggregated into an entity called STEM. Consequently, many of the practical initiatives for attracting girls have been undertaken at this level, such as “Girls into STEM” in the United Kingdom and “Komm, mach MINT” in Germany (Hutchinson, 2014).

Recently, several studies have critically assessed the validity of the various explanations for the gender gap. Kanny et al. (2014) present a review of 40 years of literature on the gender gap in college STEM majors and highlight the importance of evaluating change over time. They conclude that researchers should not focus on a single explanation and that they should also be mindful of the evolving nature of the field, meaning that the reasons behind underrepresentation may have changed over time. Ceci, Ginther, Kahn, and Williams (2014) argue that the number of women in science at all levels has increased so dramatically over the past 40 years that research based on data prior to the 1990s may have little bearing on the current circumstances women encounter. Furthermore, some scholars argue that new perspectives are required because “conventional narratives explain little of the continuing (and, in some ways, worsening) gender gap” (Mann & DiPrete, 2013, p. 1536).

Researching the gender gap at the aggregate level of STEM is troublesome in many ways. First, the concept of STEM is somewhat ambiguous and used inconsistently, with different researchers and organizations having their own
definitions of STEM. For example, STEM may or may not include social and behavioral sciences, and many studies do not explicitly define which disciplines are considered STEM (Manly et al., 2018). Manly et al. (2018) recently emphasized that “given the prevalence of inconsistent and/or unreported STEM definitions, we posit that literature on gender and STEM currently requires excessive assumption and interpretation” (p. 1). They warn that the lack of transparency in the literature is likely to lead to confusion or error and recommend that educators and researchers interpreting findings on gender and STEM need to understand that STEM is not defined uniformly in the literature.

Secondly, considering all STEM fields as if they have similar characteristics obscures differences between and within them. Smith (2011) has pointed out that even though women are studying many science subjects in higher numbers, recruitment to physics and engineering remains stagnant. Kanny et al. (2014) emphasize that the lack of subfield research has done a disservice in addressing the gender gap because of the presumption that explanations for the underrepresentation of women are the same for different subfields. Likewise, Su and Rounds (2015) stress that gender differences across STEM fields are not identical and that overlapping yet different mechanisms in different fields and subdisciplines contribute to gender disparities. Alegria and Branch (2015) illustrate the contrasting development of gender profiles in computing and life sciences, highlighting the intersections of gender, race, nationality, and field-specific factors. We can, thus, conclude that conducting research at the aggregate level means that we can only find general solutions and explanations, and addressing subject-specific challenges is rendered practically impossible.

Emerging discipline-specific research has accentuated the concerns pertaining to aggregate STEM-level studies. Studies by Sax et al. (2016), Sax et al. (2017), and Sax, Lehman, Barthelemy, and Lim (2016) show that the predictors of study interests in different STEM disciplines such as engineering, physics, and computer science not only vary with respect to the discipline and gender but also change over time. Furthermore, the variables that most explain the gender gap depend on the discipline, although engineering and computer science are alike in this respect. For example, commitment to social activism continues to result in limited interest in majoring in these disciplines, while women’s lower self-rating of their mathematical ability and lack of interest in making a theoretical contribution to science carry less weight than they did before (Sax et al., 2017; Sax, Kanny, et al., 2016) On the other hand, women planning to major in physics appear quite different from women in other STEM fields as they, for example, tend to be confident in their mathematical abilities (Sax, Lehman, et al., 2016).

Studies on the gendered perceptions of college majors are also emerging. As Ganley, George, Cimpian, and Makowski (2018) point out, it is important to study perceptions because these are what students base their decisions on when full, accurate, and timely information on various options is not necessarily available. Ganley et al. (2018) compare 20 categories of U.S. college majors to investigate how students’ perceptions of these majors differ and what differences in perceptions best explain the gender gap. They conclude that perception of potential gender discrimination is the dominant predictor in the gender gap in both STEM and non-STEM fields rather than perceptions of majors’ orientation toward math, science, creativity, making money, or helping people. Moreover, “the majors that were perceived as having the greatest potential for future income were more likely to be highly math focused and also had the highest levels of perceived gender bias (e.g. engineering, physical sciences, computer science)” (Ganley et al., 2018, p. 476; italics added). Focusing specifically on engineering, Kelley and Bryan (2018) show how gender impacts the choices students make about the type of engineering they want to study. They find that women consider typical engineers to be more masculine than men do but that these perceptions may not impact their choice of specialty as much as expected.

Since the level of and reasons behind the gender disparity vary in different STEM fields, the aggregated actions cannot guarantee positive development in engineering. As Cheryan, Ziegler, Montoya, and Jiang (2017) point out: “Reinforcing the importance of these fields to boys and girls may be a useful strategy to recruit more students into STEM but will likely do less to close gender gaps in participation. Moreover, based on current trends, raising the math performance of girls in high school may result in more women entering the social and health sciences over computer science, engineering, and physics” (p. 22). Hence, knowing more about the female engineering/technology (TECH) applicants’ preferences is crucial for devising actions to increase their number. The Finnish application system offers an interesting opportunity for scrutinizing the choices of the same applicant and the overlap between interest in different disciplines.

