MATHEMATICAL CALCULATIONS WITHIN PHYSICS LESSONS AND THEIR POPULARITY AMONG LEARNERS

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ABSTRACT

Mathematics is an important nature exploration tool used by all natural sciences. So it is usual that mathematical calculations are part of school science education. But how are these calculations perceived by the learners themselves? What are their attitudes to this part of the teaching process? The answer to this question is important for any teacher who seeks to improve her/his teaching experience. The paper deals with the research of learners´ attitudes towards using mathematical calculations within physics lessons. Semantic differential for the sample of 230 primary and secondary school pupils was used in order to determine their attitudes towards this aspect and investigate the influence of grade and gender on the attitudes. The analysis of acquired data shows slightly negative learners´attitude to the mathematical calculations and some particular differences between grades and genders.

HOW TO CITE

Highlights

- *The students' attitudes towards mathematical calculations in physics lessons were found to be generally negative.*
- *The differences between the students' attitudes with respect to age and gender were described.*
- *The attitudes of Czech and Slovak students were compared.*

INTRODUCTION

The school education system should respond to the current intensive development of technology by developing and innovating the technical education of secondary school students, not just technical schools and universities. Physics can be considered as the basis of technical education. Physics in the school system is naturally classified as a natural science subject. In many researches devoted to the perception of natural science subjects in primary and secondary schools, physics and interest in physics were perceived as the least negative (Osborne, Simon and Collins, 2003). Students' perception of physics as a challenging and little interesting subject was also confirmed by a number of researches focused directly on students' attitude to physics (Angell et al., 2004; Stefan and Ciomos, 2010). These findings led to follow-up research to identify factors that significantly affect students' attitudes towards physics. One surprising finding was that the more frequent use of experiments in physics teaching had a statistically insignificant impact on the change in the student's negative attitude to physics (Yesilyurt, 2004).

Another factor influencing students' attitudes towards physics could be mathematics, used as a basic communication language in physics. Lehavi et al. (2017) pointed out that the topic of physics-mathematics interrelations has been the focus of attention in physics education research. Also, the present research is aimed at identifying one of the possible factors that could influence students' attitude to physics. This factor is mathematics, which is the basic tool for calculations and derivation of physical formulas.

According to Boaler (2016), the general disgust and disappointment of mathematics currently prevail among students. Thus, mathematics and mathematics teaching are associated with negative emotions among students. According to Bandura (1977), students avoid things or situations that are associated with aversive experiences. The present research is based on the assumption that students transmit their negative attitudes towards mathematics and physics, as much of the physics teaching is devoted to problem solving. As physics students learn the culture of physics and grow from novice to expert, many have trouble bridging what they learn in

mathematics and how we use mathematics in physics. As instructors, many of us are distressed and confused when our students succeed in mathematics classes but fail to use those same tools effectively in physics (Redish, 2017). There are also studies focused on the perception of mathematics in physics by teachers. For example, according to the findings of Pospiech et al. (2019), physics teachers perceive the role of mathematics in teaching physics differently. Some of them see it only as an "auxiliary science", others claim that physics can only be mastered with the help of mathematics. Threfore, the aim of this research is to find out students' attitudes to mathematical calculations in physics lessons.

Measurement of attitudes

As a hypothetical psychological construct, an attitude cannot be observed directly, but it can be inferred indirectly from observable answers expressing consent or disagreement (Eagly and Chaiken, 1998). Attitudes can be measured as positive or negative (Fishbein and Ajzen, 1975) and can be changed during time (Rubinstein, 1986). The authors generally regard the notion of attitude as a disposition of an individual to respond positively or negatively to some situation.

The research assumes the existence of three different components of attitude (cognitive, affective and behavioural) (Eagly and Chaiken, 1993; Maio and Haddock, 2010). The cognitive component includes opinions, ideas and information about the considered object. The affective component contains emotions related to the attitude object. Finally, the behavioural component includes willingness to act which is connected to the attitude. Learners´ attitudes towards various aspects of the teaching process can be positive or negative. The knowledge of students' attitude may give new look into how these attitudes can make the teaching process more difficult or easy.

The attitude measurement methodology is quite complicated and various methodological approaches exist. The main problem is that an attitude, as a hypothetical construct, cannot be measured directly. Only indirect measrement by inference is possible. Data collecting for this inference is realized by various methods. Measurement scales are often used methods (Thurstone, 1928; Likert, 1931). On the other hand, semantic differential (Osgood, 1952) represents not very often used method.

