ADVANCED MATHEMATICAL SKILLS AND THE RELATING FACTORS OF ENGINEERING APPLICANTS: A CROSS-SECTIONAL STUDY

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ABSTRACT

Higher education institutions assess applicants with entrance examinations as a way to identify and rank those applicants with adequate ability to proceed in their studies. Engineering students form a significant group of higher education students, both in Europe and Finland. Finnish universities of applied sciences (UASs) developed and harmonised their student selection in the Development Project in 2017–2020. In the Development Project, a new national digital universities of applied sciences entrance examination (UAS Exam) was developed. In the current study, a cross-sectional design was used to assess advanced mathematical skills and related factors of the bachelor-level engineering applicants performing the newly developed UAS Exam. The advanced mathematical skills exam section contains mathematics and physics problems. The data were collected via the digital exam system. Altogether, 1205 engineering applicants consented to the study and performed the exam section. The data were statistically analysed. The applicants' mean scores were 4.8 (SD 5.2, median 3.9, range -4.9–20 pts) out of 20 maximum points. Over 20% of the applicants failed. Some of the background variables explain the applicants' exam results, indicating that older applicants scored better than younger ones, males better than females, and high school graduates and applicants with previous higher education degrees better than those with vocational diplomas. The results indicate that engineering applicants' advanced mathematical skills were rather poor, indicating that it may be possible that engineering applicants lack the basic skills in mathematics and physics, but this may vary between applicants.

1 INTRODUCTION

The admission of new students to universities can be described as a process of matching, guidance and selection enabling the graduation of students with the adequate skills needed in their future working life (1). Therefore, higher education institutions (HEIs) assess their applicants using entrance examinations and other selection methods to identify and rank applicants with a high probability of programme completion (2). The assessment of applicants should aim for equity and fairness, which challenges HEIs to use objective and valid selection methods (2; 3). However, student selection practices vary within and between countries (1; 2).

In Europe, engineering students form a significant group of higher education students. In 2019, there were 10.9 bachelor-level engineering graduates per thousand inhabitants in the European Union (EU) area. In Finland, there were 15.6 engineering graduates (bachelor level) per thousand inhabitants in 2019, which was the second highest number of graduates on the Eurostat list of the European countries (4). However, engineering educational systems differ across the world (5). In the Finnish educational system, higher education has a dual model consisting of science universities and universities of applied sciences (UASs) (6). In science universities, the basic degree is a master's degree, whereas UASs offer more pragmatic education and in where the basic degree is a bachelor's degree. Both university sectors offer engineering education programmes in Finland. In UASs, the duration of bachelor-level engineering education is four years, covering 240 ECTS (7).

In Finland, higher education is free of charge for citizens in EU member states and the European Economic Area (5). However, entry to Finnish HEIs is limited, so there are more applicants than study places available. Until 2016, entrance to the bachelor-level engineering education to Finnish UASs was based on success in earlier studies (matriculation examination scores) or work experience (concerning applicants with vocational diplomas) and entrance exams testing applicants' basic skills in mathematics and physics or chemistry. To be qualified as an eligible applicant, the applicants had to get enough points from the entrance exam (about one-third of the total). The final selection decision was based either on a combination of certificate scores/work experience scores and entrance exam scores or only on the entrance exam scores. Since 2017, entry to bachelor-level engineering education in Finnish UASs has been possible with certificate-based selection as well.

Finnish UASs have developed and harmonised their student selection in the Development Project for Student Selection in Finnish UASs 2017–2020. A new digital national universities of applied sciences entrance examination (UAS Exam) was developed and used for the first time in autumn 2019 (8). The UAS Exam is intended to be used in all study fields, and it includes exam sections common to all applicants and those common to applicants in specific study fields. The exam section of advanced mathematical skills is performed by all bachelor-level engineering applicants.

The purpose of the current study was to assess the advanced mathematical skills and related factors of the bachelor-level engineering applicants (to UASs). The research questions were: 1) What is the level of advanced mathematical skills of engineering applicants? 2) What factors are related to advanced mathematical skills of engineering applicants?