3 ENGINEERING AS PART OF STEM

The relationship between natural science and engineering is an intriguing one. From certain angles it is hard to tell the difference, whereas in other respects the distinction is very clear. Until quite recently, engineering was considered an
applied science, thus sharing the same basic philosophy with the natural sciences (Meijers, 2009). In the past couple of decades, there has been a growing interest in recognizing and understanding the nature of engineering and engineering sciences as an endeavor of its own (see, e.g., Hendricks, Jakobsen, & Pedersen, 2000; Meijers, 2009; Naukkarinen, 2015). Although science and mathematics still have a strong presence in engineering curricula and engineering practice, the design practices and activities in particular are receiving more attention as something typical for engineering.

In the Finnish discourse, the role of technology and engineering as part of STEM is ambiguous and somewhat invisible. This invisibility is manifested in the acronym “LUMA,” which comes from the first two letters of “luonnontieteet,” the Finnish word for natural sciences, and “mathematics” (LUMA Centre Finland, n.d.) omitting technology and engineering altogether. Although the official aim of LUMA is to inspire and motivate children and youth about mathematics, science, and technology, in practice the activities lean more toward science education than technology education as the people involved in these activities predominantly have a background in natural sciences or mathematics. Antink-Meyer and Meyer (2016) noticed that in the U.S. science teachers typically have no experience in engineering and may have quite fundamental misconceptions of it. This situation is also likely to be the case in Finland, where science teachers receive no training in engineering subjects. A solution frequently offered to the problem of encouraging more girls to study engineering is to provide them with more experiences related to natural sciences and mathematics. The effectiveness of this approach is rarely questioned.

In Finland, technology education is not taught as a separate subject, but instruction on technology-related topics comes within various subjects like crafts, a compulsory basic education subject in Finland that includes both soft and hard materials like woodwork and metalwork (Niiranen, 2016). School curricula are expected to follow the national framework curriculum (NFC), which is revised in 10- to 15-year cycles. In the 2004 NFC, technology obtained a place in the Finnish curriculum for the first time when the topic “Human Beings and Technology” was one of the seven cross-curricular themes introduced alongside the specific study subjects. However, no specific time was allocated for cross-curricular themes, nor was there any pedagogical training offered to the teachers for implementing the themes (Järvinen & Rasinen, 2015). In the 2014 NFC, the theme was replaced by “Information and Communications Technology (ICT) Competences” (Opetushallitus, 2014). This may lead to narrowing the focus of technology education only to ICT, but so far no studies have been conducted on the impact of this change.

Although the Finnish cross-curricular teaching of technology has met its objectives regarding the development of technological knowledge and attitudes toward technology, the development of technological ideas has not been implemented in teaching, and pupils have not been given opportunities to develop technological applications nor to study the lifespan of artifacts. Young people also seem to have a narrow understanding of what counts as technology and primarily see it as subject matter connected to ICT (Järvinen & Rasinen, 2015). In subjects like physics and chemistry, theoretical constructs easily overshadow practical applications, whereas in crafts and metalwork and woodwork education practical applications overshadow the theoretical aspects. Technological concepts are also rarely discussed in broader environmental, ecological, or social contexts. (Autio, 2015). Hence, it is likely that Finnish pupils’ perceptions of technology and engineering remain narrow (ICT overemphasized), and their awareness of the related skills is limited (no understanding of what engineering is nor what an engineer does).

Henwood and Miller (2001) have argued that in the research addressing gender and education, sciences, technology, and mathematics are often perceived as immutable and autonomous. They suggest that this perception is due to black boxing, where the social and cultural practices constituting the disciplines are not acknowledged and the formation and essence of gender are likewise considered given. This results in practices aimed at changing women’s attitudes, knowledge, and interests without addressing the structural and cultural matters that originally push women away from the science and technology communities (e.g., Phipps, 2007). From the perspective of engineering, it seems important that the epistemological features of the discipline are acknowledged and taken into consideration when gender issues are researched or practically tackled as they also provide means to distinguish between engineering and other STEM fields. Moreover, seeing gender and technology as continuously coproduced (see, e.g., Faulkner, 2001) can help all of us to understand and communicate that better technology requires a better balance between genders.

4 | FINNISH GIRLS AND STEM EDUCATION

The topic of the gender gap has been addressed in a myriad of studies, many of which focus on the United States. Nevertheless, it is challenging to evaluate to what extent the previous findings and suggestions are applicable to other
countries. Therefore, studying the gender gap in divergent educational systems not only increases our understanding of the situation in that culture but also advances our knowledge of the phenomenon in general.

The Finnish educational system consists of 9 years of basic education followed by 3 years of either general upper secondary education or vocational upper secondary education. Entering higher education is possible through either path of secondary education (OECD, n.d.). When applying for a Bachelor's Degree program in a university, the study right is usually also granted for the Master-level program for the same discipline in the same university, meaning that students can continue in the respective Master-level studies directly after completing their Bachelor's Degree without any admissions or application procedures required.