Semantic differential was developed by Osgood in 1952, as a means for measurement of the psychological meanings of the words or attitudes towards some aspects (Kerlinger, 1972). The results of Osgood´s research have shown that people understand the meaning of words and concepts along three main dimensions (evaluative, potency and activity dimension). The subjective rating of respondents is displayed on special scales created as bipolar adjective pairs. The simple tool is especially suitable for measuring emotional and behavioural aspects of the attitude (Hewstone and Stroebe, 2006). The method has been created to discover the connotative meaning of the words that can be depicted as points of so-called semantic space. Using factor analysis the relevant dimensions of the space and the three most important factors (evaluative, potency and activity)

can be determined. Each scale is meaningly saturated with one factor. An indisputable advantage of the method is its relatively easy administration, fast data processing and relatively high reliability and validity (Svoboda, 1992).

MATERIALS AND METHODS

Participants

The research sample contained 230 learners from Czech ($n = 20$) and Slovak ($n = 110$) primary, grammar and secondary vocational schools. The pupils of 9th grade of primary schools ($n = 94$), 1st grade of grammar schools ($n = 91$) and 2nd grade of secondary vocational schools ($n = 45$) were included into the research. The respondents´ age was in the interval 15-19 years ($x = 17.87$, SD = 1.92). These age groups were included in the research in order to monitor the development of students' attitudes during the critical period of adolescence. By comparing students at 9th grade (primary school) and secondary vocational school, we wanted to find out how students'a relationship to physics develops when they have more mathematics in physics lessons at high school. There were 94 girls (40.87%) and 136 boys (59.13%) in the sample. Given that the gender gap in learning so called STEM subjects (Wang and Degol, 2017) is a widely discussed topic, we consider the division of respondents into boys and girls in the analysis of research results to be natural.

Research Instrument

Twenty bipolar adjective pairs created as seven points scales (Table 2, in Appendix) are a major component of the questionnaire for semantic differential. The reliability of the instrument was determined using the value of Cronbach's alpha (Cronbach, 1951). The value for the whole research tool was $\alpha = 0.91$, the values for the particular factors were as follows: difficulty - $\alpha = 0.86$, usability - $\alpha = 0.87$, benefit - $\alpha = 0.66$ and perception - $\alpha = 0.82$. These values indicate the required reliability of the questionnaire. The measured data were transformed into a numerical data in such a way that the score 7 related to the most positive values and the score 1 to the most negative values. Learners´ attitude towards mathematical calculations within physics lessons can be inferred from the average score. The average value in range [3.5, 4.5] corresponds to a neutral attitude, the value above 4.5 related to a positive perception and the value below 3.5 means a negative attitude.

Data Analysis

Factor analysis with varimax rotation was realized with recoded numerical data. The standard tests of factor analysis justification for the obtain data were done before the analysis. The result of Kaiser-Meyer-Olkin (KMO) test was 0.87 and Bartlett´s test of sphericity was statistically significant ($\chi^2 = 728.51$, $p < 0.001$). The values of the tests are favorable for the use of the factor analysis.

According to the factor analysis, the items of the questionnaire were divided into 4 groups (factors) (Table 1): 1. Difficulty factor (6 items), 2. Usability factor (4 items), 3. Benefit factor (4 items), and 4. Perception factor (6 items). The factor score limit was 0.40.

			α	dim. 1	dim. 2	dim. 3	dim. 4
	1. Difficulty		0.86				
1	easy	difficult		**0.74**	0.31	0.03	0.09
4	simple	complicated		**0.84**	0.09	0.07	0.22
5	clear	confusing		**0.68**	0.16	0.25	0.16
8	causing pleasure	horrifying horror		**0.67**	0.09	0.05	0.38
14	funny	laborious		**0.71**	-0.10	-0.03	0.37
20	easy to underst.	difficult to under.		**0.63**	0.14	0.25	0.09
	2. Usability		0.87				
2	useful	insignificant		0.04	**0.82**	0.12	0.16
6	good	bad		0.23	**0.82**	0.12	0.17
7	acceptable	unacceptable		0.35	**0.74**	0.17	0.13
13	valuable	unneccesary		0.05	**0.79**	0.19	0.18
	3. Benefit		0.66				
15	organized	chaotic		0.19	0.25	**0.42**	0.21
16	harmless	dangerous		0.20	0.33	**0.67**	-0.08
18	safe	risky		-0.07	0.00	**0.85**	0.15
19	understandable	inconceivable		0.36	0.18	**0.49**	0.23
	4. Perception		0.82				
3	exciting	boring		0.37	0.22	-0.07	**0.71**
9	friendly	unfriendly		0.36	0.32	0.33	**0.48**
10	interesting	dull		-0.06	0.37	0.09	**0.62**
11	attractive	disgusting		0.31	0.17	0.20	**0.65**
12	comfortable	inconvenient		0.35	0.18	0.24	**0.56**
17	relaxed	tense		0.32	0.12	0.23	**0.49**
	Eigenvalues of factors			7.72	2.27	1.34	1.02
	Percentage of variance			38.62	11.38	6.7	5.11

