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Beyond numbers: The effect of prior mathematical knowledge on university progress of engineering students

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Abstract. Mathematics is the foundation of science, technology and engineering. At University of Debrecen Faculty of Engineering teachers can experience that the basic studies have difficulties, transition from high school to university mathematics courses is a challenge for many students. According to previous researches, prior mathematical knowledge has a central role in the initial stages of university studies. In the light of the existing literature, this report examined the mathematics level of engineering students at a Hungarian university at the end of first academic year, to investigate the relationship between prior mathematics education in secondary school and academic performance. We report about the effect of high school mathematics knowledge on the university progress of engineering students after the initial stages. We investigated whether the students are able to make up for the prior mathematical knowledge deficiency, or whether it holds them back in university progress even after one year. Our aim was to understand the factors behind of students' achievement. Based on our survey, we can conclude that at University of Debrecen Faculty of Engineering many engineering students had problems with prior mathematical knowledge deficiency, which affects university progress, significantly correlated with the first practical test, suggesting that the ability to apply knowledge in practice is more closely related to prior knowledge. We hope this paper represents a valuable addition to the literature on academic preparedness and equity in higher education.

Keywords: engineering education, educational research, mathematics education, problem solving

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1. Introduction

Mathematics is the foundation of science, technology and engineering. Association between early mathematical proficiency and later academic achievement is established [2]. Spatial ability, spatial skills can have an effect on mathematics performance and predict mathematical ability and eventual expertise in science, technology and engineering [23]. Many researchers investigating how can we measure [13, 15] and how these skills are related [5, 11, 12, 19]. Many different methods are used to test aspects of spatial ability, for example, researchers are developing Virtual Reality aided applications to generate test exercises [24, 25] and examine its effect [28]. Because of its immersive experience, it has potential to improve understanding [22]. However, in some cases we may need more comprehensive measurement.

Mathematics skills were long thought to be fixed and innate, but new research is revealing distinct individual differences in the brains and genes of math-prone individuals [3, 8, 21]. According to researches [9] mathematics self-concept was predictive of secondary school pupils' maths grades and scores. For many students, an aversion towards maths is attributed to negative experiences during their school years [6] and these experiences shape how children think about themselves in relation to mathematics (mathematics self-concept) [4, 8]. Taking these literatures into account, it is important to eliminate students' aversion to mathematics, and to assess the students' preliminary knowledge level (mathematical and spatial skills) is an important task for mathematics teachers [26].

Engineering higher education is under constant pressure to implement reforms that improve the employability of graduates [27]. At University of Debrecen Faculty of Engineering teachers can experience that the basic studies have their difficulties: there are huge differences among the pre-education level of the students, stemming from disparities in secondary education [14]. Numerous international and Hungarian studies report on this fact regarding university mathematics education, the transition from high school to university courses is a challenge for many students [1, 7, 10, 14, 18, 20]. Studies have shown that students were less successful with word problems that required practical application [20]. The literature indicates that engineering students have deficiencies in prior mathematical knowledge, with the greatest deficiencies in functions and coordinate geometry [7]. This causes problems in the assignments of Analysis and Linear Algebra courses at university. According to previous researches, prior mathematical knowledge has a central role in successfully dealing with the challenges of learning processes in the initial stages of university studies [14, 17, 29]. Engineering universities report on high dropout rates in mathematics, which has prompted the universities to offer transition courses [14, 16]. The interest, pre-knowledge and motivation of the students are very different. In the light of the existing literature, this report examined the prior mathematics level of engineering students in Hungarian higher education and their results at the end of the first academic year, which is essential for training and a starting point for the organization of transitional courses. We report about the effect of high school mathematics knowledge on the university progress of engineering students after the initial stages. We investigate whether the students are able to make up for the prior mathematical knowledge deficiency, or whether it holds them back in university progress even after one year. This is important within the domain of higher education research, particularly in the context of educational inequality and institutional support structures.

Our aim was to understand the factors behind of students' achievement. After all, behind the results of Mathematics II and Comprehensive exam in Mathematics, it is important to know what kind of prior mathematical knowledge the students started with and how they achieved this grade at university.

2. Settings, methods, methodology

We examined all first-year mechatronics engineering students, 40 students with statistical analysis SPSS at the University of Debrecen, Faculty of Engineering. 33 students came for the Comprehensive exam in Mathematics at the end of the 2nd semester. The N (number of sample elements) differs in the tables (40, 39, 33). This is due to dropout, as one student did not write Test3 and Test3Pract. Only 33 people took the Comprehensive exam in Mathematics, the rest of the students planned to take it in later semesters. We compared in the 2023/24 academic year:

- the results of premathematics knowledge from high school test, at the beginning of the 1st semester in September (PreTest),
- the results of the Mathematics II tests (in the 2nd semester): theoretical tests (Test1, Test2, Test3) and practical tests (Test1Pract, Test2Pract, Test3Pract),
- the grade of Comprehensive exam in Mathematics (CE) (at the end of the 2nd semester, in June).