The degree programs that the students apply for are quite specific from the start and changing majors is possible within certain limits, although not easy nor common. Thus, the application choices also strongly direct the possible career paths of the graduates. In mathematics and natural sciences, applicants typically choose between degree programs in mathematics, statistics, physics, chemistry, biology, geology, and environmental science. In engineering, applicants also have to choose a more specific subfield such as electrical, mechanical, civil, or industrial engineering at the application stage. Universities and universities of applied sciences (UAP) offer degrees in similar fields but the nature of the degrees is different: The university degrees have a more scientific focus and the UAP degrees, a more practical one. In engineering, the difference in profile resembles somewhat the difference between the U.S. Bachelor's Degree in engineering and the Bachelor's Degree in engineering technology.

From the start of the international research co-operation in year 2000, Finnish elementary school pupils performed extremely well in the Organization for Economic Co-operation and Development's (OECD) Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMMS) measuring proficiency in natural sciences and mathematics (Vettenranta, Hiltunen, et al., 2016; Vettenranta, Välijärvi, et al., 2016). In recent years, the results have declined especially for boys, which has resulted in Finnish girls outperforming boys both in mathematics and natural sciences. In PISA 2015, Finnish pupils' science proficiency was the second highest among the OECD countries, and confidence in their skills the same as the OECD average. Concerning collaborative problem solving, Finnish pupils were fifth among the OECD countries, with Finnish girls outperforming boys by the largest margin among all the countries (Vettenranta, Välijärvi, et al., 2016).

At the same time, educational segregation at the secondary and tertiary levels remains very strong, and girls opt out especially of technology and engineering. According to the PISA 2015 results, only 1% of Finnish ninth-grade girls are interested in a profession in science and technology. Together with Indonesian girls, this is the lowest percentage of all nations in the study (Vettenranta, Välijärvi, et al., 2016). In a national survey for high school students, 37% of the boys but only 9% of the girls stated they would like to study engineering. For natural sciences, the respective figures were 37% for boys and 30% for girls (Taloudellinen tiedotustoimisto TAT, 2016). Of all the respondents expressing interest in working in natural sciences, 62% were male and 38% were female. For engineering, the respective figures were 83% for men and 17% for women (Teräsaho & Keski-Petäjä, 2016). The proportion of women starting engineering education in Finland is also among the smallest in the OECD countries and the lowest among the Nordic countries. In Finland, only 18% of the starting engineering students are female. In Sweden the proportion is 29%, in Denmark 30%, and in Norway 24% (Keski-Petäjä & Witting, 2018).

Stoet and Geary (2018) discuss a phenomenon they call the educational gender-equality paradox, meaning that countries with a high profile in gender equality have large STEM gaps in secondary and tertiary education. They suggest that this paradox can be explained both by the life quality pressures in countries with a lower profile promoting girls' engagement with STEM subjects in a hope for better future income, and by the role and perception of individuals' academic strengths in career choices. Although in Finland girls generally outperform boys in science, their intra-individual strengths still favor reading, meaning that they are even better at reading. Stoet and Geary (2018) suggest that especially in gender-equal nations, such as Finland, the liberal conventions and smaller financial costs of foregoing STEM paths amplify the influence of intraindividual strengths and direct the educational interests of different genders more readily toward fields that seem to favor the respective strengths. This along with the lack of interest Finnish girls have in engineering indicates that engineering is not perceived as a field where reading-related skills are highly valued or needed.

Previous research has, thus, demonstrated that Finnish girls are highly capable in science, mathematics, and problem solving, but have little interest in studying technology and engineering. Although girls recognize the relevance of STEM subjects to their lives and futures (Microsoft, 2017) and have average confidence in their knowledge and skills, they still prefer to study something else. Within the STEM subjects, girls have a far greater interest in studying natural sciences than engineering. Many of the girls perceive themselves as equal to boys, and a great majority see gender
equality as desirable (Kilianmaa, 2012; Teräsaho & Keski-Petäjä, 2016); yet gender segregation of professions in Finland is among the most prominent in Europe (Keski-Petäjä & Witting, 2018).

Stoet and Geary (2018) propose using knowledge of intraindividual differences to better take into account and target STEM-related interventions especially for high-achieving girls whose personal academic strength lies in science or mathematics. From the engineering perspective, this seems viable and sufficient if we assume that mathematically oriented girls are equally likely to be interested in engineering and other STEM subjects, and if we expect that only the mathematically oriented can have a meaningful career in engineering. We will next empirically investigate the former of these assumptions.

5 | RESEARCH QUESTIONS, DATA, AND METHODS

In this article, we analyze gender differences among university-level STEM applicants in Finland by comparing applicants primarily wishing to study TECH as opposed to applicants preferring biological or physical sciences, mathematics, or computer science (SCIMA). Thus, our definition follows that of the U.S. National Center for Education Statistics but excludes agricultural sciences (Manly et al., 2018). To obtain a more nuanced understanding of this phenomenon, we seek to identify the choice patterns of these two groups of applicants and how these choice patterns are gendered.