Table 1: Results of factor analysis, 2019 (source: own calculation)

RESULTS

Overall average score obtained from the questionnaire was $x = 3.73$ (SD = 1.61), corresponding to relatively neutral attitude to the mathematical counting within physics lessons which is near to the negative one. As regards the individual dimensions, learners achieved the highest score within the dimension called "usability" ($x = 3.90$, SD = 1.63), the lowest score was found within the dimension "difficulty" ($x = 3.47$, SD = 1.59). The distribution of the score is consistent with the total score and the score of the individual dimensions can be considered as neutral attitudes, with the "difficulty" score being slightly below the limit of negative perception. The score distribution for each dimension is depicted in Figure 1.
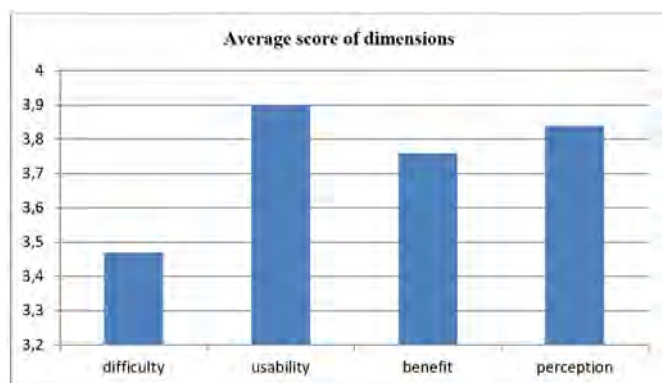

Figure 1: Average score of dimensions, 2019 (source: own calculation)

Due to the fact that parametric test (*t*-test, ANOVA) were to be used in the data analysis, the normality test of the basic set distribution was performed first. The values $W = 0.827$ and $p = 0.235$ of Shapiro-Wilk normality test obtained using the software Statistica, version 13.4.0.14 confirmed the normality assumption. Using statistical *t*-test of significance there was found out a statitically significant difference between boys´ ($x = 3.86$, SD = 1.56) and girls´ ($x = 3.52$, SD = 1.67) overall average score. The boys´ attitudes towards mathematical calculations within physics lessons is therefore more positive than the girls´ ones, but in both cases their perception can be considered as a neutral close to the negative. Investigating scores for gender-specific dimensions using statistical ANOVA test, statistically significant difference ($p < 0.05$) with more positive boys´ attitudes was found out. Relative to the dimension "difficulty", the boys reached the score of $x = 3.63$ (SD = 1.52) and girls $x = 3.24$ (SD = 1.67). For the factor called "usability", the boys achieved score $x = 4.0$ (SD = 1.64) and girls $x = 3.77$ (SD = 1.63), corresponding to slightly more positive perception of boys. Evaluating the "benefit" dimension, there were found the avarage values $x = 3.48$ (SD = 1.77) for the girls and $x = 3.95$ (SD = 1.64) for the boys. For the "perception" dimension, boys reached $x = 3.93$ (SD = 1.47) and girls $x = 3.72$ (SD = 1.58) (Figure 2). According to the Tukey post-hoc test, statistically significant differences between boys´ and girls´ scores are within the dimensions "difficulty" and "benefit".
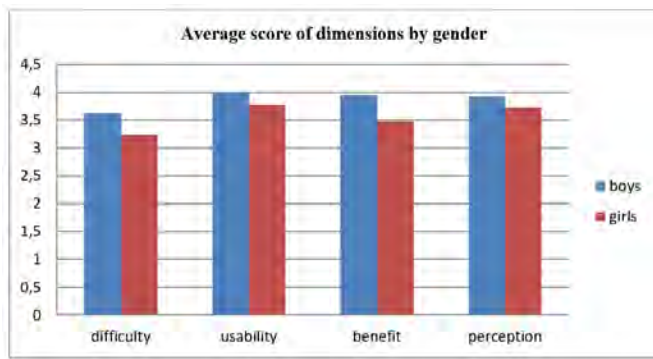
Figure 2: Average score of dimensions by gender, 2019 (source: own calculation)

