STUDENTS' KNOWLEDGE OF MATHEMATICAL DEFINITIONS

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Abstract

This paper deals with results of the mathematics tests conducted at the University of Finance and Administration in Prague in school years 2015/16 – 2018/19. The tests consisted of three theoretical questions, namely basic definitions from linear algebra. Students' ability to formulate these definitions is tested and the success of the formulations is evaluated by three degrees based on the accuracy. The ratios of completely correct, not quite correct and completely wrong answers are calculated. The results obtained in four consecutive school years are compared and any potential trends in growth or decline in student performance are examined. Furthermore, the ratios of students with homogeneous performance – students who have all the answers right or all the answers not exactly accurate or all the answers completely wrong – are calculated. Moreover, the correlation between student's ability to formulate definitions and his/her gender is examined. The results are statistically evaluated using tests of hypotheses.

Key words: mathematics, definition, student, gender

JEL Code: A22, I23, C12

Introduction

Theory has its irreplaceable role in the teaching of undergraduate mathematics courses. However, the extent and depth of interpretation may vary depending on the type and focus of the school.

At the University of Finance and Administration in Prague, students are preferred to be able to solve exercises, understand the results and interpret them correctly, however they should understand the theory as well. Unfortunately, the mathematics courses do not provide satisfactory conditions for training the students' ability to express exactly mathematical concepts – mostly because of lack of time and/or poor language skills of foreign students included in Czech speaking students groups. However, linguistically heterogeneous groups are currently a common phenomenon, not only at universities – see (Moraová and Novotná, 2018). According to (Majovská, 2013), a suitable implementation of modern applets and mathematical open source programme can improve students' knowledge, but it requires more lessons and access to computers in education. Moreover, at the University of Finance and Administration, students' knowledge, including the theory, is not checked by any tests during the semester, even though the results of such tests may positively affect the result of the final exam – see (Otavová and Sýkorová, 2018).

In this article, students' ability to formulate three given mathematical definitions is examined, the results of the tests from school years 2015/16 – 2018/19 are presented. While (Ulrychová, 2016) deals with the relationship between the knowledge of definitions and the ability to solve exercises, this article focuses on the following main aspects: the comparison of the results in individual school years, the finding out how successful the individual students were in the formulation of all these three definitions and the dependence of results on the student's gender.

In general, there are tendencies to consider males more capable in mathematics than females and logical thinking. The gender gaps in mathematics depends on various factors and it may vary in different countries and different types of schools. According to e.g. (Smetáčková, 2018), males really tend to score significantly better. However, this phenomenon has not been confirmed at the level of knowledge required at the University of Finance and Administration, as shown by research carried out in academic years 2015/2016 and 2016/2017 – see (Ulrychová and Bílková, 2018).

1 Materials and methods

There are two basic mathematics courses at the University of Finance and Administration in the winter semester – Mathematics A1 and Mathematics B1 (depending on the field of study). The topic tested in the experiment is common to both courses. The required definitions are quite simple to formulate and students routinely solve examples related to the defined terms.

At the beginning of the semester-end math exam students were asked to write three given mathematical definitions. At the same time, students were assured that the results of this part would not be counted in the exam evaluation (except when a student would like to do so). The students were asked to formulate the following concepts from linear algebra area: a linear combination of vectors, a linearly dependent set of vectors, the rank of a matrix. The results

were rated on the scale 1-3, meaning: 1 = completely correct, 2 = not exactly right, but one can assume that students are able to correct their minor mistakes, 3 = completely wrong.
The results are statistically evaluated using tests of hypotheses.

1.1 Correct/ inaccurate/ incorrect definitions – differences between two years

All the following tables indicate the calendar year in which the test was undertaken, instead of the school year, e.g. 2015 instead 2015/2016.

Table 1 shows the sample sizes in individual years.