Our research questions are:

Research Question 1: What kinds of choice patterns can be identified among applicants who primarily wish to study engineering/technology (TECH) and applicants who primarily wish to study biological or physical sciences, mathematics, or computer science (SCIMA)?

Research Question 2: How are these choice patterns gendered, that is, how do the patterns differ between males and females?

The data used in the study are derived from the Studyinfo.fi application portal and database (Finnish National Agency for Education, n.d.), which contains the information about all study programs leading to a degree in Finland. The portal is maintained by the Finnish National Agency for Education (EDUFI), and it has been used in all admissions to Bachelor-level studies since 2015. Application to all institutions of higher education, that is, universities or UAP (also known as polytechnics), is completed through the portal. The database is maintained by the national Board of Education, which may grant access to the data for scientific purposes. We requested the data for the year 2016 from the Board of Education in May 2017 and obtained the information on September 21, 2017. The original data contained all applicants to Bachelor-level studies for the year 2016 (151,369 individuals) and their application choices. Application choices appear in the database as six-digit codes according to the national classification (Statistics Finland, n.d.). This classification is based on the Unesco International Standard Classification of Education 2011 (UNESCO Institute for Statistics, 2012).

Each individual can choose up to six study programs, and these are provided in a ranking order (Choice1, Choice2, and so on). This order is binding, and the applicants are offered only the study place located highest on their preference list to which they have enough points to be accepted. For the purposes of this study, two groups were identified and selected for further analysis based on their primary application choice (Choice1) as follows:

- TECH: Applicants whose first application choice (Choice1) is engineering/technology studies at a university (B.Sc.).
- SCIMA: Applicants whose first application choice (Choice1) is biological or physical sciences (biology, chemistry, physics, and related subjects), mathematics, or computer science at a university (B.Sc.).

The data also contain certain background information on the applicants (gender, nationality, language, home country). Since we are interested in the Finnish education system, we used this information to omit applicants who do not reside in Finland. In total, the application choices of 9,104 individuals (of whom 98.7% are Finnish citizens) are included in the study. After selecting the target groups, all application choices were checked and unified so that each choice category contained only one six-digit code. In some cases, more than one code appeared per choice category in the original data. In such cases, the first one was selected as the primary application choice within that choice category. All six application choice categories were recoded for analysis purposes.
Moreover, the first application choices (Choice1) of the TECH applicants were recoded into 10 categories for further analysis. In a similar way, the first application choices (Choice1) of SCIMA applicants were recoded into 10 categories. These categories are presented in the Findings section. The analysis methods applied in this exploratory study are mainly descriptive (percentages, cross-tabs). The main background criterion used in the study is the gender (male/female) of the applicant.

6 | EMPIRICAL FINDINGS

In total, 4,821 persons selected TECH as their first application choice (Choice1) while 4,283 persons selected SCIMA. We started the analysis of the results by assessing the percentage of females in both groups. As expected, gender differences are significant: of those selecting SCIMA studies as their first choice, 42.9% are female, whereas the proportion of females among TECH applicants is 24.7% as seen in Table 1. Thus, SCIMA studies appear more attractive to females than TECH studies. To verify the statistical significance of our findings, we cross-tabulated gender and Choice1 (TECH/SCIMA) and conducted a Pearson’s Chi-square test, which confirmed that gender differences among Choice1 applicants are statistically highly significant (Pearson’s Chi-square: \( p < .000 \), two-tailed test, \( df = 1, n = 9,104 \)).

Next, we evaluated the degree of overlap between TECH and SCIMA applicants, that is, the proportion of applicants having both TECH and SCIMA programs among their application choices. To conduct this analysis, we divided the applicants into two groups based on their first choice (TECH or SCIMA) and then recoded the remaining choice categories (2–6) either 0 (TECH for TECH applicants, and SCIMA for SCIMA applicants) or 1 (other than TECH or other than SCIMA). Then, a summary variable was computed to indicate only TECH/SCIMA choices or other than TECH/SCIMA choices in these choice categories. The percentage shares of applicants with choices only in the same field as their first choice are presented in the right-hand column of Table 1.

Another way to investigate the overlap is to analyze the subsequent choices of the applicants. Therefore, Choices 2–6 of each applicant were grouped into TECH, SCIMA, and OTHER categories. The analysis reveals a similar pattern for all three groups: The relative proportions of the categories remain similar, and the total number of applicants decreases by 15–20% when moving from Choice2 to Choice3, and so on. The pattern indicates that the analysis of the second choice (Choice2) provides a reliable enough estimate of the applicants’ interest in other disciplines. Therefore, detailed information about Choices 3–6 is omitted from this article.

