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CRITICAL THINKING AND PHYSICS PROBLEMS

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KEY WORDS

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ABSTRACT

Critical thinking is considered to be one of the most important abilities which help us to solve problems, interpret information or make decisions in everyday life. Every person needs to use critical thinking, therefore, it is important to develop students' critical thinking in all classes including Physics. We summarize various definitions of critical thinking and we describe the survey, where students solve problems whose solution requires critical thinking. We compare students` results to see if they can solve problems without physics content with better successfulness than the problems with physics content and to see how the school attendance impacts its development.

GLOBAL KNOWLEDGE ACADEMICS

1. Definitions of critical thinking

To make decisions, choose criteria, solve problems, evaluate arguments or interpret limitless information, we use critical thinking skills. Every person needs to use critical thinking skills in certain situations. Experts say that critical thinking is not inherent (Gavora, 1995, p. 11). Therefore, it is important that students have an opportunity to learn how to think critically and how to improve this skill.

There are various definitions of critical thinking and experts understand this term in different ways. In 1989, the Iowa Department of Education published, "A Guide to Developing Higher Order Thinking Across the Curriculum", where they present an integrated thinking model (Iowa Department of Education, 1989, p. 7 – 9). They describe critical thinking as a part of complex thinking processes and they state:

> Critical thinking behaviors involve reorganizing in meaningful ways the "accepted knowledge" from the content/basic thinking; (Iowa Department of Education, 1989, p. 7)

They divide critical thinking into three sub-categories, namely, analyzing, connecting, and evaluating. Next, they characterize these categories and list skills associated with each one (Iowa Department of Education, 1989, p. 18).

Subsequent to several years of research on the topic of critical thinking, the American Philosophical Association published, "The Delphi Report" which presents a consensus of views on the topic from experts from divergent fields such as philosophy, education, psychology (Facione, 1990). The report states in part:

> We understand critical thinking to be purposeful, self-regulatory judgement which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological criteriological, or contextual considerations upon which that judgement is based. (Facione, 1990, p. 2)

The experts in the report also state that good critical thinking includes a skill dimension and also a dispositional dimension (Facione, 1990, p. 4). There are six cognitive skills identified in the report associated with critical thinking and these include: interpretation, analysis, evaluation, inference, explanation, and self-regulation. These skills are then defined along with their respective sub-skills. The authors also state that these skills can be correlated with various cognitive dispositions to be exercised appropriately. These dispositions include: concern to become and remain generally well-informed, trust in the processes of reasoned inquiry, self-confidence in one's own ability to reason, open-mindedness regarding divergent world views, willingness to reconsider, and revise views where honest reflection suggests that change is warranted, etc. (Facione, 1990, p. 6–13).

The earliest research on critical thinking in Slovakia was conducted in 1994 by researchers from the faculty of education at Comenius University in Bratislava. As a result of their research, the authors describe critical thinking as a tool which helps the student to uncover connections, understand what he/she is learning and reach his/her own conclusions (Gavora, 1995, p. 7).

In contemporary society, critical thinking is considered to be one of the most important abilities. The Organisation for Economic Co-operation and Development (OECD) states:

> Students will need to apply their knowledge in unknown and evolving circumstances. For this, they will need a broad range of skills, including cognitive and meta-cognitive skills (e.g. critical thinking, creative thinking, learning to learn and self-regulation); social and emotional skills (e.g. empathy, self-efficacy and collaboration); and practical and physical skills (e.g. using new information and communication technology devices). (OECD, 2018, p. 5)

Therefore, its development is essential for students' futures. Based on the State Educational Program in Slovakia, the development of critical thinking is included in the general educational aims for students enrolled both in primary schools (ŠPÚ, 2015a, p. 4) and secondary schools (ŠPÚ, 2015b, p. 4). These students should be provided with the opportunity to develop their critical thinking skills in all subjects, including physics.

While the development of critical thinking in all subjects is important (Kosturková, 2016, p. 37, Facione, 1990, p. 4), nevertheless, it can be hard for teachers to identify tasks and activities to do so. One of the possible ways to develop critical thinking in physics classes is to have students identify physics mistakes in movies (Velmovská, 2011, 2014).

2. The survey focused on critical thinking and solution of physics problems

This quantitative survey was designed to evaluate how the physics content affects the successfulness of solution. Problems whose solution requires critical thinking were used. The following section describes the hypotheses, methodology, survey sample, and results.

2.1 Hypotheses

The survey employed the following four research hypotheses:

H1: Students of primary and secondary schools will be less successful in solving the problems with physics content whose solution requires critical thinking than in solving the problems without physics content whose solutions require critical thinking.