Tab. 1: Sample sizes

	Mathematics A1	Mathematics B1	Mathematics A1 + B1
Year 2015	18	120	138
Year 2016	33	102	135
Year 2017	33	122	155
Year 2018	29	85	114

Source: own research

Table 2 shows the sample ratios of students with correct (Ratio 1), inaccurate (Ratio 2) or incorrect (Ratio 3) formulations of the relevant definitions.

Tab. 2: Sample ratios: Mathematics B1, Mathematics A1, Mathematics A1+B1

	Linear combination			Linear dependence			Matrix rank		
	Math B1	Math A1	Math A1+B1	Math B1	Math A1	Math A1+B1	Math B1	Math A1	Math A1+B1
Year 2015									
Ratio 1	0,1667	0,2778	0,1812	0,2667	0,3889	0,2826	0,5833	0,6111	0,5870
Ratio 2	0,2333	0,0556	0,2101	0,4500	0,2222	0,4203	0,2583	0,2222	0,2536
Ratio 3	0,6000	0,6667	0,6087	0,2833	0,3889	0,2971	0,1583	0,1667	0,1594
Year 2016									
Ratio 1	0,1176	0,2727	0,1556	0,3725	0,3636	0,3704	0,5882	0,5455	0,5778
Ratio 2	0,3137	0,1818	0,2815	0,4118	0,3333	0,3926	0,2941	0,3030	0,2963
Ratio 3	0,5686	0,5455	0,5630	0,2157	0,3030	0,2370	0,1176	0,1515	0,1259
Year 2017									
Ratio 1	0,2295	0,2121	0,2258	0,3607	0,3939	0,3677	0,7295	0,7576	0,7355
Ratio 2	0,2869	0,2121	0,2710	0,3689	0,3939	0,3742	0,1148	0,0909	0,1097
Ratio 3	0,4836	0,5758	0,5032	0,2705	0,2121	0,2581	0,1557	0,1515	0,1548
Year 2018									
Ratio 1	0,1176	0,2069	0,1404	0,2353	0,3793	0,2719	0,6706	0,7931	0,7018
Ratio 2	0,2941	0,1379	0,2544	0,4235	0,3448	0,4035	0,1059	0,1379	0,1140
Ratio 3	0,5882	0,6552	0,6053	0,3412	0,2759	0,3246	0,2235	0,0690	0,1842

Source: own research

Tests of hypotheses (at the 5% significance level, the critical range: $W_{0,05} = \{u\colon u \geq 1{,}645\}$ or $W_{0,05} = \{u\colon u \leq -1{,}645\}$) on equality of relative frequencies of two alternative distributions are performed to demonstrate the differences between two consecutive years. The results for each of the three definitions are shown in Tables 3 and 4. Table 3 shows the results in Mathematics B1, table 4 shows the results in Mathematics B1 and A1 both together. No tests were performed for Mathematics A1 due to small sample sizes.

We denote by indices the ratio of students with correct formulation (index 1), with inaccurate formulation (index 2) and with incorrect formulation (index 3).

