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Students' propositional logic thinking in higher education from the perspective of disciplines

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Logic and logical thinking are present and play an important role in most of the disciplines at the university level but in different ways. In our research, which has been ongoing for several years, we are investigating the use of propositional logic among university students in different study programmes. Our current study evaluated data from 1,429 respondents involving students from 15 universities. The non-standardised knowledge test was previously pilot-tested and consisted of 15 tasks from selected elements of propositional logic in a different natural science subject-specific context. Significant differences in average results were found in terms of students' gender, age, type of secondary school leaving exam and parents' highest education level. Our research mainly aimed to compare students' test scores by students' fields of study. On average, mathematics-informatics students had the highest success rate of 67.4%, compared to students in engineering (61.0%), economics (57.9%), education (56.6%), science (56.5%) and humanities (54.7%). The result is significant (F = 13.521, p-value < 0.001). Furthermore, we found that the students performed differently in three selected areas of formal logic (F = 1108, df = 2, p < 0.001), with the lowest performance on statement negation tasks. The difference in means across groups of tasks is significant by the gender of the students and by their secondary education level.

KEYWORDS

propositional logic, logical thinking, scientific tasks, fields of study, university students

1. Introduction

The tools of logic, or at least elements or parts of them, are used in practically all disciplines, from the natural sciences to the social sciences, economics or law. Logic is the science of clear and consistent thinking, which no discipline can do without, and in stating and proving its propositions, all disciplines, whether deliberately or by instinct, take logical steps and apply the rules of logic.

In an academic study in every age, the study of logic and its role in use has been of fundamental importance. Logic as a research discipline saw its greatest leap of development in the first half of the twentieth century, but with all that progress in research, its relative importance in the teaching portfolio of the academy has diminished. What is the reason for this? According to Restall (2015), the reason for this is greater specialisation and differentiation and excessive learning. Due to this phenomenon, students avoid taking it even if a university offers logic as a subject. Restall declares this phenomenon as a cultural problem. "*The research culture of logic - the kind of work it produces - seems radically alien to that of its elsewhere academic disciplines*" (Restall, 2015).

The disciplines have different aims, values and traditions. They have different questions to ask and problems to solve. They also have different techniques and tools to apply. How does this reflect on the knowledge of the current generation of students studying in various fields of disciplines? To understand the differences between the disciplines, one needs to understand the features of disciplines. While the science disciplines aim to give an objective view and third-person descriptions of the world, many branches of the sciences use prediction and testing of hypotheses based on observation and theory development. Different things need to occur in the humanities. The humanities are not just about an objective reality to be described from the perspective of the independent observer (third-person) view. Expressive elements, viewed from the first-person, involve agency and subjectivity at their core humanities. It does not mean that the sciences do not involve creativity or agency. The engineering discipline aims to solve problems involving our actions in the world around us (Restall, 2015).

2. Theoretical background

Propositional logic is the simplest of the classical logical questions. According to Klement (2004) definition propositional logic *"is the branch of logic that studies ways of joining and/or modifying entire propositions, statements or sentences to form more complicated propositions, statements or sentences, as well as the logical relationships and properties that are derived from these methods of combining or altering statements."*

Propositional logic can be applied in many areas of life and science, including decision making, problem solving, developing critical thinking, improving communication by making arguments and information analysis by evaluating the truth or falsity of information. Logic is generally concerned with statements in natural language and the conclusions that can be drawn from them. Propositional logic is concerned with statements and the basic logical operations, or logical connections that link them. It plays a significant role in many areas where rigorous analysis and evaluation of claims and arguments is required and integrates reasoning and thinking skills into our everyday lives. In the Stanford Encyclopaedia of Philosophy, the concept of propositional logic is defined as "*the study of the meanings of, and the inferential relationships that hold among, sentences based on the role that a specific class of logical operators called the propositional connectives have in determining those sentences' truth or assertability conditions*" (Franks, 2023).

