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RESEARCH AND EVALUATING OF HYPOTHETICALLY-DEDUCTIVE STUDENT REASONING IN REPUBLIC SERBIA †

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Abstract. *The goal of this research is an examination of the degree of development of hypothetical-deductive reasoning in general high schools ("gymnasiums") in the Republic of Serbia. Hypothetical-deductive reasoning is one of the categories of scientific reasoning that can be measured by the Lawson test. The main characteristic of this reasoning is the indication of the degree of development of abstract thinking in adolescents. Adolescents who have developed this method of reasoning can "operate" statements, establish complex relationships among them, and combine them in a systematic way by reaching a set of all possible combinations. Hypothetical-deductive reasoning is especially important during experiments in physics teaching. It is therefore important to examine how many students have reached this level of reasoning, and find a way to increase the level of scientific reasoning of students. The research involved 654 high school students from Novi Sad and Bačka Palanka. The results of the study showed that around 13% of gymnasiums answered correctly all questions related to hypothetical-deductive reasoning. The obtained data indicate that for most students, hypothetical-deductive reasoning has not been developed. The paper presents the way in which hypothetical-deductive reasoning can be developed or stimulated.*

Key words: *hypothetical-deductive reasoning, physics education, students, experiments*

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1. INTRODUCTION

A central purpose of education is to improve students' scientific reasoning abilities (Lawson, 1985). Scientific reasoning can be defined as a method through which evidence is collected and analyzed and linkages between concepts and theories have been created (Schen, 2007). Therefore, it is the task of teachers, methodologists and all who participate in the cognitive development of a child, especially teachers and methodologists of physics, to help students to acquire thinking skills (Lawson, 1985). According to Piaget, there are four stages of the child's cognitive development. When a child fully overcomes the possibilities of a single stage, it overcomes it and moves to the next stage (Stepanović, 2004a). For the teaching of physics, the last two stages are particularly interesting, the stage of concrete operations and the stage of formal-logical operations. Within the stage of concrete operations, students master the conservation of the number, volume, and mass, which is the basis of empirical-inductive reasoning (Lawson, Banks, & Logvin, 2007; Marušić & Sliško, 2012). During the stage of formal-logical operations abstract thinking develops and students become able to think in abstract categories, they can make conclusions based on abstract assumptions and formulate general laws and principles (Stepanović, 2004b). Therefore, this stage is the basis for hypothetical-deductive reasoning, which can be defined as the cognitive process used to generate a hypothesis, devise an appropriate experiment to test the hypothesis, deduce a prediction, and determine the agreement of the evidence with the prediction (Schen, 2007). Viewed from the perspective of physics methodology, hypothetical-deductive reasoning is particularly important in order to properly understand experiments carried out in the course of physics and to correctly understand abstract concepts that are studied in the course. By observing the problem of understanding the experiments carried out in the course of teaching, two approaches can be distinguished: empirical-induction and hypothetical-deductive approach. Within the empirical-inductive approach, the students derive from empirical facts in order to formulate general principles (Flavell, 1977, according to Stepanović, 2004b), while in the framework of a hypothetical-deductive approach it starts from theoretical settings in order to establish or verify the actual relations between phenomena (Piaget, 1953, according to Stepanović, 2004b). In the work of Ju (2016), a formal definition of hypothetical-deductive reasoning is stated and binds it to propose hypotheses and testing their acceptability or falsity by determining whether their logical consequences are consistent with observed data. Therefore, in order to encourage the hypothetical-deductive approach and hypothetical-deductive reasoning, the development of critical thinking and proper argumentation should be encouraged. Pešić in his paper (Pešić, 2007) states that the majority of authors find that the arguments are crucial for critical thinking because it is that the arguments contain the thesis (what someone tries to convince us) and the reason (which makes us assure us of the justification of such betting). Observing student arguments, i.e. theses and reasons, one can see if the students really understand the teaching materials and the problem presented to them. Adolescents who developed this way of thinking, that is, reasoning can "operate" statements, establish complex relationships among them and combine them in a systematic way, coming to the set of all possible combinations (Stepanović, 2004a). Therefore, based on student questions and arguments in the formulation and testing of the hypothesis, the effectiveness of the applied education system can be pointed out (Bady, 1979; Chin, Osborne, 2008), viewed from the point of development of critical thinking and higher levels of scientific reasoning. Noting the

importance of encouraging the proper development of student argumentation, Lawson explained in his papers (Lawson, 2010; Lawson et al., 2000) each step in the formation and verification of the hypothesis using the implications of If/Then/Therefore. Hypothetical-deductive reasoning is especially expressed when performing experiments in physics teaching. In this paper, an explanation is given based on the implications for experiments related to hypothetical-deductive reasoning, which are covered by the Lawson test. There are two experiments assigned. The first experiment is related to the understanding of the general principles of thermodynamics and the basic equation of the ideal gas state, while the second experiment is related to understanding the concept of osmosis. Both experiments were presented under the Methodology section.

2. METHODOLOGY

2.1. Subject and Purpose of Research

A group of corporations (Partnership for 21st Century Skills) who partnered with the U.S. The Department of Education has created a framework that identifies the key skills for success (Hann, 2013). They identified ten skills as the most important skills of the 21st Century. The first three places are Ways of Thinking:

1. Creativity and innovation
2. Critical thinking, problem-solving, decision making
3. Learning to learn, Metacognition.

Since the ways of thinking are recognized as important skills for the 21st Century, the subject of this research was to examine how our gymnasiums are ready for the problem solving and decision making, and to what extent have they developed hypothetical-deductive reasoning as the highest level of scientific reasoning.

The aim of the research is to examine the degree of development of hypothetical-deductive reasoning in gymnasiums in the Republic of Serbia.