2 METHODOLOGY

2.1 Design, setting, participants and data collection

A cross-sectional study was conducted. Altogether, 20 UASs that were geographically spread out and that used the UAS Exam in autumn 2019 participated. Engineering applicants (bachelor level) who answered the advanced mathematical skills section in the UAS Exam and gave their consent were included. The collected data comprised the applicants' automatically calculated exam scores from the digital exam system and background variables of age, gender, previous education, socioeconomic background (according to mother/father), place of birth (own/parent) and study programme/field of an applicant. The applicants performed the UAS Exam under supervision at the participating UASs using their own devices between 29 October 2019 and 1 November 2019. Approval to undertake the study was granted by the UASs, and ethics committee approval for the study was obtained (27 September 2019).

The advanced mathematical skills exam section assesses applicants' abilities in mathematics and physics. The problems concerning mathematics involve simplifying algebraic expressions, solving equations and problems involving plane geometry and trigonometry, for example, a right-angled triangle. Physics problems involve conclusions and calculations based on the given physical models or basic knowledge related to physical phenomena, as well as interpreting charts and graphs. Unfortunately, the more specific presentation of the concrete exam questions is beyond the scope of the current paper. In autumn 2019, there were altogether seven exam questions (multiple choice). The maximum scores were 20, the minimum pass score was 1, and penalty scores were used to avoid guessing behavior.

The validity evaluation of the advanced mathematical skills exam section was conducted as part of a larger research project (8). In the research project, the exam questions were evaluated by an expert panel and pilot tested, and psychometric testing utilising both classical test theory and item response theory methods was conducted (8).

2.2 Data analysis

The data were analysed using the Statistical Analysis Software (SAS 9.4®). Descriptive statistics were used to describe the applicants' success in the advanced mathematical skills section (exam scores) and describe the demographic characteristics. The relating factors were analysed from two perspectives: by analysing the associations between the background variables and exam scores and between the background variables and failed exam results (i.e., the applicant scored below the minimum pass score limit). Analysis of variance with Tukey's test in post hoc multiple group comparisons was used to analyse those factors related to the applicants' exam scores. Logistic regression analysis was used to explain applicants' failed exam results and related factors. The data were analysed as part of a wider research analysis focusing on the exam results for the entire UAS Exam and its sections. Therefore, all the background variables were included in our analysis. However, the variable of 'study field' is not reported in the current study because its practical importance was considered minimal because only the engineering applicants performed the advanced mathematical skills exam section.

3 RESULTS

3.1 Applicants' demographic characteristics

Altogether, 1205 out of 1756 engineering applicants participated in the study (response rate 68.6%), thus performing the advanced mathematical skills section in the UAS Exam. Most of the applicants were 20–24 years old, and less than 10% of the applicants were younger than 20 years old (Table 1). Two-thirds of the applicants were male. Most of the applicants were high school graduates or had a vocational diploma. Applicants' parents were most often manual workers by their socioeconomic background. Most of the applicants were born in Finland. (Table 1.)

Table 1. Demographic factors of the participants (n=1205).

Demographic factor	**f**	**%**
Age		
< 20	108	9.0
20–24	479	39.8
25–29	261	21.7
> 29	357	29.6
Gender		
Male	866	71.9
Female	339	28.1
Previous education		
High school	469	38.9
Vocational school	431	35.8
Double qualification (high school and vocational school)	43	3.6
Higher education degree	93	7.7
Other	169	14.0
Socioeconomic background (father)		
Self-employed persons	215	17.8
Upper-level employees (with administrative, managerial, professional and related occupations)	202	16.8
Lower-level employees (with administrative and clerical occupations)	193	16.0
Manual workers	417	34.6
Students	27	2.2
Pensioners	114	9.5
Others (Unemployed)	37	3.1
Socioeconomic background (mother)		
Self-employed persons	115	9.5
Upper-level employees	154	12.8

	(with administrative, managerial, professional and related occupations)		
	Lower-level employees (with administrative and clerical occupations)	297	24.6
	Manual workers	476	39.5
	Students	25	2.1
	Pensioners	73	6.1
	Others (Unemployed)	65	5.4
Place of birth (own): born in Finland			
	Yes	1107	91.9
	No	98	8.1
Place of birth (parent): one parent or both parents born outside Finland			
	Yes	156	12.9
	No	1049	87.1

3.2 Applicants' advanced mathematical skills and related factors

The applicants' mean scores in the exam section of the advanced mathematical skills were 4.8 (SD 5.2, median 3.9, range -4.9–20 pts) out of 20 maximum points. Over 20% (n=299, 24.8%) of the engineering applicants failed (scored less than +1 points). The score distribution of the applicants is presented in Figure 1.