We found that male TECH applicants tend to be more constricted in their choices of field than females: 72.5% of the men applying to engineering/technology programs did not apply to any other field. This means that although the applicants can select up to six study programs, which can be in any field, three of four men chose only engineering/technology studies if their first choice was in this area. For women, the corresponding percentage is 58.6%. Moreover, 71.7% of the male and 65.7% of the female TECH applicants selected another engineering/technology program as their second choice (Choice2). On the other hand, slightly over half of the SCIMA applicants, 54.4% of the males and 52.5% of the females, opted only for SCIMA programs, and less than half (41.5% of the males and 48.7% of the females) selected other fields.

### Table 1

| Field | Applicants by their first choice | Applicants’ secondary choice in comparison with their first choice | Applicants’ choices 2–6[^a] | All choices in the same field (%) |
|-------|---------------------------------|---------------------------------------------------------------|-------------------------------|---------------------------------|
|       | Total number of applicants (n)  | Percent of females (%)                                        | Same field (%)                | Complementing field (%)[^b]     | Any other field (%)[^c]          | All choices in the same field (%) |
|       |                                 |                                                               | Males: 71.7                   | Males: 6.3                      | Males: 5.6                      | Males: 72.5                     | Females: 58.6                    |
|       |                                 |                                                               | Females: 65.7                 | Females: 7.6                    | Females: 11.1                   | Females: 54.4                    |                                    |
| TECH  | 4,821                           | 24.7                                                          |                               |                                 |                                 |                                    |
| SCIMA | 4,283                           | 42.9                                                          | Males: 41.5                   | Males: 11.3                     | Males: 19.5                     | Males: 54.4 | Females: 52.5 |

Abbreviations: SCIMA, natural sciences and mathematics; TECH, engineering and technology.

[^a]: Applicants could choose up to six study programs, provided in a binding ranking order.

[^b]: Complementing field: SCIMA for TECH applicants, TECH for SCIMA applicants.

[^c]: Any other field: all the study options outside the SCIMA and TECH programs.
another SCIMA program as Choice2. In general, SCIMA applicants, thus, have more variation in their application choices than TECH applicants.

Based on our findings, the applicant group with the most interest in a complementing discipline (TECH for SCIMA applicants, and vice versa) was male SCIMA applicants, of whom 11.3% selected an engineering/technology program as a second choice. However, even in this group, other study programs seem more appealing than TECH studies to applicants as almost 20% selected some other program as Choice2. Additionally, only 4.6% of the female SCIMA applicants selected engineering/technology programs as Choice2 while 25% selected some other program. On the other hand, TECH applicants did not show high interest in SCIMA studies, as only 6.3% of the males and 7.6% of the females selected SCIMA programs as their second choice. With the exception of male TECH applicants, all groups had a program in some other field as a second choice more often than in the complementing field. We can, thus, conclude that the overlap between TECH and SCIMA applicants is limited.

We also conducted a more detailed analysis of engineering/technology applicants. We categorized the original six-digit codes of Choice1 thematically into 10 subgroups, based on the similarity of the program content as well as the gender profile, that is, the male/female ratio. A degree program-level analysis was conducted to ensure that this grouping does not hide anything crucial from the gender perspective. Because the within-group gender profiles are quite similar, we are convinced that the subgroups provide detailed enough information.

Categorization of the engineering/technology programs (TECH) resulted in 10 subgroups:

- Electrical engineering and energy technology
- Mechanical and automation engineering
- Information and communications technology
- Industrial engineering and knowledge management
- Engineering sciences and technical physics
- Civil engineering and geoinformatics

![Gender distribution of first choice (Choice1) of TECH applicants by disciplinary subgroups](image_url)
- Chemical and process engineering
- Materials engineering, geoengineering, and mining technology
- Environmental engineering and biotechnology
- Architecture and landscape architecture

Because there is no uniform way of naming the degree programs, the subgroups and their names are our own.

Assessment of the number of applicants reveals that one in three (34%) of all female applicants in the engineering/technology programs wish to study architecture or landscape architecture ($n = 405$). By absolute numbers, the next most popular groups are industrial engineering and knowledge management ($n = 164$), information and communications technology ($n = 163$), and environmental engineering and biotechnology ($n = 113$). These three together make up another 37% of all the female applicants. However, owing to the different preferences of their male counterparts, gender profiles vary considerably among the subgroups (see Figure 1). These gender differences are also statistically highly significant (Pearson's Chi-square: $p < .000$, two-tailed test, $df = 9$, $n = 4,821$).

Figure 1 illustrates the differences in the gender distribution of TECH applicants among different subgroups, ranging from fewer than 10% of the female applicants in electrical engineering and energy technology as well as in mechanical and automation engineering, to close to half in environmental engineering and biotechnology, and more than half in architecture and landscape architecture. Figure 1 also reveals that despite the relatively large proportion of female applicants opting for industrial engineering and knowledge management as well as information and communications technology, approximately one-fifth of all the applicants in these subgroups are women. In general, the programs with a relatively large proportion of female applicants are those with fewer applicants (and study places), and the programs with a relatively small proportion of female applicants are the ones accepting the most students. These results highlight significant gender segregation when engineering is viewed in its totality.