Tab. 3: Tests of hypotheses: Mathematics B1

Linear combination		**Linear dependence**		**Matrix rank**	
Null and alternative hypothesis	**Test criterion value**	**Null and alternative hypothesis**	**Test criterion value**	**Null and alternative hypothesis**	**Test criterion value**
$H_0\colon \pi_{2015C1} = \pi_{2016C1}$ $H_1\colon \pi_{2015C1} > \pi_{2016C1}$	1,0380	$H_0\colon \pi_{2015D1} = \pi_{2016D1}$ $H_1\colon \pi_{2015D1} < \pi_{2016D1}$	**-1,6908**	$H_0\colon \pi_{2015R1} = \pi_{2016R1}$ $H_1\colon \pi_{2015R1} < \pi_{2016R1}$	-0,0739
$H_0\colon \pi_{2016C1} = \pi_{2017C1}$ $H_1\colon \pi_{2016C1} < \pi_{2017C1}$	**-2,1778**	$H_0\colon \pi_{2016D1} = \pi_{2017D1}$ $H_1\colon \pi_{2016D1} > \pi_{2017D1}$	0,1826	$H_0\colon \pi_{2016R1} = \pi_{2017R1}$ $H_1\colon \pi_{2016R1} < \pi_{2017R1}$	**-2,2316**
$H_0\colon \pi_{2017C1} = \pi_{2018C1}$ $H_1\colon \pi_{2017C1} > \pi_{2018C1}$	**2,0459**	$H_0\colon \pi_{2017D1} = \pi_{2018D1}$ $H_1\colon \pi_{2017D1} > \pi_{2018D1}$	**1,9205**	$H_0\colon \pi_{2017R1} = \pi_{2018R1}$ $H_1\colon \pi_{2017R1} > \pi_{2018R1}$	0,9144
$H_0\colon \pi_{2015C2} = \pi_{2016C2}$ $H_1\colon \pi_{2015C2} < \pi_{2016C2}$	-1,3443	$H_0\colon \pi_{2015D2} = \pi_{2016D2}$ $H_1\colon \pi_{2015D2} > \pi_{2016D2}$	**3,3394**	$H_0\colon \pi_{2015R2} = \pi_{2016R2}$ $H_1\colon \pi_{2015R2} < \pi_{2016R2}$	-0,5955
$H_0\colon \pi_{2016C2} = \pi_{2017C2}$ $H_1\colon \pi_{2016C2} > \pi_{2017C2}$	0,4363	$H_0\colon \pi_{2016D2} = \pi_{2017D2}$ $H_1\colon \pi_{2016D2} > \pi_{2017D2}$	0,6560	$H_0\colon \pi_{2016R2} = \pi_{2017R2}$ $H_1\colon \pi_{2016R2} > \pi_{2017R2}$	**3,3636**
$H_0\colon \pi_{2017C2} = \pi_{2018C2}$ $H_1\colon \pi_{2017C2} < \pi_{2018C2}$	-0,1123	$H_0\colon \pi_{2017D2} = \pi_{2018D2}$ $H_1\colon \pi_{2017D2} < \pi_{2018D2}$	-0,7918	$H_0\colon \pi_{2017R2} = \pi_{2018R2}$ $H_1\colon \pi_{2017R2} > \pi_{2018R2}$	0,2004
$H_0\colon \pi_{2015C3} = \pi_{2016C3}$ $H_1\colon \pi_{2015C3} > \pi_{2016C3}$	0,4733	$H_0\colon \pi_{2015D3} = \pi_{2016D3}$ $H_1\colon \pi_{2015D3} > \pi_{2016D3}$	1,1558	$H_0\colon \pi_{2015R3} = \pi_{2016R3}$ $H_1\colon \pi_{2015R3} > \pi_{2016R3}$	0,8720
$H_0\colon \pi_{2016C3} = \pi_{2017C3}$ $H_1\colon \pi_{2016C3} > \pi_{2017C3}$	1,2683	$H_0\colon \pi_{2016D3} = \pi_{2017D3}$ $H_1\colon \pi_{2016D3} < \pi_{2017D3}$	-0,9490	$H_0\colon \pi_{2016R3} = \pi_{2017R3}$ $H_1\colon \pi_{2016R3} < \pi_{2017R3}$	-0,8225
$H_0\colon \pi_{2017C3} = \pi_{2018C3}$ $H_1\colon \pi_{2017C3} < \pi_{2018C3}$	-1,4828	$H_0\colon \pi_{2017D3} = \pi_{2018D3}$ $H_1\colon \pi_{2017D3} < \pi_{2018D3}$	-1,0925	$H_0\colon \pi_{2017R3} = \pi_{2018R3}$ $H_1\colon \pi_{2017R3} < \pi_{2018R3}$	-1,2397

Source: own research

Linear combination: At the 5% level of significance, it has been proved that the ratio of students with correct formulation of linear combination is lower in 2016 than in 2017 and the ratio of students with correct formulation of linear combination is higher in 2017 than in 2018. In other cases, the inequalities have not been proved at the 5% level of significance.