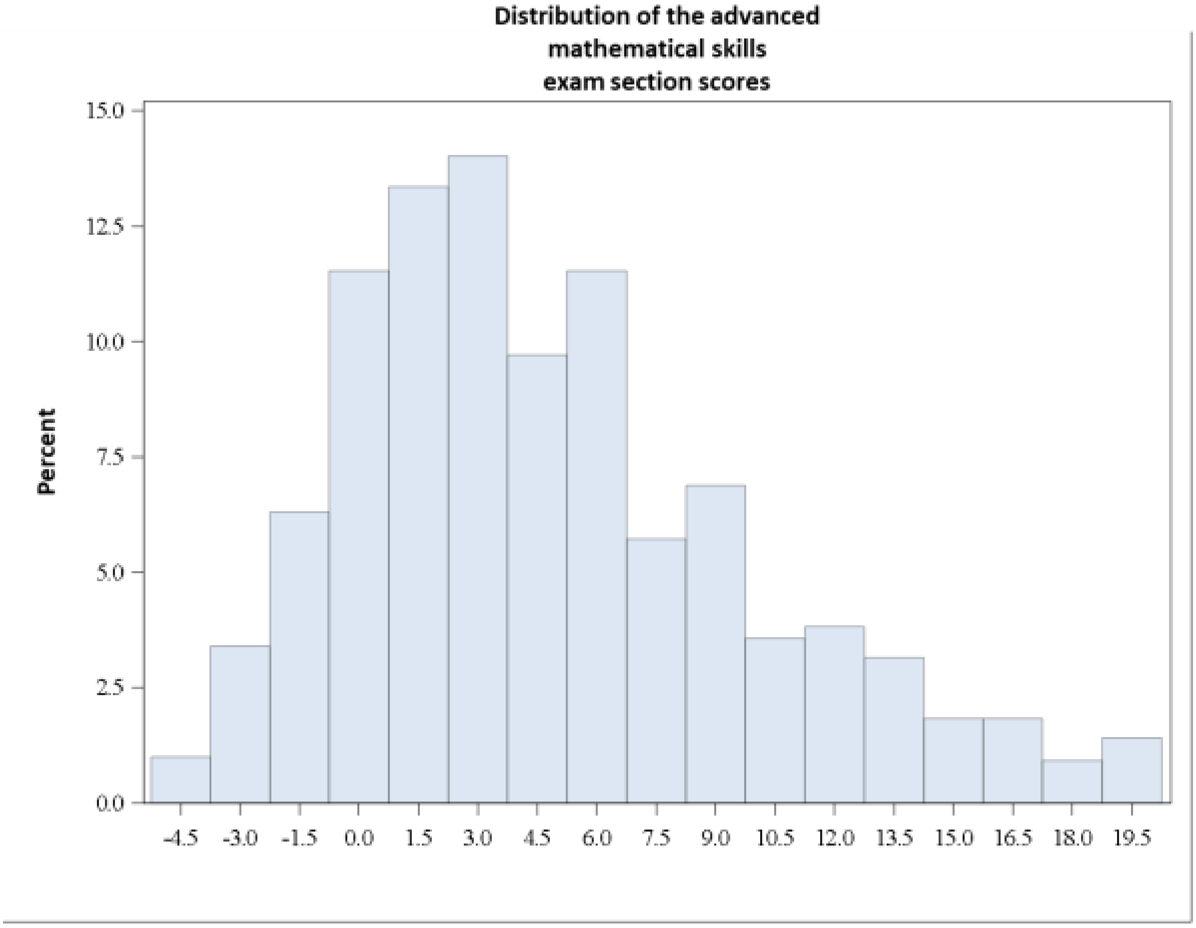

Figure 1. Score distribution of the advanced mathematical skills exam section.

Age, gender and previous education explained the applicants' success in the advanced mathematical skills exam section (Table 2). The oldest applicants (> 29 years) scored better than the youngest age groups (< 20 years and 20–24 years), and male applicants scored better than female applicants. Concerning previous education, the main result was that those applicants with previous higher education degrees and who graduated from high school scored better than the applicants with vocational diplomas. (Table 2.)