All tests in the survey were compiled by mathematics teachers from technical higher education institution. The tests were 60 minutes long and were written by the students at the beginning of class. We investigated whether there is a close relationship between the results of the mentioned tests and Comprehensive exam in Mathematics. Comprehensive Exam in Mathematics is a test that assesses students' comprehensive knowledge of the basic mathematical concepts covered in their program and requires students to cover two semesters of Mathematics course material. Furthermore, are the students able to make up for the prior mathematical knowledge deficiency, or does it still hold them back in university progress after one year. Topics of tests:

- Test1 and Test1Pract: Differentiation and integration of multivariable functions. Scalar field, gradient. Young's theorem. Directional derivative. Local and global extrema.

- Test2 and Test2Pract: Parametric curves. Notions of differentiation, linear approximation, curvature, torsion. Parametric surfaces, tangent plane, linear approximation. Surfaces of revolution. Vector fields. Derivatives. Divergence and curl. The notion of double and triple integrals. The extensions of the integrals. The arc length of curves, surface area. Line and surface integrals.

- Test3 and Test3Pract: Differential equations. First order differential equations. Determination of solutions of inhomogeneous first order linear differential equations. Second-order differential equation. Solution of linear homogeneous and inhomogeneous differential equations of order two having constant coefficients. Method of undetermined coefficients. Special second order differential equations.

The criteria used to select the 21 items for the PreTest: When compiling the questions, mathematics teachers at technical higher education institution kept in mind the examination of the knowledge necessary for successful progress in technical higher education, the measurement of the necessary basic skills, problem-solving strategies, and took into account the high school mathematics graduation requirements. The PreTest actually measured high school math knowledge. The PreTest consisted of 21 tasks, which included a variety of tasks, aiming to get the most accurate picture of the students' knowledge of high school mathematics. A total of 90 points could be achieved here. This pre-mathematics test was 90 minutes long. Students were not allowed to use calculators on any of the tests. The generalizability and comparability of the results are limited by the fact that test results in this research were not compared with other measurement tools or external criteria. Topics of PreTest:

- Numbers and operations
- Functions
- Equations, System of equtions
- Trigonometry
- Vectors, Coordinate geometry
- Plane geometry: Area, Perimeter
- Space geometry: Surface, Volume

3. Results

Data analysis in Table 1 showed that there is a significant correlation between some of theoretical tests solutions by students with SPSS (Test1 and Test2: $r = 0.351$, $p = 0.026$, $p < 0.05$, Test2 and Test3: $r = 0.618$, $p < 0.01$). So Test1 has significant correlation with Test2, and Test2 has significant correlation with Test3 with weak and moderate relationships. Data analysis (Table 1) showed that there is a significant correlation between some of practical tests solutions by students (Test1Pract and Test2Pract: $r = 0.447$, $p = 0.004$, $p < 0.01$, Test2Pract and Test3Pract: $r = 0.553$, $p < 0.01$). So Test1Pract has significant correlation with Test2Pract, and Test2Pract has significant correlation with Test3Pract. But there is not significant correlation between other tests solutions.

Table 1. Relationship between Mathematics Tests and Comprehensive exam in Mathematics.

		Test1	Test1Pract	Test2	Test2Pract	Test3	Test3Pract	CE
Test1	Pearson Correlation	1	,410**	,351*	,479**	0,162	0,255	0,039
	Sig. (2-tailed)		0,009	0,026	0,002	0,326	0,117	0,828
	N	40	40	40	40	39	39	33
Test1Pract	Pearson Correlation	,410**	1	0,27	,447**	0,169	0,248	0,242
	Sig. (2-tailed)	0,009		0,092	0,004	0,303	0,128	0,175
	N	40	40	40	40	39	39	33
Test2	Pearson Correlation	,351*	0,27	1	,569**	,618**	0,27	,443**
	Sig. (2-tailed)	0,026	0,092		0	0	0,096	0,01
	N	40	40	40	40	39	39	33
Test2Pract	Pearson Correlation	,479**	,447**	,569**	1	,349*	,553**	0,264
	Sig. (2-tailed)	0,002	0,004	0		0,029	0	0,137
	N	40	40	40	40	39	39	33
Test3	Pearson Correlation	0,162	0,169	,618**	,349*	1	,545**	,544**
	Sig. (2-tailed)	0,326	0,303	0	0,029		0	0,001
	N	39	39	39	39	39	38	32
Test3Pract	Pearson Correlation	0,255	0,248	0,27	,553**	,545**	1	,557**
	Sig. (2-tailed)	0,117	0,128	0,096	0	0		0,001
	N	39	39	39	39	38	39	32
CE	Pearson Correlation	0,039	0,242	,443**	0,264	,544**	,557**	1
	Sig. (2-tailed)	0,828	0,175	0,01	0,137	0,001	0,001	
	N	33	33	33	33	32	32	33

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Data analysis in Table 1 showed that there is a significant correlation between some of theoretical and practical tests solutions with weak and moderate relationships (Test1 and Test1Pract: $r = 0.410$, $p = 0.009$, $p < 0.01$, Test1 and Test2Pract: $r = 0.479$, $p = 0.002$, $p < 0.01$, Test2 and Test2Pract: $r = 0.569$, $p < 0.01$, Test3 and Test2Pract: $r = 0.349$, $p = 0.029$, $p < 0.05$, Test3 and Test3Pract: $r = 0.545$, $p < 0.01$). So – apart from the theory and practice of the same tests – Test1 has significant correlation with Test2Pract, Test3 has significant correlation with Test2Pract. But there is not significant correlation between other tests solutions.