In terms of the overall grade-specific average score, the value for 9th grade of primary schools was $x = 3.52$ (SD = 1.54), corresponding to almost negative relationship of this age category to the mathematical calculations within physics lessons. There is only a very small difference between the 1st grade ($x = 3.89$, SD = 1.69) and 2nd year of secondary vocational school pupils ($x = 3.85$, SD = 1.59) (Figure 3). The statistical ANOVA test confirmed the existence of statistically significant differences between the average scores of the individual age categories ($p < 0.001$). The follow-up Tukey post-hoc test revealed statistically significant differences between the 9th grade and the 1st grade ($p < 0.001$), between the 9th grade and the 2nd grade of the secondary school ($p < 0.001$).
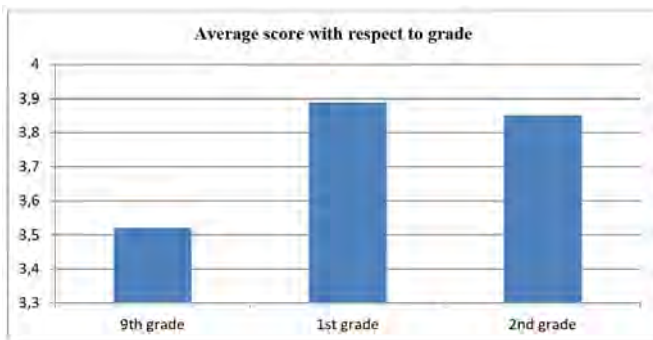

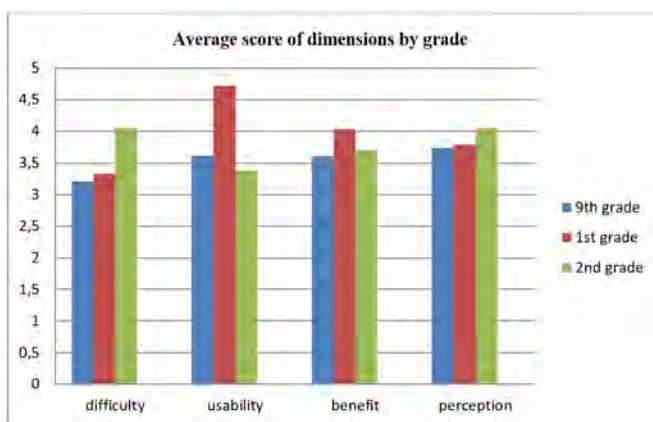**Figure 3: Average score with respect to grade, 2019 (source: own calculation)**

Figure 4: Average score of dimension by grade, 2019 (source: own calculation)

Evaluating the score for each factor in term of the attended grade, within the factor "difficulty" the pupils of the 9th grade reached the score $x = 3.20$; SD = 1.43, the pupils of the 1st grade achieved score $x = 3.33$; SD = 1.61 and for the 2nd grade of the secondary school $x = 4.05$; SD =1.66 (Figure 4). The statistical ANOVA test showed an existence of statistically significant difference ($p = 0.021$) and subsequent Tukey post-hoc test acknowledged statistically significant differences between the 9th grade and the 1st grade ($p = 0.031$) and between the 9th grade and the 2nd grade ($p = 0.035$). For the "usability" factor, the following values were found out: 9th grade – $x = 3.61$; SD =1.47, 1st grade – $x = 4.72$ (positive attitude); SD = 1.61; 2nd grade – $x = 3.38$; SD = 1.54. The p-value 0.016 of ANOVA test indicates that there exist significant differences for this dimension and Tukey post-hoc test showed the differences between the 9th grade and the 1st grade ($p < 0.001$) and between the 1st grade and the 2nd grade ($p < 0.001$).

Avarage values for the factor „benefit" were the following: 9th grade – $x = 3.60$; SD = 1.83; 1st grade – $x = 4.03$; SD =1.62; 2nd grade – $x = 3.69$; SD = 1.58. The ANOVA test revealed statistically significant differences ($p < 0.001$) and Tukey post-hoc test confirmed the differences between the 9th grade and the 1st grade ($p < 0.001$) and between the 1st grade and the 2nd grade ($p = 0.009$). For the factor „perception", ANOVA test indicated statistically insignificant differences between the grade categories ($p = 0.120$): 9th grade – $x = 3.74$; SD = 1.45; 1st grade – $x = 3.79$; SD = 1.63; 2nd grade – $x = 4.05$; SD = 1.47. Comparing the results of Czech and Slovak students, we find that there is no statistically significant difference between their average score (Czech students – $x = 3.74$, SD = 1.82; Slovak students – $x = 3.71$, SD = 1.42). However, gender difference can be observed in this case. While there was not find any statistically significant difference between Slovak boys and girls (Slovak boys – $x = 3.70$, SD = 1.39; Slovak girls – $x = 3.74$, SD = 1.39), in the case of the Czech pupils it was (Czech boys – $x = 3.99$, SD = 1.67; Czech girls – $x = 3.30$, SD = 1.92). The average scores of the Czech pupils depending on the grade are quite different. The value for 9th grade of primary schools comes out $x = 3.39$ (SD = 2.17), indicating negative relationship of this age category to the mathematical calculations. There is only a very small difference between the 1st grade ($x = 3.89$, SD = 1.69) and 2nd year of secondary school students ($x = 3.63$, SD = 1.52). The countries under comparisom formed for many years one state with one school system. After the division into two states, various reforms of the education system took place. We wanted to find out if the system for teaching mathematics and physics is better set up in any of the countries.