Since propositional logic is a broad area of mathematics, we focussed our research on three elements: quantifiers, negations, inferences. The main elements of the language of mathematics are quantifiers, which are designated as either universal or existential. According to Saban (2014) quantifiers have an undeniable importance in giving meaning to mathematical information. Furthermore, the ability to deal with quantifiers is vital not just for obtaining mathematical knowledge, but also for efficiently exploiting mathematics' diverse conceptual frameworks (Dubinsky et al., 1998). It is known that students receiving secondary education and university education experience considerable difficulties in understanding quantifiers (Dubinsky and Yiparaki, 2000). Negation is the most basic logical connective (logical operator), which states the falsity of a proposition and, unlike negations and other emphases in natural language, does not indicate the cause of the falsity. As defined by Mosley and Baltazar (2019) "*negations are compound propositions formed from a simpler proposition.*" In everyday life and in formal systems, logic is also the study of the forms of correct inference. According to Mosley and Baltazar (2019), people are naturally and usually logical; whether a person is educated or not is irrelevant. Inference, as they put it "*is the process by which the truth of one proposition (the conclusion) is affirmed on the basis of the truth of one or more other propositions that serve as its premise or premises*" (Mosley and Baltazar, 2019). According to another author, Kumar (2017) "*an inference is a conclusion that a person can draw from certain observed or supposed facts.*"

Developing logical thinking and reasoning skills is one of the main goals of science learning. Logical thinking is a process of thinking logically, rationally and reasonably (Lazear, 2004; Yaman, 2015). One of science learning objectives is to empower students' logical thinking abilities (Parmin et al., 2017), and this ability is needed by each individual in order to be able to solve a variety of complex problems (Sezen and Bülbül, 2011). Logical thinking is also associated with the function of all senses and processed information, which means that students can distinguish, criticise, and process knowledge in words based on phenomena through logical thinking. Therefore, they can discover the answer to each problem. Practicum work in science learning is a problem-solving method which also requires logical thinking abilities (Hibbard, 2000). Logical thinking ability connects the science concept with students' knowledge and experience so that students can solve complex problems (Pezzuti et al., 2014). In Taber (2017) view science is often associated with logical thinking, and this is indeed an important feature of science, because "*logic is needed to work out predictions consistent with particular hypotheses or models, and logic is needed to interpret data in terms of different principles, laws and theories, and to construct arguments to persuade other scientists of the validity of conclusions.*"

According to Bakır et al. (2015), four factors have influenced how humans create knowledge: language skills, logical thinking ability, experience, and interest. With logical thinking, the students solve the problem by conducting various mental practices or reaching principles or rules by executing some abstraction and generalisation. The students' conceptions from useful prior knowledge can build on (Titler, 2002) with logical thinking abilities that should be given new emphasis in science teaching and learning (Fah, 2009). Students who do not have the mental structures for conditioned reasoning may have difficulties acquiring knowledge in science. Also, if the reasoning is a filter between experience and mental schemas, then it is evident that students who cannot use conditional reasoning operations perform worse in science (Piburn, 1980). Low scientific reasoning skills can be discussed in the current education system. Lay (2010) points out that the education system influences logical thinking abilities, particularly in a system that places more importance on examination results. Other authors suggest that improving logical reasoning skills as part of higher-order thinking skills is an important objective of education (Zohar and Dori, 2003).

Piburn and Baker (1988) researched to examine the relationship between logical reasoning ability and school science grades. According to the results obtained by the Propositional Logic Test and Test of Logical Reasoning, correlations of grades in science with the PLT (0.57) and the TOLT (0.63) were high. Pallrand et al. (1981) researched a sample of nearly 2,000 undergraduate students oriented toward the ability to use formal logic. The results showed systematic and consistent errors in students' interpretations of logical propositions. The study pointed to a specific misunderstanding of the meaning of a conditional statement, an inconsistent use of truth tables, an error in contraposition, and the use of tautology, in which all choices are seen as correct.

According to Kumar (2017), studying formal logic helps improve the thinking process and tries to refine and improve the thinking ability. The objectives of Kumar's study are to know the effectiveness of formal logic courses and to determine the critical thinking variables that are effective and that are ineffective. The analysis revealed no significant relationship between critical thinking variables and formal logic courses. Riyanti et al. (2019) examined the relationship between logical-thinking ability and students' science achievement. The results show an insignificant relationship between logical-thinking ability and students' science achievement. The results of the pre-test and post-test evaluation of the formal logic course indicate to be sensitive enough to detect a positive effect on students' critical thinking and problem-solving skills. Making decisions based on mindset and cognitive knowledge is an important skill in logical thinking ability (Pezzuti et al., 2014; Seyhan, 2015).