A comparison of our results with publicly available admissions data reveals that the patterns among applicants are very similar to the patterns among admitted students. For example, in 2016, there were 15,228 primary applicants to...
TECH and SCIMA university studies, a total of 9,387 persons were offered a place in a university, and 8,256 persons accepted the place offered. Thirty-three percent of those accepting the offered study place were women, but their percentage varied considerably depending on the program (e.g., 72% in biology, 55% in architecture, 50% in chemistry, and 14% in electrical engineering and energy technology) (Vipunen, n.d.).

As among TECH applicants, the gender distribution of SCIMA first choice applicants differs markedly depending on the discipline, as can be seen in Figure 2. Over or nearly two-thirds of the applicants in environmental science, biology, and bioscience are female, whereas in statistics, mathematics, physics, and computer science, more than two-thirds of the applicants are male. The subgroup “Other SCIMA” consists of several small programs with few primary applicants each and includes, for example, biomedical sciences, aquatic sciences, and nutritional science.

The analysis of the second choices (Choice2) of female TECH applicants by subgroups reveals interesting differences, which are illustrated in Figure 3. (Note that here the categories of TECH and SCIMA also include the programs in universities of applied sciences.) A strong preference for engineering/technology is evident, with over or nearly half of the second choices in all subgroups representing engineering/technology subjects. Yet, there are clear differences among the subgroups. In some subgroups, TECH female applicants have very little interest in disciplines other than TECH and practically no interest in SCIMA. This applies to electrical engineering and energy technology, mechanical and automation engineering, materials engineering, geotechnology, and architecture and landscape architecture.

In the last case, the second choice for most applicants (67%) is also a program in the same subgroup as the first choice.

There are, however, subgroups where natural sciences and mathematics (SCIMA) are clearly options for the applicants. These include engineering sciences and technical physics, chemical and process engineering, information and communications technology, and environmental engineering and biotechnology. The engineering programs in these subgroups are the ones that seem to have a “sibling program” among SCIMA programs (i.e., physics, chemistry, computer science, environmental science, biochemistry). Furthermore, the only engineering degree program that includes teacher training (Engineering Science at Tampere University of Technology) belongs to one of these subgroups.

![Figure 3](image-url)
FIGURE 4  The analysis of second choices (Choice2) of female SCIMA applicants by disciplinary subgroups of their first choice (Choice1)
Choice 1 applicants in the remaining subgroups (industrial engineering and knowledge management; civil engineering and geoinformatics) appear to have a strong interest in technology but also some interest in SCIMA. Yet, other programs seem to be an equally or even more viable option than SCIMA as Choice 2. This also applies to applicants in chemical and process engineering, and environmental engineering and biotechnology.

Similar patterns also emerge when analyzing the secondary choices of male TECH applicants. Therefore, it can be concluded that among engineering/technology applicants, preferences range from a rather strong interest in natural sciences and mathematics (i.e., considerable overlap between TECH and SCIMA) to zero interest (no overlap). Moreover, the areas of no overlap seem to be located either in the area of architecture or in the mechanical, electrical, and automation engineering programs.

The second choices of female SCIMA applicants illustrated in Figure 4 show that these applicants are not quite as committed to SCIMA subjects as the female TECH applicants are to TECH programs. This is also illustrated by the percentage of applicants applying only to TECH or only to SCIMA (see Table 1). In general, SCIMA applicants show only limited interest in TECH programs. The greatest interest can be seen in the “sibling programs,” namely physics, computer science, bioscience, and chemistry, which attracted the most attention from the TECH applicants. Geology applicants also seem to have some interest in TECH programs. However, although environmental engineering and biotechnology applicants show some inclination toward SCIMA programs, environmental science applicants do not seem to be attracted to TECH programs, including environmental technology. This result is intriguing as one would expect the environmentally minded applicants to consider both options.

7 | DISCUSSION

Our findings reveal that the overlap between the SCIMA and TECH applicants is surprisingly small: Over 70% of the TECH applicants and more than 50% of the SCIMA applicants apply only to their respective programs, and only a small minority select the complementary field (SCIMA for TECH and TECH for SCIMA) among their further application choices.

However, exploring the results in more detail reveals some interesting gender differences. Female engineering applicants tend to be slightly more open to other options than their male counterparts, and among the female engineering applicants, there are subgroups with considerable interest in SCIMA subjects as well as subgroups with virtually no interest. Because different engineering subdisciplines have different gender distributions of applicants, there is most likely some correlation between the TECH versus SCIMA interest patterns of different genders and different subdisciplines. This possibility appears to support the suggestion by Mann and DiPrete (2013) that a greater curricular flexibility and the possibility to pursue coursework in other fields of interest enhances women’s interest in a discipline, and on the other hand, diverts them from fields of engineering lacking curricular flexibility.