DISCUSSION

The analysis of acquired data shows the overall negative attitude of students to mathematical calculations in physics. According to the findings of Kaya and Böyük (2011), students' attitude to physics is neutral and, according to the research conducted by Ornek, Robinson and Haugan (2008), one of the factors affecting physics is the lack of a link between the theoretical part of physics and solved tasks in physics teaching. In view of

the above studies, it can be concluded from the present research that mathematical calculations have a significant negative impact on the physics perception of students. If we compare the method of teaching physics at primary and secondary school, we will find the following. In primary school, physics is taught by learning about the physical rules of the outside world. At secondary school, the use of physics knowledge in practical life prevails, and this is done predominantly through a mathematical problem solvings.

Changing the way of teaching mathematics and physics may not automatically change students' attitudes. According to the results of the research (Stejskalová et al., 2019), students are not inclined to change the way of teaching and learning. Other research on the development of the learning style (e.g. Vermetten, Vermunt, and Lodewijks 1999, Vermunt and Minaert, 2003) confirms the change in student's learning style when changing the way of teaching. Therefore, we recommend freqeuent including conceptual tasks that require students to create their own problem solving (Schneider, Grabner, and Paetsch, 2009). For example:

Peter Sagan has a 15 minute lead in a solo escape on the 24.3 km long rise to Passo dello Stelvio when the peloton arrives at the foot of the hill. The pursuers move in the rise at an average speed of 16 km.h⁻¹. Will Sagan win if he moves at an average speed of 14 km.h⁻¹?

The given task is from real life and its solving requires the identification of mathematics and the creation of a mathematical model, which are the basic elements of mathematical literacy (OECD, 2016). Tasks from everyday life require flexibility of procedural knowledge these are closely connected with conceptual knowledge (Rittle-Johnson and Star, 2011).

The change in students' attitudes towards the use of mathematics in the teaching of physics consists in teaching focused on balanced building of the conceptual and procedural knowledge (Hecht and Vagi, 2012). Verschaffel (2002) described the need to bring reality to the mathematics class, to create opportunities for learning and practice various aspects of applied problem solving. This would replace algorithms drilling and emphasize the creativity and independence of students in finding a solution. To increase the activity of students in the solving problems, it is appropriate to use the heuristic method, where students are actively looking for a way to solve a given task. Placing mathematical solvings in physics into semantic space allows the division of individual questionnaire items by factor analysis into individual dimensions. Based on the average score ($x = 3.47$) of the first dimension (difficulty), the mathematical solvings have a slightly negative impact on the physics' difficulty. Apparently, students who achieve weaker mathematics results also have problems in physics, in the case that mathematical solvings and the interpretation of their results form a significant part of physics teaching. This finding also corresponds to the results of other researches (Uz and Eryilmaz, 1999).

The already mentioned frequent use of real-life word problems in mathematics lessons could lead to an increase of student's success in solving physical problems. Word problems in mathematics lessons (as well as physics problems in physics lessons) require mathematization of the given task (creation of a mathematical model) and after finding a solution of the model, its interpretation in the conditions of the given problem. According to Boaler (2016), students do not see the importance of teaching mathematics, they see no links to real life. Physics is considered to be a part of science that uses the most of mathematical knowledge. However, based on the average score ($x = 3.90$) of the second dimension (usability), mathematical solvings are perceived significantly negatively. The mathematical solvings are considered to be of little use in physics. It can be concluded that the need for mathematical solvings in physics teaching is not sufficiently evident to students. Teaching mathematics often takes the form of practicing numerical algorithms (Boaler, 2016). Students believe that they learn mathematics in order to be able to solve equations and inequalities. However, there is lack of knowledge that each equation is essentially a mathematical model of some real situation.

The solution of this situation could be the use of project teaching already at primary school. In general, project-based teaching is a dynamic approach in which students explore real-life issues and challenges. This active and engaged way of learning inspires students to gain a deeper knowledge of the subjects they are studying (Dym et al., 2005; Mills and Treagust, 2003; Prince, 2004). If more emphasis were placed in project teaching at schools, students would be more aware of the mathematics usefulness in solving the problems of everyday life. An important aspect of teaching mathematics is the correct understanding of the context in the form of word problems (Chapman, 2006). Students also negatively perceive the contribution of mathematical solvings to understanding physical knowledge (benefit dimension, $x = 3.76$). It follows from the obtained data that the implementation of mathematical solvings rather increase the difficulty of learning physical knowledge. The average score ($x = 3.84$) of the fourth dimension (perception) is consistent with the findings within the previous dimensions.