Linear dependence: At the 5% level of significance, it has been proved that the ratio of students with correct formulation of linear dependence is lower in 2015 than in 2016 and higher in 2017 than in 2018, the ratio of students with inaccurate formulation of linear dependence is higher in 2015 than in 2016. In other cases, the inequalities have not been proved at the 5% level of significance.

Matrix rank: At the 5% level of significance, it has been proved that the ratio of students with correct formulation of matrix rank is lower in 2016 than in 2017 and the ratio of students with inaccurate formulation of matrix rank is higher in 2016 than in 2017. In other cases, the inequalities have not been proved at the 5% level of significance.

Tab. 4: Tests of hypotheses: Mathematics A1 + B1

Linear combination		**Linear dependence**		**Matrix rank**	
Null and alternative hypothesis	**Test criterion value**	**Null and alternative hypothesis**	**Test criterion value**	**Null and alternative hypothesis**	**Test criterion value**
$H_0: \pi_{2015C1} = \pi_{2016C1}$ $H_1: \pi_{2015C1} > \pi_{2016C1}$	0,5649	$H_0: \pi_{2015D1} = \pi_{2016D1}$ $H_1: \pi_{2015D1} < \pi_{2016D1}$	-1,5473	$H_0: \pi_{2015R1} = \pi_{2016R1}$ $H_1: \pi_{2015R1} > \pi_{2016R1}$	0,1541
$H_0: \pi_{2016C1} = \pi_{2017C1}$ $H_1: \pi_{2016C1} < \pi_{2017C1}$	-1,5106	$H_0: \pi_{2016D1} = \pi_{2017D1}$ $H_1: \pi_{2016D1} > \pi_{2017D1}$	0,0475	$H_0: \pi_{2016R1} = \pi_{2017R1}$ $H_1: \pi_{2016R1} < \pi_{2017R1}$	**-2,8321**
$H_0: \pi_{2017C1} = \pi_{2018C1}$ $H_1: \pi_{2017C1} > \pi_{2018C1}$	**1,7657**	$H_0: \pi_{2017D1} = \pi_{2018D1}$ $H_1: \pi_{2017D1} > \pi_{2018D1}$	**1,6550**	$H_0: \pi_{2017R1} = \pi_{2018R1}$ $H_1: \pi_{2017R1} > \pi_{2018R1}$	0,6091
$H_0: \pi_{2015C2} = \pi_{2016C2}$ $H_1: \pi_{2015C2} < \pi_{2016C2}$	-1,3706	$H_0: \pi_{2015D2} = \pi_{2016D2}$ $H_1: \pi_{2015D2} > \pi_{2016D2}$	0,4659	$H_0: \pi_{2015R2} = \pi_{2016R2}$ $H_1: \pi_{2015R2} < \pi_{2016R2}$	-0,7902
$H_0: \pi_{2016C2} = \pi_{2017C2}$ $H_1: \pi_{2016C2} > \pi_{2017C2}$	0,1996	$H_0: \pi_{2016D2} = \pi_{2017D2}$ $H_1: \pi_{2016D2} > \pi_{2017D2}$	0,3216	$H_0: \pi_{2016R2} = \pi_{2017R2}$ $H_1: \pi_{2016R2} > \pi_{2017R2}$	**3,9886**
$H_0: \pi_{2017C2} = \pi_{2018C2}$ $H_1: \pi_{2017C2} > \pi_{2018C2}$	0,3052	$H_0: \pi_{2017D2} = \pi_{2018D2}$ $H_1: \pi_{2017D2} < \pi_{2018D2}$	-0,4876	$H_0: \pi_{2017R2} = \pi_{2018R2}$ $H_1: \pi_{2017R2} < \pi_{2018R2}$	-0,1107
$H_0: \pi_{2015C3} = \pi_{2016C3}$ $H_1: \pi_{2015C3} > \pi_{2016C3}$	0,7665	$H_0: \pi_{2015D3} = \pi_{2016D3}$ $H_1: \pi_{2015D3} > \pi_{2016D3}$	1,1217	$H_0: \pi_{2015R3} = \pi_{2016R3}$ $H_1: \pi_{2015R3} > \pi_{2016R3}$	0,7909
$H_0: \pi_{2016C3} = \pi_{2017C3}$ $H_1: \pi_{2016C3} > \pi_{2017C3}$	1,0179	$H_0: \pi_{2016D3} = \pi_{2017D3}$ $H_1: \pi_{2016D3} < \pi_{2017D3}$	-0,4149	$H_0: \pi_{2016R3} = \pi_{2017R3}$ $H_1: \pi_{2016R3} < \pi_{2017R3}$	-0,7047
$H_0: \pi_{2017C3} = \pi_{2018C3}$ $H_1: \pi_{2017C3} < \pi_{2018C3}$	**-1,6622**	$H_0: \pi_{2017D3} = \pi_{2018D3}$ $H_1: \pi_{2017D3} < \pi_{2018D3}$	-1,1923	$H_0: \pi_{2017R3} = \pi_{2018R3}$ $H_1: \pi_{2017R3} < \pi_{2018R3}$	-0,6385