Propositional logic and logical reasoning are present and play an important role in both the natural and social sciences. The various tools and elements of logic are used in practically every discipline. It is therefore necessary to pay adequate attention to the preparation of students of different study programmes in propositional reasoning during their university studies. The purpose of our research was to reveal the differences in the application of propositional logic knowledge of university students. The main research questions were to (1) examine and assess the knowledge of the basic elements of propositional logic and logical reasoning and to compare the students' performance within different scientific disciplines. In addition we wanted to (2) investigate the background variables by means of which significant differences can be detected between the various groups of students and (3) compare students' performance in the selected areas of propositional logic.

3. Materials and methods

The main objective of our research was to examine and compare the results of a knowledge test of formal logic tasks concerning the students' scientific discipline based on their study programme. The survey participants were students from Central European universities studying in Hungarian language. Students from 15 universities participated in the research; most participants were from Slovakia, 511 (35.8%), 404 (28.3%) from Hungary, 363 (25.4%) from Romania, 138 (9.7%) from Serbia and 13 (0.9%) from Ukraine. A total of 1,505 students completed the online test. After data validation, 1,429 respondents were included in the study. The study sample included 528 (37.0%) men and 899 (63.0%) women, and mostly (1211, 84.9%) from the age group 18–25 years. The sample is not representative.

Students were categorised into six scientific disciplines based on their study programme. The largest proportion of students in the sample are paedagogical students (500, 35.0%), which includes students studying pre-primary education and teacher education. In addition, 401 (28.1%) students are studying economics, 178 (12.5%) are studying mathematics or computer science, 151 (10.6%) are studying engineering, 121 (8.5%) are studying humanities and 78 (5.5%) are studying various natural sciences. The sociodemographic characteristics of the participants are reported in **Table 1**.

The results of the respondents were also analysed according to the highest educational level of the parent (**Table 2**).

As a research tool, a non-standardised, previously pilot-tested knowledge test was used, which consisted of 15 tasks from selected elements of propositional logic. These tasks were placed in different natural sciences subject-specific content: physics, chemistry, biology and also mathematics, and context from everyday life. The tasks were divided into three groups considering the three selected propositional logic topics. The first group (A) included five tasks on understanding quantifiers, five tasks in the second group (B) used negation of statements, and another five tasks (C) dealt with a formulation of inferences. The test includes tasks on universal and existential quantifiers, and uses the terms of *at least*, *at most*. The tasks contain the logical operators *and*, *or*, the correct interpretation of which is important for the solution. The test is available in the Appendix. Except for one biology task, the test included multiple-choice tasks with one correct answer. Each of

TABLE 1 Demographic characteristics of the sample (N = 1429).

Characteristics	*n*	Valid%
Gender		
Men	528	37.0
Women	899	63.0
Age		
18–25	1211	84.9
>25	216	15.1
Scientific discipline		
Mathematics/informatics	178	12.5
Engineering	151	10.6
Economics	401	28.1
Natural sciences	78	5.5
Paedagogy	500	35.0
Human sciences	121	8.5
Type of secondary school		
Secondary grammar school	735	51.5
Secondary school	693	48.5

TABLE 2 Parents' highest education level.

Characteristics	Father		Mother	
	n	Valid%	*n*	Valid%
Primary school	126	8.9	151	10.7
Secondary school without an exam	478	33.9	333	23.5
Secondary school with an exam	571	40.5	633	44.7
Higher education	236	16.7	299	21.1

the 15 logic tasks in the test was worth 1 point for a correct answer and 0 points for a wrong answer.

The survey was performed online using Google Forms, involving each partner university. The test was disseminated with the cooperation of university lecturers. Students received the Google Form link to the test directly from their teachers during the lectures, and they solved the questions under their personal supervision. Data collection was carried out during the winter semester of 2022. The final database, including the data of 1,505 respondents, was downloaded from Google Forms as a Microsoft Excel sheet. The data were further examined and analysed in IBM SPSS Statistics version 27.0.

Numerical data were summarised as means and standard deviations, and categorical data were presented as frequencies and proportions. The Shapiro–Wilk test was performed to evaluate variable distribution. Since the sample size is sufficiently large, we used statistical parametric tests, which assume normal distribution of the variable. One-way ANOVA was employed to compare score distributions by task-groups and the tasks′ subject-specific context. Independent samples *t*-test was used to compare means of continuous variables between two groups. The test results were statistically significant for a *p*-value less than 0.05.