Based on the integrated thinking model mentioned above, critical thinking reorganizes the “accepted knowledge” from the content/basic thinking (Iowa Department of Education, 1989, p.7). When students solve problems they need to have some basic knowledge from the related area and only after that they can use critical thinking. Therefore, when students solve problems with physics content they need to have some basic knowledge from the related area of physics and then they can use critical thinking to reorganise this knowledge in meaningful ways. Students might miss basic knowledge from physics and therefore they may be less successful in solving problems with physics content than solving problems without it.

H2: Students who attended school for more years will be more successful in solving the problems whose solution requires critical thinking than the students who attended school for fewer years.

The length of school attendance might have a positive impact on the level of students’ critical thinking skills. Students who attended school for more years may have more opportunities to develop their critical thinking skills and therefore, may be more successful in solving critical thinking problems than students who attended school for fewer years.

H3: Students from the class for intellectually gifted children will be more successful in solving the problems whose solution require critical thinking than the students of the same age from ordinary class.

Students from classes for intellectually gifted children may have better basic knowledge and therefore, may be more successful in solving critical thinking problems.

H4: Students from Slovakia will be as successful in solving problems whose solution requires critical thinking as students of the same age from a foreign country.

The aim of each educational system is to prepare students to be successful as contributing members of their respective society. Whereas critical thinking is one of the essential skills set in everyday life for students everywhere, it nevertheless, may be developed differently in schools contingent upon idiosyncratic societal differences. Despite of all these difference, each educational system tries to develop critical thinking in the best possible way. Therefore, students from disparate countries across the world, with their respective different education systems, may be equally successful in solving critical thinking problems.

2.2. Methodology

The data was collected utilizing a survey that incorporated ten problems whose correct solution requires students’ use of critical thinking skills. Five of the problems included physics content and five of the problems did not include physics content. The test was divided into two parts. The first part consisted of three problems with physics content and two problems without physics content. The second part consisted of two problems with physics content and three without it. The division of the test into two parts was purposely designed to avoid having students read four pages of text at one time.

The problems with physics content included the following five topics: density, temperature, heat conduction, the properties of liquids, and measurement of length. Based on the State Educational Program in Slovakia (ŠPÚ, 2015c), these topics are studied in the sixth grade and at the beginning of the seventh grade of primary school (the age range of these students is 11 to 12). The problems without physics content included the following five topics: starting a company, discovery of Angel's falls, an avalanche in the Cascade Range, flight hours of aircraft's captain, and ice hockey championship. A more complete description of the problems and solutions have been annotated elsewhere (Trúsiková, 2018). Statement 1 and 6, are examples of the problem without physics content and with physics content, respectively.

Statement 1: John has started a new company. Michael owns a company with a long tradition. New companies are more likely to fail than companies with a long tradition. Based on the previous information, we can say:

1. John's company will fail.
2. Michael's company will have a better profit than John's company.
3. Michael's company won't fail.
4. John's company is more likely to fail than Michael's company.
5. John's company is newer than Michael's.

Statement 6: January 2017 was really cold in Slovakia. In mayor part of Slovakia, they measured the lowest average air temperature for the preceding thirty years. The air temperature decreased even under -30 °C in some places. Based on this information we can say:

1. January 2017 was colder than we expected.
2. The average air temperature in January 2017 was lower than in January 2016 in mayor part of Slovakia.
3. In January 2017 it snowed the most for preceding thirty years in mayor part of Slovakia.
4. The average air temperature was -30 °C in some places in January 2017.
5. The air temperature didn't decrease -30 °C in January 2016.

Each problem consists of a statement followed by five declarative sentences. Students were instructed to circle the correct declarative sentences based on the information in each problem. They could circle multiple declarative sentences related to each problem. In response to problem one, the correct declarative sentences were items four and five. In response to problem six, the correct declarative sentence was item two. A five-point scale was used for the five declarative sentence options. A respondent received one point for each declarative sentence marked correctly. Therefore, each student could attain a maximum of five points for each problem. In total, students could reach 50 points; 25 points for solving problems with physics content and 25 points for solving problems without physics content.

2.3. Sample of survey

The survey was administered to three different schools in Slovakia (Grammar school in Nové Mesto nad Váhom, Primary school in Tvrdošovce and Primary school with the class for intellectually gifted children in Trenčín); and at one school in the USA (Eastern Hills High School in Fort Worth, Texas). Grammar school is a type of secondary school in Slovakia, where study the students who usually continue at some university.

The survey was administered to the Slovak students in February and March of the school year 2017/2018. The survey was administered to students from the USA in April of the school year 2018/2019. The age range of Slovak students was 12 to 18 and the age range of students from the USA was 16 to 18. Table 1 displays the number of students who completed both parts of the survey.