Source: own research

Linear combination: At the 5% level of significance, it has been proved that the ratio of students with correct formulation of linear combination is higher in 2017 than in 2018 and the ratio of students with incorrect formulation of linear combination is lower in 2017 than in 2018. In other cases, the inequalities have not been proved at the 5% level of significance.

Linear dependence: At the 5% level of significance, it has been proved that the ratio of students with correct formulation of linear dependence is higher in 2017 than in 2018. In other cases, the inequalities have not been proved at the 5% level of significance.

Matrix rank: At the 5% level of significance, it has been proved that the ratio of students with correct formulation of matrix rank is lower in 2016 than in 2017 and the ratio of students with inaccurate formulation of matrix rank is higher in 2016 than in 2017. In other cases, the inequalities have not been proved at the 5% level of significance.

1.2 Ratios of students with homogeneous results – differences in 2015-2018

Table 5 show the ratios of students with homogeneous performance – students with all the three definitions correct or all the three definitions inaccurate or all the three definitions incorrect.

Tab. 5: Ratios of students with all definitions correct/ inaccurate/ incorrect

	Correct			Inaccurate			Incorrect		
Year	**Math B1**	**Math A1**	**Math A1+B1**	**Math B1**	**Math A1**	**Math A1+B1**	**Math B1**	**Math A1**	**Math A1+B1**
2015	0,1000	0,2778	0,1232	0,0083	0,0000	0,0072	0,0833	0,1111	0,0870
2016	0,0784	0,1515	0,1037	0,0392	0,0303	0,0370	0,0588	0,1212	0,0741
2017	0,1721	0,1515	0,1677	0,0082	0,0000	0,0065	0,0902	0,0606	0,0839
2018	0,0588	0,1724	0,0877	0,0118	0,0000	0,0088	0,1765	0,0690	0,1491

Source: own research

Tests of hypotheses (at the 5% significance level, critical range: $W_{0,05} = \{\chi^2 : \chi^2 \geq 7{,}815\}$) on equality of relative frequencies of more alternative distributions are performed to demonstrate the differences in years 2015 through 2018. In all cases, the alternative hypothesis H_1 means: at least one equality from H_0 is not valid. The results are shown in Table 6.

Tab. 6: Tests of hypotheses: differences in 2015-2018

Null and alternative hypothesis	**Test criterion value**		
	Math B1	**Math A1**	**Math A1+B1**
H_0: $\pi_{2015,1} = \pi_{2016,1} = \pi_{2017,1} = \pi_{2018,1}$ H_1: non H_0	**8,3982**	1,5545	4,6329
H_0: $\pi_{2015,2} = \pi_{2016,2} = \pi_{2017,2} = \pi_{2018,2}$ H_1: non H_0	4,4183	2,4456	6,1402
H_0: $\pi_{2015,3} = \pi_{2016,3} = \pi_{2017,3} = \pi_{2018,3}$ H_1: non H_0	**8,0830**	1,0066	4,8419

Source: own research

Mathematics B1: At the 5% level of significance, it has been proved that the proportions of the students of Mathematics B1 with all the definitions correct as well as the students with all the definitions incorrect differ in individual years. In other cases, the inequalities have not been proved at the 5% level of significance.