In the present research, a statistically significant shift from a slightly negative attitude towards mathematical solvings in the physics of primary school students to a significantly negative attitude of secondary school students (Figure 3) was recorded. This shift is probably due to the fact that mathematical solvings are gradually becoming the core of physics teaching. And, unfortunately, similarly to the teaching of mathematics, drilling solutions to a given type of problems is also preferred in the teaching of physics.

From a methodological point of view, it is debatable whether we are entitled to use the parametric t-test and ANOVA test in the case of detecting statistically significant diferences between average scores obtained from the scales. This issue has been under discussion for almost 80 years. Some researchers recommend the use of a non-parametric (e.g. Wilcoxon) tests because they are free of the normality assumption and the assumption of interval data (Doane and Seward, 2011). However, many authors consider the scaled data as the interval ones (Boone and Boone, 2012). Consequently, they argue that the parametric tests can be applied for the scaled data that are widely used in the social sciences (Meek, Ozgur and Dunning, 2007). So, we can use those statistical methods.

CONCLUSION

According to PISA (Programme for International Student Assessment) 2015, the number of students reaching the 5th and 6th levels of mathematical literacy is decreasing and a significant proportion of pupils (27.7%) are in the risk group (OECD, 2016). Student results in PISA do not change significantly, in some cases slightly decrease. This finding indicates a more fundamental change in teaching mathematics towards task solvings from practical life. Teaching mathematics still runs in isolation. Individual parts of mathematics are often taught in isolation and mathematics itself is presented as isolated from other disciplines within the education (Boaler, 2016). Students often learn mathematics as a set of rules and practices without the necessary understanding. According to the findings of Mazur (1997), students do not focus on understanding the physical nature of the solution in solving physical tasks, but focus on the operation of the objects in the solvings. Even on the basis of the presented research, it can be stated that students transfer their mathematics habits to physics learning, specifically to solve physical tasks. The results of this research confirm the fact that mathematics, that students do not understand, will not help them to understand incomprehensible physics. Applying mathematical skills in physics requires a higher level of mathematical literacy because these are basically the verbal tasks.

In verbal tasks, it is necessary to be able to identify the mathematical knowledge that needs to be used in the task solving. This is the reason why verbal tasks are the biggest problem for students (OECD, 2016). In secondary school mathematics, their share in teaching is very low, which is counterproductive, as the share of mathematics is increasing in secondary school physics. Another factor that negatively affects the perception of mathematics usability in physics lessons is the fact that physical formulas are in fact the equations with a parameter, and understanding the term parameter is also one of the demanding parts of mathematics teaching. Understanding mathematical and physical symbols is not easy for students (Spelke and Tsivkin, 2001). Proper acquisition of these symbols by students requires an increased level of teaching focused on conceptual cognition. It is appropriate for students as well as teachers to realize that understanding mathematical symbols and concepts is as important as manipulating them in calculations (Leung, 2014). To achieve this goal, it is necessary to ensure that the expertise of mathematics and physics teachers is closely related to didactic knowledge in the context of specific teaching situations.

Based on the findings of the present research, the content of mathematics teaching should be based on the needs of the science disciplines. The verbal tasks from different areas of life but also from physics, chemistry, biology, etc. should be the foundation of secondary school mathematics. This would bring school mathematics back to true mathematics and, in addition to its usefulness and need, pupils would rediscover its beauty and creativity in it. We consider the project-based teaching to be the most suitable form of teaching to achieve this goal. The great advantage of this form of teaching is especially the possibility of an interdisciplinary approach to solving of a given problem. It would also be appropriate in the framework of teaching of mathematics and science to give students the opportunity for independent discovery of a solution of the problem in the form of heuristic teaching. A positive attitude towards mathematics would be transferred to other areas of life where mathematics is used, including physics.

REFERENCES

Angell, C., Guttesrud, O., Henriksen, E. K. and Isnes, A. (2004) 'Physic: Frightful, but fun, Pupils´ and teachers´ view of physics teaching', *Science Education*, Vol. 88, No. 5, pp. 683–706. https://dx.doi.org/10.1002/sce.10141

Bandura, A. (1977) *Social learning theory*, Engelwood Cliffs, New Jersey: Prentice Hall.

Boaler, J. (2016) *Mathematical mindsets*, San Francisco: Jossey-Bass, A Wiley Brand.

Boone, H. N. and Boone, D. A. (2012) 'Analyzing Likert Data', *Journal of Extension*, Vol. 50, No. 2, pp. 12–16.