Table 1.
Number of participating students in the survey

	Slovak students	Students from the USA	In total
Number	160	39	199

2.4. Results

As noted previously, students could achieve a maximum of 50 points for successful completion of both parts of the survey. The highest score was achieved by a second grade student of a grammar school in Slovakia. She achieved 47 points; 22 points for problems with physics content and 25 points for problems without physics content. None of the students participating in the survey reached 25 points for problems with physics content.

The four hypotheses were tested using the free software for statistical computing, namely, the R project (R Core Team, 2018). The first hypothesis tested was H1. The null hypothesis H01 was chosen for the purpose of data analysis. H01 is stated as follows:

H01: Students of primary and secondary schools will be as successful in solving the problems with physics content whose solution requires critical thinking as in solving the problems without physics content whose solutions require critical thinking.

In order to test hypothesis H01, two sets of data were compared; the number of points reached in problems with physics content and the number of points reached in problems without physics content. The results of students from the class for intellectually gifted children were not included in this analysis. Therefore, the results of the 185 students in the other three schools were compared. First, the Shapiro-Wilk (1965) test of normality was employed and revealed that there was not a normal distribution of data for either the set of data for the problems with physics content ($p_{stat} = 0.0353 < p_{crit} = 0.05$) or, in the set of data for problems without physics content ($p_{stat} = 0.002 < p_{crit} = 0.05$). Next, the Wilcoxon-Mann-Whitney nonparametric test (Fay, Proschan, 2010) was used to compare means of both sets of data and revealed that $p_{stat} = 0.02644 < p_{crit} = 0.05$. Based on an analysis of the means scores, the null hypothesis H01 was rejected. Then a comparison of the average number of points reached in problems with physics content (16.82 points) with the average number of points reached in problems without physics content (17.53 points) was conducted and revealed that students might have statistically better results solving the problems without physics content and therefore, hypothesis H1 is not rejected.

Next, hypothesis H2 was then tested. The null hypothesis H02 was chosen for the purpose of the analysis of the data. H02 is stated as follows:

H02: Students who attended school for more years will be as successful in solving the problems whose solution requires critical thinking as students who attended school for fewer years.

To test hypothesis H02 only the results of Slovak students were utilized. In addition, the results of students from the class for intellectually gifted children were excluded because only one class participated in the survey. The remaining six sets of data were then compared, corresponding to the seventh, eighth and ninth grade of primary school and the first, second and third grade of grammar school. In total, the results of 146 students were analyzed. These sets contained the total number of points reached in both parts of the test. The Shapiro-Wilk (1965) test of normality was used and revealed a normal distribution of the data for all grades. Next, a two-sample Student`s t-test (Fay, Proschan, 2010) was used to calculate p-values in particular grades. A comparison was then made of the seventh-grade students' results with eighth, ninth, first, second, and third-grade students' results. Subsequently a comparison was then made of the eighth-grade students' results with ninth, first, second, and third-grade students' results. A comparison of the results continued in this way culminating in the comparison of the second-grade students' results with the third-grade students' results. P-values adapted by Benjamini-Yukutieli (Dohler, 2018) procedure are shown in Table 2 below.

Table 2.
P-values adapted by Benjamini-Yukutieli procedure

Grades	8th	9th	1st	2nd	3rd
7th	0.088	**0.001**	**1.2×10^{-4}**	**1.3×10^{-7}**	**1.0×10^{-6}**
8th		**0.030**	**0.002**	**1.2×10^{-4}**	**1.2×10^{-4}**
9th			**0.023**	**1.9×10^{-5}**	**6.1×10^{-5}**
1st				0.418	0.963
2nd					0.202

P-values $p_{crit} < 0.05$ are marked in bold and the null hypothesis H02 is rejected in these cases. Comparing the seventh-grade students' results with the eighth-grade students' results the null hypothesis H02 is not rejected, nor is it rejected comparing the first-grade students' results with the second and third-grade students' results, and the second-grade students' results with the third-grade students' results. The relatively small number of participating students is a limiting factor in making a wider generalization, but the results suggest that the length of school attendance might have a positive impact on the level of critical thinking.

Next, hypothesis H3 was tested. The null hypothesis H03 was chosen for the purpose of the analysis of the data. H03 is stated as follows:

H03: Students from the class for intellectually gifted children will be as successful in solving the problems whose solution require critical thinking as students of the same age from ordinary class.