Mathematics B1 and Mathematics A1+B1: The inequalities have not been proved at the 5% level of significance in any case.

1.3 Dependence on student's gender

Results of both Mathematics A1 and B1 together are processed. The Chi-square independence test (at the 5% significance level, critical range: $W_{0,05} = \{\chi^2 : \chi^2 \geq 5{,}991\}$) is performed to demonstrate the dependence of results on the student's gender. The results for are shown in Table 7.

In all cases, the null hypothesis H_0 means that the fact that the student formulated the relevant definition correctly or inaccurately or incorrectly does not depend on his/her gender. The alternative hypothesis H_1 means that the fact that the student formulated the relevant definition correctly or inaccurately or incorrectly depend on his/her gender.

Tab. 7: Chi-square independence test: gender independence

Year	Test criterion value		
	Linear combination	**Linear dependence**	**Matrix rank**
2015	1,4786	0,5381	1,5753
2016	0,7861	0,2649	0,9062
2017	5,0023	**9,1471**	4,5128
2018	**7,5730**	**12,6226**	0,0772

Source: own research

At the 5% level of significance, it has been proved that the result depends on student's gender only in the case of linear dependence in 2017 and linear combination and linear dependence in 2018.

In other cases, the dependence has not been proved at the 5% level of significance.

2 Results

In point of the results in individual school years, the results don't tend to get better or worse – they alternate over the years. The results in Mathematics A1 seem to be more stable, but no tests were performed due to small sample sizes.

Some differences in Mathematics B1 have been proved by comparing results between every two consecutive years: between 2015 and 2016, there was an improvement in the definition of linear dependence – the ratio of the correct answers increased at the expense of the ratio of the inaccurate answers. Between 2016 and 2017, there was an improvement in the definition of linear combination and rank of matrix – the ratio of the correct answers increased, whereas the ratio of the inaccurate definitions of rank decreased. On the contrary – the result of linear combination and rank of matrix worsened between 2017 and 2018.

When evaluating both Mathematics B1 and A1 together, the differences have been proved between 2016 and 2017, when the ratio of the correct definitions of rank of matrix increased at the expense of the ratio of the inaccurate answers, and between 2017 and 2018, when the results of both linear combination and linear dependence worsened. Simultaneously with the decrease in the ratio of correct definitions of linear dependence, the ratio of wrong definitions increased.

In point of students with "homogeneous output" (all answers right or all answers inaccurate or all answers wrong), only the fact that the ratios of students of Mathematics B1 having all definitions right/wrong vary over the years has been proved.

In point of gender, the dependence of the results on the gender has been proved only in 2017 in the case of linear dependence and in 2018 in the cases of linear combination and linear dependence.

Conclusion

Students' ability to formulate mathematical definitions is not satisfactory and does not improve over time. The results got rather worse between the last two tested years, but no coherent deteriorating trend during the years 2015 - 2018 has been proved. The ratio of students having all definitions right/wrong is different over the years. Student's gender does not matter in most cases – the dependence of the results on students' gender has been proved only rarely.

The level of mathematics knowledge is reflected in a number of skills, and not only in technical, where we would expect direct link. Application is reflected in professional roles in economics, finance or accounting. Mathematical background is also the basis of a logical and systems thinking, which is a prerequisite for the correct solution of routine and conceptual system problems of economic practice. (Exnarová, Dalihod and Mildeová, 2011) demonstrated by student testing at the University of Economic, Prague, that this ability is not on a desirable level.

However, with a small number of math lessons at some universities – see e.g. (Ulrychová, 2007) and with the current teaching method the improvement of students' mathematical skills cannot be expected – see e.g. (Milková and Kořínek, 2014) or (Widenská, 2014).

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