4. Results

When analysing the data, the test score was calculated, and the success rate as a percentage of the maximum score for each respondent. Students' scores were analysed and compared according to each background variable for the evaluation. We also compared results on the entire set of tasks and the three task-groups from the disciplines′ perspective. The variable "score" is not normally distributed according to the Shapiro-Wilk test ($W = 0.983$, $p < 0.001$). The SW test indicates that the data are not normal, and skewness and kurtosis are larger than their 1.96 standard errors (2.06 and 2.69, respectively). According to recent studies (Orcan, 2020) Mann-Whitney *U*-tests or other non-parametric tests should be used to test mean differences. On the other hand the sample size is sufficiently high ($N = 1429$), therefore we can use statistical methods assuming normal distribution of variables.

The respondents' average test score was 8.79 (SD = 2.58), 95% confidence interval is 8.66–8.92. The overall correct answer rate was 58.6%. The median value was nine points. Significant differences in average test scores were found regarding students' gender, age, type of secondary school leaving exam and the parents' highest education level (Table 3).

TABLE 3 Comparison of the respondents' results.

Characteristics	Mean	SD	Test stat	*p*-value
Gender				
Men	9.19	2.64	4.428[a]	<0.001
Women	8.56	2.51		
Age				
18–25	8.73	2.58	−2.080[a]	0.038
>25	9.13	2.57		
Type of secondary school				
Secondary grammar school	9.14	2.53	5.401[a]	<0.001
Secondary school	8.41	2.58		
Highest education level/father				
Primary school	8.35	2.42	5.475[b]	0.001
Secondary school without an exam	8.72	2.55		
Secondary school with an exam	8.71	2.53		
Higher education	9.36	2.74		
Highest education level/mother				
Primary school	8.07	2.41	9.632[b]	<0.001
Secondary school without an exam	8.49	2.55		
Secondary school with an exam	8.91	2.58		
Higher education	9.28	2.55		

[a]Independent samples *t*-test (t). [b]One-Way ANOVA (F).

The sample included 528 (37.0%) men and 899 (63.0%) women. Men scored significantly better with 9.19 points compared to women with 8.56 points. Students aged 18–25 years achieved an 8.73 average score, which is significantly lower than those over 25 years (9.13). According to the type of secondary school, students who finished grammar school achieved significantly better results in average total score (9.14) compared to the students who finished other types of secondary school (8.41). The results also show that the parents' educational level impacts the score. The best results were achieved by students whose parents had a higher education. Considering the father's education, the students' highest score was in the group with higher education (9.36), and in the case of the mother's higher education, it was 9.28 points. Students with higher scores were those whose parents had higher education degrees.

4.1. Students' results in the perspective of disciplines

The main objective of our research is to assess the knowledge of the basic elements of propositional logic and logical reasoning and to compare the students' results within different scientific disciplines. Accordingly, we compared the test scores of respondents by their discipline. Significant differences in average test scores were found regarding students' discipline ($F = 13.521$, $p < 0.001$). The mathematics or computer science students achieved the highest average score of 10.11, with a 67.4% success rate. Next in order are engineering students (61.0%), economics students (57.9%), students studying paedagogical sciences (56.6%), natural sciences (56.55) and finally, human sciences (54.7%). Test score distributions by the students' disciplines are shown in **Figure 1**.

The ANOVA *post hoc* pairwise comparison between group means with *t*-test shows which means differ. There are 15 pairings in total, comparing each of the 6 disciplines. When paired with all 5 majors, the mathematics/informatics group score shows a significant difference in means. The means for the groups of engineering, economics, natural sciences, and paedagogy students are at the same level (with no significant difference). Students of human sciences achieved the lowest score.

Significant differences were found ($F = 1108$, df = 2, $p < 0.001$) comparing the mean score in three task-groups with the tasks on quantifiers (3.48), negation (1.73), inferences (3.58). The lowest average score (1.73) was achieved in task-group B on statement negation. *Post hoc* analysis shows the different pairwise distributions for groups A–B, B–C, and A–C. We conducted independent samples *t*-tests to compare averages separately for each group of tasks (**Table 4**). The results show that the differences in mean score are significant in all task-groups, according to the gender of the students, with men scoring higher in all three task-groups. The average score in the age group over 25 years is higher in all three groups A, B, and C, but: based on the *t*-tests, there is a significant difference only in task-group C-inferences (**Table 4**). As we can see in **Table 4**, the mean score is higher for students who graduated from secondary grammar school compared to students from other types of secondary schools. The *t*-tests indicate that the difference is statistically significant not only comparing the average score on the entire set of tasks but also in the three task-groups.