Chapman, O. (2006) 'Classroom practices for context of mathematics word problems', *Educational Studies in Mathematics*, Vol. 62, No. 2, pp. 211–230. https://dx.doi.org/10.1007/s10649-006-7834-1

Cronbach, L. J. (1951) 'Coefficient Alpha and the internal structure of tests', *Psychometrika*, Vol. 16, No. 3, pp. 297–334. https://dx.doi.org/10.1007/BF02310555

Doane, D. P. and Seward, L. E. (2011) *Applied Statistics in Bussines and Economics*, New York: McGraw Hill Irwin.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D. and Leifer, L. J. (2005) 'Engineering design thinking, teaching, and learning', *Journal of engineering education*, Vol. 94, No.1, pp. 103–120. https://doi.org/10.1002/j.2168-9830.2005.tb00832.x

Eagly, A. H. and Chaiken, S. (1993) *The Psychology of Attitudes*, Orlando: Harcourt Brace Jovanovich College Publishers.

Eagly, A. H. and Chaiken, S. (1998) 'Attitude structure and function', in Gilbert, D. T., Fiske, S. T., and Lindzey, G. (ed.) *The handbook of social psychology*, New York: McGraw-Hill, pp. 269–322.

Fishbein, M. and Ajzen, I. (1975) *Belief, attitude, intention and behaviour: An introduction to theory and research*. Reading, MA: Addison-Wesley.

Hecht, S. A. and Vagi, K. J. (2012) 'Patterns of strengths and weaknesses in children's knowledge about fractions', *Journal of Experimental Child Psychology*, Vol. 111, No. 2, pp. 212–229. https://doi.org/10.1016/j.jecp.2011.08.012

Hewstone, M. and Stroebe, W. (2006) *Sociální psychologie. Moderní učebnice sociální psychologie* [*Social Psychology. Modern Textbook of Social Psychology*], Prague: Portál.

Kaya, H. and Böyük, U. (2011) 'Attitude towards physics lesson and physical experiments of the high school students', *European Journal of Physics Education,* Vol. 2, No. 1, pp. 38–49.

Kerlinger, F. N. (1972) *Základy výzkumu chování. Pedagogický a psychologický výzkum.* [*Fundamentals of Behavioral Research. Pedagogical and Psychological Research*]. Prague: Academia.

Lehavi, Y., Bagno, E., Eylon, B. S., Mualem, R., Pospiech, G., Böhm, U., Krey, O. and Karam, R. (2017) 'Classroom evidence of teachers' PCK of the interplay of physics and mathematics', in: Greczyło, T., and Dębowska, E., (ed.), *Key Competences in Physics Teaching and Learning*, Vol. 190, Chum: Springer International Publishing. pp. 95–104. https://dx.doi.org/10.1007/978-3-319-44887-9_8

Leung, K. C. I. (2014) 'Prospective Teachers' Understanding of the Constant π and their Knowledge of How to Prove its Constant Nature through the Concept of Linearity', *Research in Mathematical Education*, Vol. 18, No. 1, pp. 1–29. https://doi.org/10.7468/jksmed.2014.18.1.1

Likert, R. (1931) *A technique for the measurement of attitudes. Archives of Psychology*, New York: Columbia University Press.

Maio, G. and Haddock, G. (2010) *The Psychology of attitude and attitude change*, London: SAGE Publications Ltd.

Mazur, E. (1997) 'Understanding or memorization: Are we teaching the right thing?', *Conference on the Introductory Physics Course on the occasion of the retirement of Robert Resnick*, New York, pp. 113–124.

Meek, G. E., Ozgur, C. and Dunning, K. (2007) 'Comparison of the t vs. Wilcoxon Signed- Rank Test for Likert Scale Data and Small Samples', *Journal of Modern Applied Statistical Methods*, Vol. 6, No. 1, pp. 91–106. https://dx.doi.org/10.22237/jmasm/1177992540

Mills, J. E. and Treagust, D. F. (2003) 'Engineering education, Is problem-based or project-based learning the answer', *Australasian journal of engineering education*, Vol. 3, No. 2, pp. 2–16.

OECD (2016) PISA 2015 Results (Volume I). Excellence and Equity in Education, Paris: OECD Publishing. http://dx.doi.org/10.1787/9789264266490-en

Ornek, F., Robinson, W. R. and Haugan, M. P. (2008) 'What makes physics difficult?', *International Journal of Environmental and Science Education*, Vol. 3, No. 1, pp. 30–34.

Osborne, J., Simon, S. and Collins, S. (2003) 'Attitudes towards science: a review of the literature and its implications', *International Journal of Science Education*, Vol. 25, No. 9, pp. 1049–1079. https://dx.doi.org/10.1080/0950069032000032199

Osgood, C. (1952) 'The nature and measurement of meaning', *Psychological Bulletin*, Vol. 49, No. 3, pp. 172–237. https://dx.doi.org/10.1037/h0055737

Pospiech, G., Lehavi, Y., Bagno, E. and Eylon, B. S. (2019) 'Views and Strategies of Teachers Concerning the Role of Mathematics and Physics in Physics Lessons', in McLoughlin E., van Kampen P. (ed.) *Concepts, Strategies and Models to Enhance Physics Teaching and Learning*, pp. 181–192, Cham: Springer. https://doi.org/10.1007/978-3-030-18137-6_16