Data analysis in Table 1 showed that there is a significant correlation between some of tests solutions and Comprehensive exam in Mathematics (CE) with weak and moderate relationships (Test2 and CE: $r = 0.443$, $p = 0.01$, Test3 and CE: $r = 0.544$, $p = 0.001$, $p < 0.01$, Test3Pract and CE: $r = 0.557$, $p = 0.001$, $p < 0.01$). So Test2, Test3 and Test3Pract have significant correlation with CE. Although tasks from all task types (from Mathematics I and Mathematics II) were included in the Comprehensive exam in Mathematics equally, nevertheless there is not significant correlation between other tests and CE.

Table 2. Relationship between PreTest, Mathematics Tests and Comprehensive exam in Mathematics.

		Test1	Test1Pract	Test2	Test2Pract	Test3	Test3Pract	CE
PreTest	Pearson Correlation	0,277	,457**	0,148	0,278	0,083	0,053	0,22
	Sig. (2-tailed)	0,083	0,003	0,362	0,082	0,616	0,751	0,219
	N	40	40	40	40	39	39	33

** Correlation is significant at the 0.01 level (2-tailed).

Data analysis in Table 2 showed that there is a significant correlation between Test1Pract solutions and PreTest with weak relationship ($r = 0.457$, $p = 0.003$, $p < 0.01$), and there is not a significant correlation between PreTest and other tests (Test1 and PreTest: $r = 0.277$, $p = 0.083$, Test2 and PreTest: $r = 0.148$, $p = 0.362$, Test2Pract and PreTest: $r = 0.278$, $p = 0.082$, Test3 and PreTest: $r = 0.083$, $p = 0.616$, Test3Pract and PreTest: $r = 0.053$, $p = 0.751$, in all: $p > 0.05$).

So based on the study, it seems that in the second semester the prior knowledge mathematics deficiency has a significant effect only on the Test1Pract with practial tasks o topics of differentiation and integration of multivariable functions, scalar field, gradient, Young's theorem, directional derivative, local and global extrema. So the students can make up for this deficiency, and after one year, it already hinders them to such an extent in university progress.

4. Conclusion

This article reports about the effect of high school mathematics knowledge on the university progress of engineering students. We agree with that and during the research we also found that although prior mathematical knowledge has a central role in successfully dealing with the challenges of learning processes in the initial stages of university studies [12–14, 17, 29], numerous international and Hungarian studies report on the basic studies have their difficulties: there are huge differences among the pre-education level of the students [1, 7, 18, 20]. In the light of the existing literature, this report investigated the mathematics level of first-year engineering students in Hungarian higher engineering education and their results at the end of the first academic year, which is essential for training. The study's central question, whether and to what extent higher education mitigates these initial inequalities. These types of studies serve to inform and shape targeted catch-up or support programs that increase equity and efficiency in higher education.

Our results are consistent with the existing body of literature, based on our survey, we can conclude that many engineering students had problems with prior mathematical knowledge deficiency, which affects university progress [1, 7, 20], significantly correlated with the first practical test [14, 20]. However, in our further investigations, we found that there was no significant correlation with other tests. However, the significant correlation with the first practical test persisted, suggesting that the ability to apply knowledge in practice is more closely related to prior knowledge. While the results of all tests of the first semester Mathematics I subject were closely related to prior mathematical knowledge, this was not the case for all tests of the second semester Mathematics II subject and Comprehensive exam in Mathematics, only on the first practical test.

Based on the results obtained, we discuss how universities can support diverse student populations and help to level the academic playing field? Many literature in mathematics education focuses on how teaching, learning mathematics could be improved in mathematics courses [18]. The observations mentioned in this research allow useful conclusions for future programs of mathematics education. At the beginning of the first semester, an even more effective course is needed, the purpose of which is to develop the students' mathematical knowledge, mathematics self-concept and spatial perception, supplement the missing knowledge, and reduce their aversion to mathematics. Furthermore, it is important to use professional examples in the mathematics curriculum. In this way, we can ensure that mathematical knowledge is detached from the context, and that students can also apply their mathematical knowledge in professional tasks. Thus, it is hoped that the lack of high school mathematics knowledge will not have such a negative impact on the first practical test of the second semester.

Limitation of the study is the small sample size and the fact that only a single discipline at a single university were examined. Considering the results and limitations of our study, it is promising to extend the survey to a larger sample of students from other Hungarian universities and specialisations, the students' high school graduation results, investigating the relationship with additional engineering subjects, where mathematical knowledge is essential. In this case, it is possible to form a relevant picture of the overall situation in Hungary. By exploring the relationships and gaps in prior high school mathematics knowledge in more detail, and by expanding the survey to more universities and a much larger student population, it is possible to provide more precise and effective support in order to reduce dropout.

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