Analysing the students' results by disciplines (**Table 5**), the mathematics/informatics students performed best in all three groups of tasks. Humanities students performed the poorest in the logic tasks. They scored the lowest average in all three groups of tasks, and in the case of the paedagogy students, they were the worst in inferences by one hundredth of a point.

The results of the 15 propositional logic tasks were summarised in **Table 6** by indicating with a "+" sign the values when the students' scores by their discipline were higher than the overall average. The score below the average was marked with a "−" sign. The tasks were marked in each task group with the letters M (mathematics), P (physics), B (biology), Ch (chemistry), and EL (everyday life). As a result of this overview, we can find that mathematics/informatics students achieved the best results with 14 times above-average values. Engineering students obtained 11 above-average results. All other students by the disciplines scored below the average on more than half of the 15 tasks. Economics and natural sciences students got 6 + signs, paedagogy students 4 + signs, and respondents studying human sciences obtained 2 + signs for an above-average score.

Table 6 also shows in which subjects or task contexts the students were successful in. The students majoring in mathematics or informatics performed above average in all five tasks in part A. Regarding engineering specialisations, 3, economics, natural science and paedagogy specialisations performed above average in 2 tasks, while students studying the humanities remained below average in all tasks. Most did not know task A4 (task no. 4 in task group A, subject: chemistry) with 58.5%; this also applies to each specialisation separately. A total of 18.4% of those who filled in completed all five tasks and achieved maximum points; this figure is 30.9% for mathematics or informatics specialisations.

In the case of task group B, the mathematics/informatics students performed above the average in all five tasks. Students with an engineering specialisation had above-average results in 4 questions, but in the economics, natural sciences and paedagogy specialisation, they scored above the average in only 1 question. Humanities students completed below average on all questions. Most did not know task B2 (question from everyday life) with 76.7%; this does not apply to the disciplines separately. The mathematics/informatics specialisations students made a mistake on question B3 (physics question), the engineering and paedagogy specialisations got B2 (a question from everyday life), and the economics, natural sciences and humanities specialisations got B4 (chemistry question) they knew the least. Those who solved all five tasks correctly are 2.4% of the total; for the mathematics/informatics students, this is 7.9%. Among those who filled in, 13.9% achieved 0 points in group B of questions; regarding specialisations, natural science students performed the worst (19.2%).

In the case of task group C, students majoring in mathematics or informatics performed the best (above average in 4 tasks), economics specialisation students performed above average in 3 questions, natural sciences and humanities students in 2 questions, and paedagogy students performed above average in only 1 question. Most (55.3%) incorrect answers were given for task C1 (chemistry question); this also applies separately to the majors. Mathematics or informatics specialisations performed below average on task C5 (biology). Evaluating the entire group, 28.3% of the sample solved all five tasks correctly; in the case of mathematics-informatics students, this was 41%. A total of 1.5% of those who filled in received 0 points; students with teacher specialisation finished last with 2%.

5. Discussion

Our research focussed on examining university students' logical thinking and knowledge of selected elements of propositional logic, considering their different fields of study. Based on the scores achieved, the students have significant differences in solving the tasks regarding the scientific disciplines by the student's study programme. The best results were achieved by students majoring in mathematics or computer science, while the worst results were achieved by students studying humanities.

Several studies have pointed out the correlation between formal logic and success in science. Mitchell and Lawson (1988) showed formal reasoning ability as an important determinant of the ability to solve genetic problems and interpret text material in biology. Chandran et al. (1987) pointed out that formal thinking is more influential in predicting achievement in chemistry than prior knowledge. Siváková et al. (2018) showed how to develop thinking