If the applicants are really interested in either engineering or science, is there a point in trying to sell them both as one “STEM package”? Even worse, is there a danger that emphasizing the unity of science and engineering deters some potential applicants? In her study of successful Swedish students, Engström (2016) found two profiles among male students who, despite their interest in technology, did not find mathematics and science particularly easy, interesting, or enjoyable. This kind of practical technology interest was not found among the female students. Earlier research also suggests that female applicants do not even apply for engineering if they have doubts about their academic success or interest in science subjects (e.g., Du, 2006). This makes us wonder whether women with a more practice-oriented mindset could be successful in engineering in the same way as men.

For many years, chemistry, physics, and mathematics courses were placed at the beginning of the Finnish engineering curricula, with the assumption that students had to master these topics to be able to apply them in their later engineering courses. A similar principle seems to be reflected in the idea that the elementary school technology education naturally emerges from science classes where pupils learn about phenomena so that they can later apply them for practical purposes. This “theory first” approach was challenged in an experiment delivering integrated science, technology, and engineering education focused on real-world practice. The integrated approach was noted to significantly improve both the knowledge of science, technology, and engineering content and pupils’ aspirations for engineering (Yoon, Lucietto, Capobianco, Dyehouse, & Diefes-Dux, 2014). Using the engineering design process as a teaching framework for physics and biology was also found to increase female students’ interests in physical sciences in particular (Ward, Lyden, Fitzallen, & de la Barra, 2015).

There are currently ongoing attempts to profile young people according to their interests in STEM subjects and careers (Motivation & YoungWorks, 2010; Teknikföretagen, 2017). The profiles discovered clearly illustrate different
reason that people have for being interested in STEM subjects both separately and as a group. Some are equally interested in science and technology or theory and practice. They want not only to understand principles but also to be able to put them into practice. Some people are driven by practice, and the more theoretical knowledge is interesting only when it clearly serves a practical purpose. Others are theorists to whom practice does not necessarily appeal at all. Moreover, there are those who are the most interested in using instead of producing technologies. Interestingly, there are also secondary education pupils, typically more girls than boys, choosing STEM subjects who are not interested in them but opt for them to keep their options open (Yazilitas, Saharso, de Vries, & Svensson, 2017).

One viable option for addressing the interests of the practically minded potential applicants already in their basic education could be the integrated science, technology, and engineering education suggested by Yoon et al. (2014). As their approach did not weaken the academic results at the expense of improving practical knowledge and aspirations, it is likely that it would not put the pupils interested in science in a worse position but could benefit the science learning and the identity formation of the pupils interested in “only technology.” In essence, this integrated approach is a way of increasing the visibility of engineering design and the creative side of engineering work, which is often weakly acknowledged by K-12 pupils (Capobianco, Diefes-Dux, Mena, & Weller, 2011). Seeing the creative side of engineering can be a substantially appealing factor for young people with an inventive mind and/or practical mindset who may not find the mathematics or science attractive in themselves.

There are notable differences among the technological subdisciplines with respect to both the gender distribution of the applicants and the applicants’ interests in other STEM disciplines. There are several plausible explanations for this difference: Some subdisciplines appear more feminine in nature than others because of their emphasis on social imperatives or their interdisciplinary content or methods (Barnard, Hassan, Bagilhole, & Dainty, 2012; Brawner, Camacho, Lord, Long, & Ohland, 2012; Foor & Walden, 2009; Mann & DiPrete, 2013); the influence of socializers such as parents, teachers, and friends (Ikonen, Leinonen, Asikainen, & Hirvonen, 2017); and different personal motives linking with different subdisciplines (Engström, 2016). Kelley and Bryan (2018) show that female students in the subdisciplines with the greatest proportion of females have the most masculine perceptions of engineering in general. They suggest that females would, therefore, seek specialty areas with more females to increase their level of comfort. Another explanation for this is that although women perceive a typical engineer as masculine, they may perceive their choices as atypical and, hence, more appealing. Ganley et al. (2018) argue that in addition to perceived gender representation, the perceived gender discrimination is an important factor behind the gender differences in choice of major.

Different subdisciplines appear to attract somewhat different applicants although women interested in technology and engineering have been found to be a more homogeneous group than men (Engström, 2016). Engström (2016) identified one profile among the Swedish engineering students that was present among the female students but had no counterpart among the male. Students in this profile emphasized their willingness to do something good for society and humanity. A similar observation was made by Shealy et al. (2015), who discovered that females interested in civil engineering were more likely to wish to address societal issues, such as poverty or distribution of wealth and resources, than males interested in civil engineering or both females and males interested in other fields of engineering. These kinds of more general motives could provide a better starting point for the understanding of choice patterns in totality instead of explaining the applicants’ behavior through the first choice only. From this viewpoint, it was particularly interesting to note that practically none of the female applicants for environmental sciences applied to environmental engineering or any other engineering program as their second choice. This suggests that many young, environmentally minded women with possible altruistic study motives do not perceive engineering as a discipline that allows them to help society and environment. This, however, is a topic that calls for further study.