Table 2. Factors related to engineering applicants' (n=1205) advanced mathematical skills.*

BACKGROUND VARIABLES	**TOTAL SCORES** Difference between means (95% confidence interval), **p-value/**NS = not significant
Age	
20–24 vs. > 29	-1.44 (-2.41– -0.46), **0.0009**
< 20 vs. > 29	-1.64 (-3.09– -0.18), **0.0201**
Gender: Male vs. female	1.79 (1.13–2.44), **<.0001**
Previous education	
Vocational school vs. higher education degree	-3.75 (-5.37– -2.12), **<.0001**
Vocational school vs. high school	-2.69 (-3.63– -1.75), **<.0001**
Higher education degree vs. other	3.54 (1.70–5.39), **<.0001**
Other vs. high school	-2.50 (-3.78– -1.22), **<.0001**
Socioeconomic background (father)	NS
Socioeconomic background (mother)	NS
Place of birth / own	NS
Place of birth / parent	NS

*Only the statistically significant results in group comparisons are presented.

Gender and previous education were the only background variables explaining the failed exam results (Table 3). Female applicants were more likely to fail than male applicants. Applicants with vocational diplomas were more likely to fail than those with previous higher education degrees and high school graduates. (Table 3.)

Table 3. Background variables explaining engineering applicants' failed exam results in the advanced mathematical skills section (n=299/N=1205).

	OR*	**95% confidence interval**	**p-value**
Age	-	-	NS
Gender: Male vs. female	0.48	0.36–0.65	**<.0001**
Previous education			
Higher education degree vs. vocational school	0.39	0.21–0.71	**0.0024**
Other vs. vocational school	1.06	0.71–1.59	NS
High school vs. vocational school	0.54	0.39–0.75	**0.0002**
Double qualification vs. vocational school	0.64	0.30–1.37	NS

Socioeconomic background (father)	-	-	NS
Socioeconomic background (mother)	-	-	NS
Place of birth / own	-	-	NS
Place of birth / parent	-	-	NS

**OR = Odds Ratio. When the OR is higher than 1, there are more failed exam results in the group on the left than in the right one. When the OR is lower than 1, there are less failed exam results in in the group on the left than in the right one.*

4 SUMMARY

The purpose of the current study was to assess advanced mathematical skills and the related factors of the bachelor-level engineering applicants (to UASs). A new objective and digital assessment method (UAS Exam) was used. The results indicate that engineering applicants' advanced mathematical skills were rather poor and that a considerable number of applicants failed the exam section. In Finland, advanced mathematical skills, such as mathematics and physics, have been assessed for years in engineering student selection. Previously, it has been reported that entry-level engineering students lack the basic abilities in mathematics and physics, and the failure percentage in engineering entrance examinations can be very high (9). According to recent educational statistics in Finland, the number of UAS applicants who have included the physics test on their matriculation examination (a national examination taken at the end of Finnish upper secondary school) is rather low (10). Based on the results of the present study, it is possible that many UAS engineering applicants lack the basic skills in mathematics and physics, but there may be a large amount of variation between applicants and, thus, between prospective students' skills. These results should be acknowledged both in the upper secondary level when preparing students for higher education studies and in the entry/first semester of the UAS studies to find solutions that can help in filling the gap in new students' skills. Overall, it is not ideal to fail a high number of applicants in student selection. However, it is possible that the applicants' low exam scores may also relate to the difficulty level of the exam and use of penalty scores. Therefore, the scoring technique and difficulty of the advanced mathematical skills section should be further evaluated. The study results indicate that some background variables may explain engineering applicants' success and failed exam results. Male applicants scored better than females, but men were the major applicant group. An important result is that high school graduates scored better than applicants with vocational diplomas. Upper secondary education (11) should prepare students for higher education studies, but it seems that high school graduates are better prepared than those applicants with vocational diplomas. The results of the current study highlight the importance of preparing upper secondary students for higher education studies, especially in vocational education. The results can be used in further development of the UAS Exam and of fair and objective student selection practices. Furthermore, the results have international implications because HEIs are encouraged to develop their student selection practices (3).

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