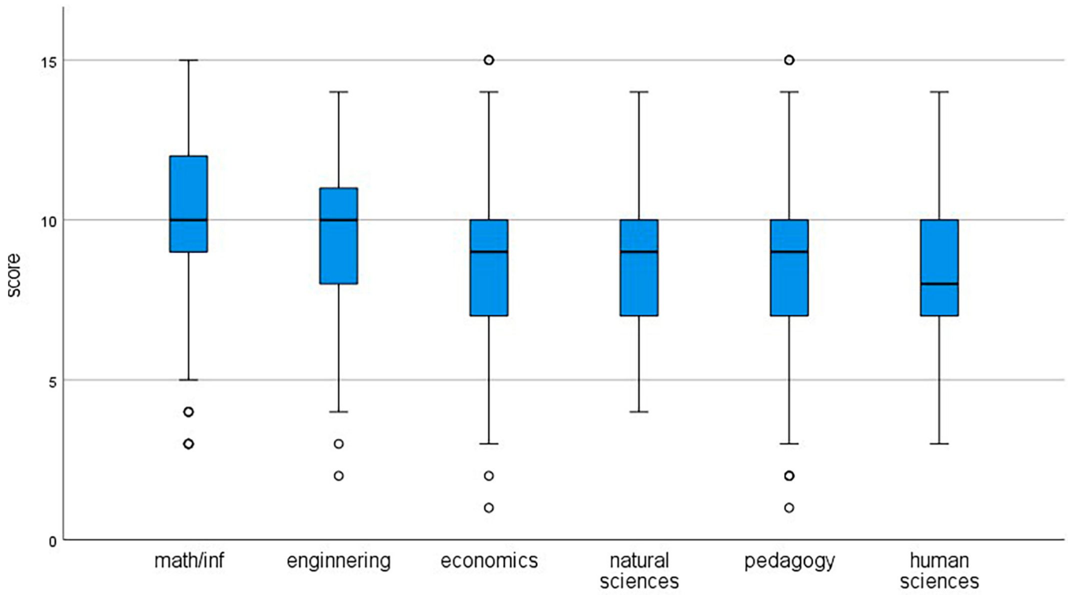

FIGURE 1
Test score distribution by the students disciplines.

skills in chemistry lessons. There were also correlations between physics achievement with inductive and deductive reasoning (Enyeart et al., 1980). The studies also showed that formal thinking and the ability to interpret logical connectives differ (Lawson et al., 1978; Lawson, 1983). The result of research conducted by Pallrand et al. (1981) showed that those students who are more successful in science are also those who can use formal logic and can use the rules of conditional reasoning in the correct way. Zulkipli (2020) in a study carried out to investigate scientific reasoning skills among science pre-service teachers. They found no significant relationship between the studied science disciplines and the scientific reasoning patterns of the science pre-service teachers.

We found a significant difference in test results according to gender, age group, the student's type of secondary school leaving exam and also according to the parent's education level. Our survey results show that men performed better on the propositional logic tasks in the three task groups. Several studies have examined gender differences related to mathematics learning compared to using variables including innate abilities, attitudes, motivation, talent and performance. The literature has recognised the relationship between gender and mathematics performance (Goodchild and Grevholm, 2009; Munroe, 2016; Lin et al., 2020) and concludes that there is a higher performance rate among males in mathematics than females. It is evident that there is a tendency for males to perform better on mathematics tests than females when it comes to learning mathematics, and according to Arnup et al. (2013), these discrepancies might be partly explained by the differences in the cognitive styles of the individuals. Vos et al. (2023) examined which factors could cause gender differences in mathematical performance tests. Results showed that women scored significantly lower than men on the arithmetic and cognitive reflection tests. The results of Niwas (2018) research show that significant differences exist among low, average and high logical thinking on achievement in science in favour of high logical thinking for all groups (rural male, urban male, rural female and urban female) and the total sample.

Based on our results, students whose parents have a higher education achieved better results than those whose parents graduated from secondary or elementary school. According to our assumption, this may be related to the greater expectations and requirements of the parents during the student's entire schooling. However, it may also play a role that the parents who have graduated from the university can support their child to a greater extent in learning, mastering and understanding the curriculum, and being a positive example. They also serve in the children's further education and can take a more significant part in the financial support of their studies.

Most literature sources show that parents' educational level strongly influences educational and economic opportunities for their children (Dubow et al., 2009; Kalil et al., 2012; Benner et al., 2016). Several researchers say parental education is an important predictor of children's educational and behavioural outcomes (Dearing et al., 2001; Davis-Kean, 2005). A study by Davis-Kean (2005) examined how socioeconomic status, specifically parents' education and income, indirectly relates to children's academic achievement through parents' beliefs and behaviours. The author found that the socioeconomic factors were related indirectly to children's academic achievement through parents' beliefs and behaviours.