In order to test hypothesis H03, two sets of data were compared. The total number of points reached by the eighth grade students (N = 28) from the primary school in Tvrdošovce (ordinary primary school) was compared to the total number of points reached by the eighth grade students (N = 14) from the primary school in Trenčín (class for intellectually gifted children). First, we used Shapiro-Wilk (1965) test of normality and determined that there was a normal distribution for both sets of data. With respect to the ordinary class of students the results were: $p_{stat} = 0.429 > p_{crit} = 0.05$, whereas the results for the class for intellectually gifted students, were $p_{stat} = 0.276 > p_{crit} = 0.05$. A Student`s t-test (Fay, Proschan, 2010) was then employed to compare means scored and revealed that $p_{stat} = 1.74 \cdot 10^{-6} < pcrit = 0.05$. Therefore, the null hypothesis H03 was rejected. Comparison of the average number of points reached by students from an ordinary class (31.71 points) with the average number of points reached by students from class for intellectually gifted children (38.79 points), revealed that students from the class for intellectually gifted children might have statistically better results. Therefore, the hypothesis H3 is not rejected.

Finally, hypothesis H4 was tested. Six sets of data were analyzed including the results of the 16, 17 and 18 years old Slovak students (N = 72) and the corresponding results of 16, 17 and 18 years old students from the USA (N = 39). First, the Shapiro-Wilk (1965) test of normality was conducted to determine p-values. As indicated in Table 3, the p-values of particular sets of data are displayed. Based on the fact that in all sets of data, the $p > p_{crit} = 0.05$, the data distribution is considered to be normal.

Table 3.
P-values calculated by Shapiro-Wilk test

Age	P-values	
	Slovak students	Students from the USA
16	0.20	0.06
17	0.85	0.55
18	0.10	0.54

Next, a Student`s t-test (Fay, Proschan, 2010) was conducted to compare the results of 16 years old Slovak students with the results of 16 years old students from the USA. The data analyses revealed that $p_{stat} = 0.002679 < p_{crit} = 0.05$, and the hypothesis related to the equality of means is therefore, rejected. The analyses then continued with a comparison of mean scores. Slovak students reached 37.0 points on average and students from the USA reached 29.55 points on average. Next, the results of 17 years old Slovak and USA students were compared in the same way, with the resultant p-values; $p_{stat} = 1.162 \cdot 10^{-8} < p_{crit} = 0.05$. Based on these results the hypothesis about the equality of means is rejected. Slovak students reached 38.52 points on average and students from the USA reached 31.53 points on average. Finally, the results of 18 years old Slovak and USA students were analyzed and revealed that $p_{stat} = 4.468 \cdot 10^{-7} < p_{crit} = 0.05$. Therefore, the hypothesis related to the equality of means is rejected. Slovak students achieved 38.63 points on average whereas, students from the USA achieved 27.82 points on average. The data suggest that Slovak students might reach statistically better results than students from the USA in all age categories.

2.4. Discussion and Conclusion

There were four hypotheses tested in this survey and following provides a brief summary and commentary. Hypothesis H1 is not rejected because the data indicates that students might reach statistically better results in solving survey problems without physics content. Students may likely have already studied the terms used in the problems with physics content. However, at the same time, students might not understand all of these terms and concepts correctly and therefore, may be missing the key knowledge that could be reorganized by critical thinking.

Hypothesis H2 is not rejected because the comparison of students' results suggests that the length of school attendance might have a positive impact on the level of critical thinking. However, there was a very small number of students who participated in the survey. Therefore, inferring broader generalizations in this regard cannot be made. Subsequent research with a larger number of subjects is warranted to test this hypothesis.

Hypothesis H3 is not rejected because the data indicates that students from the class for intellectually gifted children might reach statistically better results than students of the same grade from an ordinary class. It may be that students from the class for intellectually gifted children might have better level of basic knowledge. It may also be true that their critical thinking is better developed. Therefore, they may have more basic knowledge to be reorganized and they also can reorganize in a better way than the students from the ordinary class. These speculations need investigation with a larger student sample with instrumentation designed to address these differences.

Finally, hypothesis H4 is rejected. The data indicate that Slovak students might reach statistically better results than students from the USA. However, only a small number of students with the age range 16 to 18 participated in the survey (39 students from the USA and 72 students from Slovakia). Therefore, the very small sample size precludes broader generalizations. Another limiting factor to wider generalization is difference in the types of schools included in the study. For example, the Slovak students all attended grammar schools. A very high percentage of students who attend grammar schools in the Slovak Republic go on to attend the university. On the other hand, students from the USA who participated in the survey, were all enrolled at a regular high school. Subsequent studies might test these hypotheses with larger numbers of students controlling for the type of secondary school in both countries.

All data is considered as a starting point for the next research. It can be used to design more problems whose solution requires critical thinking. Mentioned problems should include different physics topics. The data will be also used to design the indicators to assess the level of critical thinking in the education of physics.

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