As our results also show, different engineering subdisciplines attract women to varying degrees. Nonetheless, as Cheryan et al. (2017) argue, even if women are interested in other fields, it does not mean that they could not be equally interested in engineering if the culture of the discipline signaled to them that they belong there. Therefore, instead of or in addition to encouraging more Finnish girls to study science and mathematics in K-12 education, it is also necessary to open up the black box of technology (Henwood & Miller, 2001) and help girls as well as boys to better understand what engineering and development of technology are about. This, however, is not primarily a question of giving young people information but rather a question of creating and presenting a wider disciplinary self-understanding. This requires a cultural change and critical contemplation of values as suggested by Ulriksen, Möller Madsen, and Holmegaard (2010).

As a part of the cultural change required, engineering as a discipline needs to discuss and better communicate the added value of women and other nontraditional groups for the field. This, on the other hand, may call for more discussion about both the disciplinary nature of engineering and the purpose of engineering for society—both topics not very often discussed within the engineering community. This means changes in both academic and managerial engineering
discourse as well as in the liberal education discourse in the engineering education institutions (Stonyer, 2002). The altruistic and humanitarian aspects of technology have been noted to be more important to women than men (Engström, 2016; Motivaction & YoungWorks, 2010), and the women's stronger commitment to social activism is one of the variables that most explain the gender gap in engineering (Sax, Kanny, et al., 2016). Thus, emphasizing the opportunities to serve society in engineering has the potential to attract more women to the field. Yet, the dualistic discourse of the discipline often devalues these aspects and considers them less essential (Faulkner, 2000) or “imaginary engineering” (Foor & Walden, 2009, p. 41).

8 | LIMITATIONS

The data on the application choices used in this study were derived from the Studyinfo portal (Finnish National Agency for Education, n.d.). We had to define which data were necessary for conducting this study very early in the application process and limit our investigation only to that data. As this is the first study of the kind (to our knowledge) to be conducted using the Studyinfo data, we decided that a descriptive approach would best suit our objectives. Since we were interested in the choice patterns of applicants and how these choice patterns are (potentially) gendered, we selected the application choices (1 to 6) and the gender of the applicant as our main focus. Gender in the database is a binary variable (male/female) and, therefore, does not allow variety of gender identities to be taken into account. Further studies could analyze the importance of other demographics not contained in our data set, such as the age of the applicants (although the majority of applicants to Bachelor studies in Finland are between the ages of 18 and 19).

The results reflect the Finnish educational system, and the applicability of our findings naturally depends on similarities and differences between systems. In the Finnish system, the choice of degree program is much more tightly connected to the future career than, for example, in the United States, where one can more easily change their major during college or continue to Master-level education or professional education from several different Bachelor’s degrees. Thus, the decisions made in application to tertiary education have different consequences in different educational systems and may also be influenced by different factors.

9 | CONCLUSIONS

The findings presented in this article show that, as expected, studies in engineering or technology (TECH) and studies in biological or physical sciences, mathematics, or computer science (SCIMA) attract men and women to varying degrees. Our results also reveal that TECH and SCIMA subjects are not perceived as alternative options by male or female applicants. Over 70% of the TECH applicants and more than 50% of the SCIMA applicants apply only to their respective programs, and the TECH applicants considering other options prefer other subjects to SCIMA, and vice versa. Indeed, considering the tendency to perceive science, technology, engineering, and mathematics as one entity (STEM) and to emphasize the strong relationship between science and technology, the overlap between SCIMA and TECH applicants is surprisingly small. Applicants to TECH and SCIMA Bachelor studies in Finnish universities have clearly decided on which discipline they are interested in.

Our findings also reveal notable differences between the technological subdisciplines with respect to both the gender distribution of the applicants and the applicants’ interests in other STEM disciplines. For almost two-thirds of the female engineering applicants, the second choice was also engineering/technology, but this percentage varied from 48% for chemical and process engineering applicants to 74% for electrical engineering applicants. Additionally, the applicants’ interests in science and mathematics varied from no interest at all to more than 30% of the applicants applying for SCIMA disciplines as their second choice. These differences cannot be explained by the perceived representation or perceived gender discrimination of the first choice as previous studies have suggested.

As this and several earlier studies have pointed out, conducting research at the aggregate level yields only general solutions and explanations. Moreover, when practical initiatives are based on explanations provided by aggregate research, addressing subject-specific challenges is rendered practically impossible. Our findings indicate that although emphasizing the importance of finding means for attracting more women to study STEM may be necessary, it is not a sufficient solution to attract more women into engineering. Thus, it is necessary to better articulate what engineering and the development of technology are about—for both girls and boys. To achieve the required cultural change, engineering as a discipline needs to discuss and better communicate the added value of women and other non-traditional groups for engineering and technological development.
Engineering has several subdisciplines, some of which attract women more than others. Nevertheless, engineering design and human–technology interface are central aspects in any field of engineering. Thus, the ideas described earlier could and should be taken into account consistently throughout the field instead of using them to create “female-friendly” subdisciplines, which easily become devalued and perceived as softer or “imaginary” engineering and actually work to maintain the status quo of engineering as masculine as it has hitherto been.

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