A meta-analysis by Sirin (2005) reviewed the literature on socioeconomic status and academic achievement in journal articles published between 1990 and 2000. The results showed a medium to strong socioeconomic status–achievement relation and that factors such as parental occupation, education and income are strongly related to student academic outcomes. Some other studies have also investigated the relationship between parental education and students' overall academic achievements. All these studies

TABLE 4 Test results by logic elements.

Characteristics	Mean	SD	Test stat (t)	*p*-value
Quantifiers				
Gender				
Men	3.58	1.05	2.677	0.008
Women	3.42	1.09		
Age				
18–25	3.47	1.08	−1.009	0.313
>25	3.55	1.11		
Type of secondary school				
Secondary grammar school	3.58	1.05	3.691	<0.001
Secondary school	3.37	1.10		
Negation				
Gender				
Men	1.85	1.29	2.705	0.007
Women	1.66	1.12		
Age				
18–25	1.72	1.17	−0.688	0.492
>25	1.79	1.31		
Type of secondary school				
Secondary grammar school	1.84	1.22	3.562	<0.001
Secondary school	1.62	1.14		
Inferences				
Gender				
Men	3.76	1.27	4.060	<0.001
Women	3.48	1.26		
Age				
18–25	3.55	1.28	−2.866	0.004
>25	3.80	1.16		
Type of secondary school				
Secondary grammar school	3.73	1.25	4.445	<0.001
Secondary school	3.43	1.27		

consistently show that parental education is an important variable for predicting academic achievement (Terfassa, 2018); moreover, father's and mother's high education positively contributes to their children's academic achievement (Idris et al., 2020). Parents with higher educational attainment can explain the difference in children's achievement and attach more importance and value to education than parents with lower formal education and can provide activities that stimulate and promote children's cognitive and intellectual development (Şengönül, 2022).

The studies above showed a relationship between parental education and students' academic achievements. Research results are also indicating a positive relationship between mathematics achievement. Students whose parents were university-educated performed about two-thirds of a proficiency level higher than those whose parents had no more than a high school education (Education Matters, 2004). Moreover, students whose parents worked in an occupation that required advanced mathematics skills performed almost one proficiency level higher than students whose parents had similar education levels but whose occupations did not require advanced mathematics. Schreiber (2002) examined

TABLE 5 Evaluation of task-groups by disciplines.

	Mean (SD)		
Discipline	Quantifiers	Negation	Inferences
Mathematics/ informatics	3.87 (1.05)	2.30 (1.33)	3.94 (1.20)
Engineering	3.62 (0.98)	1.72 (1.19)	3.81 (1.26)
Economics	3.45 (1.03)	1.69 (1.18)	3.55 (1.24)
Natural sciences	3.33 (0.99)	1.56 (1.16)	3.58 (1.18)
Paedagogy	3.41 (1.12)	1.63 (1.11)	3.45 (1.31)
Human sciences	3.18 (1.16)	1.55 (1.10)	3.46 (1.23)

TABLE 6 Evaluation of tasks by disciplines.

Discipline	Quantifiers (A)					Negation (B)					Inferences (C)				
	M	P	B	Ch	EL	M	P	B	Ch	EL	M	P	B	Ch	EL
Mathematics/ informatics	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+
Engineering	+	+	–	+	–	+	–	+	+	+	+	+	+	+	–
Economics	–	+	–	–	+	–	+	–	–	–	+	+	–	–	+
Natural sciences	–	–	+	–	+	–	+	–	–	–	–	–	+	+	+
Paedagogy	–	–	+	+	–	–	–	–	+	–	–	–	–	–	+
Human sciences	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+

advanced mathematics achievement with 1,839 students from 162 schools, and it was stated that parental education levels positively affected students' success in mathematics achievement.

The results of our survey show that there are also differences in the results of task groups A (quantifiers), B (negation), and C (inferences), which shed light on which propositional logic tasks are problematic for students. Examining the three selected areas of propositional logic, understanding and defining negations proved to be the most difficult. According to our experience, statements of this kind often cause problems for students during their studies, which can even be traced back to incorrectly interpreted logical connections in primary school but are often caused by expressions misused in everyday life. Most students have trouble interpreting the terms "at least" and "at most," and as a result, they cannot correctly define the negation of such statements either. According to one example of this faulty thinking, the negation of "at most" is "at least," which is not true on the set of integers. In the survey, we also noticed that many people responded to the denial of the "true for all x" type statement with the statement "not true for any x," obviously incorrectly.