Prince, M. (2004) 'Does active learning work? A review of the research', *Journal of engineering education*, Vol. 93, No. 3, pp. 223–231. https://dx.doi.org/10.1002/j.2168-9830.2004.tb00809.x

Redish, E. F. (2017) 'Analysing the competency of mathematical modelling in physics', in Greczyło T., Dębowska E. (ed.) *Key competences in physics teaching and learning*, Vol. 190 Cham: Springer, pp. 25–40. https://doi.org/10.1007/978-3-319-44887-9_3

Rittle-Johnson, B. and Star, J. R. (2011) 'The power of comparison in learning and instruction: Learning outcomes supported by different types of comparisons', in Mestre, J. P. and Ross, B. H. (ed.) *Psychology of learning and motivation: Cognition in education*, Vol. 55, San Diego: Elsevier, pp. 199–225. https://doi.org/10.1016/B978-0-12-387691-1.00007-7

Rubinstein, M. F. (1986) *Tools for thinking and problem solving*. New Jersey: Prentice Hall.

Schneider, M., Grabner, R. H. and Paetsch, J. (2009) 'Mental number line, number line estimation, and mathematical achievement: their interrelations in grades 5 and 6', *Journal of Educational Psychology*, Vol. 101, No. 2, pp. 359–372. https://doi.org/10.1037/a0013840

Spelke, E. S. and Tsivkin, A. (2001) 'Language and number: A bilingual training study', *Cognition*, Vol. 78, No. 1, pp. 45–88. https://doi.org/10.1016/S0010-0277(00)00108-6

Svoboda, M. (1992) *Psychologická diagnostika dospělých*. [*Psychological diagnostics of adults*]. Prague: Portál.

Stefan, M. and Ciomos, F. (2010) 'The 8th and 9th grade students attitude towards teaching and learning physics', *Acta Didactica Napocensia,* Vol. 3, No. 3, pp. 7–14.

Stejskalová. I., Komárková. L., Bednářová. M. and Štrach, P. (2019) 'Student Adoption of a Non-Traditional Teaching Method in Accounting: How Previous Experience Impedes Willingness to Change', *Journal on Efficiency and Responsibility in Education and Science*, Vol. 12, No. 1, pp. 1–11. https://dx.doi.org/10.7160/eriesj.2019.120101

Thurstone, L. L. (1928) *Implicit attitudes can be measured*. [Online], Available: http://timss.bc.edu/timss2011 [1 Jul 2014].

Uz, H. and Eryilmaz, A. (1999) 'Effects of socioeconomic status, locus of control, prior achievement, cumulative GPA, future occupation and achievement in mathematics on students´ attitude toward physics', *Hacettepe Journal of Education*, Vol. 16–17, pp. 105–112.

Vermetten, Y. J., Lodewijks, H. G. and Vermunt, J. D. (1999) 'Consistency and variability of learning strategies in different university courses', *Higher Education*, Vol. 37, No. 1, pp. 1–21. https://doi.org/10.1023/A:1003573727713

Vermunt, J. and Minnaert, A. (2003) 'Dissonance in student learning patterns: when to revise theory?', *Studies in Higher Education*, Vol. 28, No. 1, pp. 49–61. https://doi.org/10.1080/03075070309301

Verschaffel, L. (2002) 'Taking the modeling perspective seriously at the elementary level: Promises and pitfalls', *Proceedings of the 26th Annual Meeting of the International Group for the Psychology of Mathematics Education*, Norwich, pp. 64–80.

Wang, M. and Degol, J. L. (2017) 'Gender Gap in Science, Technology, Engineering, and Mathematics (STEM): Current Knowledge, Implications for Practice, Policy, and Future Directions', *Educational Psychology Review*, Vol. 29, pp. 119–140. https://doi.org/10.1007/s10648-015-9355-x

Yesilyurt, M. (2004) 'Student teachers´ attitudes about basic physics laboratory', *The Turkish Online Journal of Educational Technology,* Vol. 3, No. 4, pp. 49–57.

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APPENDIX

	1	2	3	4	5	6	7	
Easy								Difficult
Useful								Insignificant
Exciting								Boring
Simple								Complicated
Confusing								Clear
Good								Bad
Causing pleasure								Horrifying horror
Friendly								Unfriendly
Comfortable								Inconvenient
Valuable								Unnecessary
Laborious								Funny
Chaotic								Organized
Harmless								Dangerous
Risky								Safe
Understandable								Inconceivable
Easy to understand								Difficult to understand
Unacceptable								Acceptable
Interesting								Dull
Disgusting								Attractive
Relaxed								Tense

Table 2: Bipolar adjective pairs