We also found that secondary grammar school graduates achieved significantly better results than those who finished other types of secondary school. Similar results were shown in research conducted by Végh and Gubo (2022), which focussed on measuring computer science students' algorithmic and logical thinking skills. The results show that university students participating in the research who had a subject with similar content in secondary school performed better than those who did not. Examining the development level of reasoning and inductive thinking of engineering students, Tóth et al. (2021) point to differences between students and suggest the need to identify the thinking skills at the beginning of higher education by means of an input competence measurement.

In the education system of the Central European countries, secondary grammar schools are educational institutions at the secondary school level, which are characterised by general preparation in each discipline. In grammar school education, there is no specific priority given to certain subjects, although there may be high schools where they start a special mathematics class or a humanities or natural sciences class. However, even in these cases, general theoretical education is the main characteristic, unlike vocational secondary schools, where practical training comes to the fore. Logic or logical thinking is closer to thinking on a theoretical level, which also characterises secondary grammar school education. The text of the test tasks also primarily required theoretical consideration, which can be used to justify the significantly better results of those who graduated from secondary grammar school.

Regardless of the text context, the students studying mathematics or informatics performed above average in all but one task. Here we can see the result of the fact that students majoring in mathematics or computer sciences have adequately mastered the concepts of propositional logic during their studies, and these concepts are regularly present in their studies; they are a permanent part of them. They not only understand logical connections but can apply them in various tasks. The test results showed that the students majoring in mathematics or informatics solved the chemistry, physics or biology tasks similarly, meaning that the task context was less confusing for them. These students know, understand and can apply the given logic scheme, so the task context is not decisive.

On the contrary, we see the situation with students majoring in humanities and paedagogy. They probably already lack logical knowledge; they do not understand logical operations. In their case, this determines the low effectiveness of the tasks. Although a student majoring in humanities (e.g., history or philologist) is also expected to formulate his thoughts logically, the greater problem is evident in the case of students majoring in paedagogy. As future teachers, they will have to introduce their students to the methods of logical thinking and lay the foundations of scientific thinking.

We think that our research has several strengths but also limitations. Our research is specific in examining the elements of propositional logic and comparing its application to university students in different disciplines in the Hungarian speaking environment of the Central European region. During the mapping of the literature on the subject of research, we realised that it is difficult to find studies on propositional logic reasoning comparing results by scientific disciplines that are comparable to our topic, not only at the Central European level, but also at the global level. From this point of view, we consider our study to be a niche.

The strength of our research is also the sample size; however, the sample is not representative, 1,505 students from 15 universities participated in the research. Due to voluntary participation we had no influence on the sample composition, our sample was not balanced regarding gender or other background variables. As the countries of the participating university students have partially different education systems, this factor also affects the outcomes when comparing the students' performance by discipline. Another limitation is that the research tool was a non-standardised knowledge test, but it was previously pilot-tested.

6. Conclusion

The habits and form of thought gained in applying logic might have their place as a tool suitable for conceptual understanding in all disciplines. In logic, we learn how to use theories, deducing things from them, and we learn how to examine a theory from the outside, referring to the theories, analysing and finding ways it could be interpreted as true, or interpreted as false, and testing different models of the theory. This is a fundamentally important skill which is not straightforward to learn.

Our research focussed on examining university students' propositional logic thinking and knowledge of selected elements of propositional logic, considering their different fields of study. Based on the scores achieved, university students have significant differences in solving the tasks regarding the scientific disciplines by the student's study programme. The best results were achieved by students majoring in mathematics or computer science, while the worst results were achieved by students studying humanities. We found a significant difference in test results according to gender, age group, the student's type of secondary school leaving exam and also according to the parent's education level.

We conclude that those who know and understand mathematics (precisely, logic) have less problem solving a task that requires mathematical abstraction, but the task itself is in an arbitrary context. If this is true, it is also crucial for a good chemist, biologist or physicist to know and understand the relevant mathematical concepts. However, a good mathematician does not need to understand the specialised text and can still solve the task (of course, here we are thinking of tasks based on some mathematical abstraction). It follows that the university education of STEM specialists cannot be without the necessary mathematical foundations.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.1247653/full#supplementary-material

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