2.2. Research instrument and procedures

In order to investigate the degree of development of hypothetical-deductive reasoning in gymnasiums in the Republic of Serbia, the questions from the Lawson Classroom Test of Scientific Reasoning (CTSR) were used. As part of the questions, two experiments were presented theoretically (one related to the understanding of the basic principles of thermodynamics and the basic equation of an ideal gas state, and the second one related to understanding the notion of osmosis). After explaining the experiment, the students were asked to explain the described process, as well as to find an explanation for the misinterpreted experiment, or the phenomenon is shown. Questions are scored with 1 if the students gave the correct answer and with 0 if they gave an incorrect answer. Data were collected from January to February 2017 at the physics classes.

2.3. Description of the experiments

Experiment 1: The experiment consists of a glass, a cup of coffee, water and candles. First, the candle lit up and placed on the plate to stand, then the water drains around the

candle on the plate. When the glass is covered, fresh water enters the glass and the candle is turned off (Figure 1). After this observation, the following question can be posed: why does water enter the glass?

Fig. 1 Experiment 1

One explanation is that the flame of the candle converts oxygen into carbon dioxide, and as oxygen from the water does not extract rapidly as carbon dioxide is produced, a higher concentration of carbon dioxide will result in lower air pressure in the beaker. If a similar shift experiment is repeated to be used additionally and dry ice (which is frozen carbon dioxide), in order to provide possible explanations?

Experiment 2: If a couple of drops of blood are placed on a plate and viewed under a microscope, it can be seen (as shown) that magnified red blood cells resemble small round balls. However, if a few drops of dissolved salt are added in water, it will be detected that the cells have become smaller (Figure 2). So the question can be posed why it reduces red blood cells? There are two possible explanations:

1. The ionic salts (Na+ and Cl-) enter the cell membranes and consequently decrease the cells.

2. Water molecules are attracted by ionic salts and water molecules can get out of the cell and make it smaller.

Fig. 2 Experiment 2

In order to examine these explanations, an experiment will be performed. It will be taken with water, a very precise instrument for measuring the mass and a plastic bag filled with water. It is assumed that plastic will act as a membrane in red blood cells. It is necessary to measure the mass of the prepared plastic bag, then immerse it in for ten minutes and re-measure the weight of the bag. What result of the experiment would best show that explanation 1 or 2 is probably wrong?

2.4. Research sample

The survey sample numbered 654 pupils, of which 289 boys (44.2%) and 365 girls (55.8%). The research involved students from the second to the fourth grade of the high school "Jovan Jovanovic Zmaj", "Isidora Sekulic" and "Svetozar Markovic" from Novi Sad and gymnasium "20. October" from Bačka Palanka. The application http://www.raosoft.com/samplesize.html was used to select the sample size. The maximum sample size estimated at

around 3,500 students, and the value of the majority of the 654 samples taken for this study is greater than the value defined with the confidence level of 99%, and therefore the sample was considered convenient.

2.5. Data processing

One-factor variance analysis with the Scheffe posthoc test and descriptive statistics within the SPSS 20.0 program was used for data processing.

3. RESULTS AND DISCUSSION

The descriptive analysis showed that the median value of the student achievement M = 1.78, SD = 1.25, which is 44.5% of the total number of points. Figure 3 presents the distribution of accurate answers according to the achieved number of points.

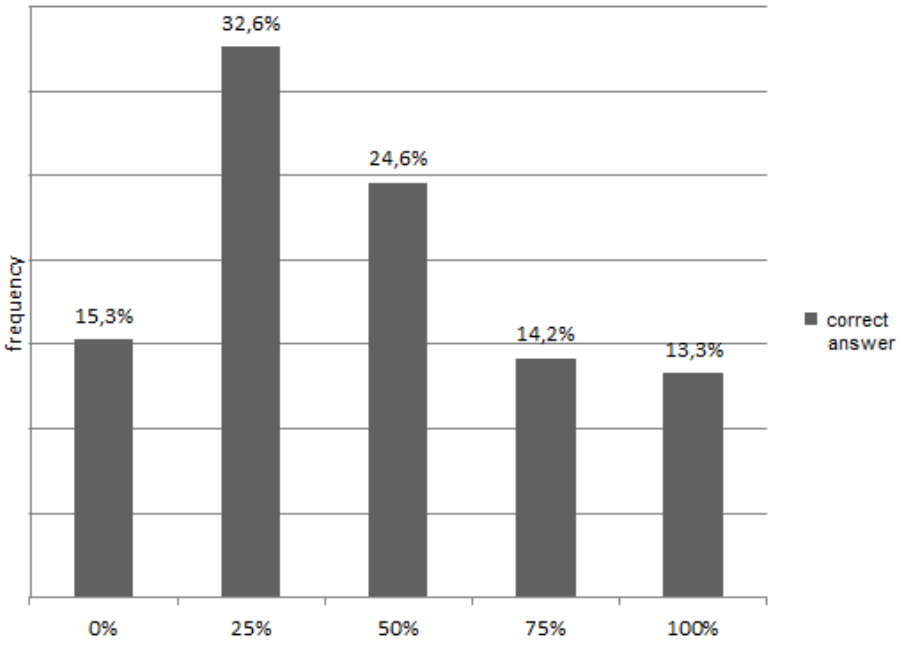

Fig. 3 The proportion of correct answers

As can be seen from Figure 3, the majority of students answered exactly one-quarter of the questions, while approximately one-seventh of respondents answered all the questions correctly. It is interesting to note that about one-seventh of the respondents did not give an exact answer.

If we look at the obtained result in more detail, on questions related to experiment 1, 29% of the respondents answered correctly, and most often, as an incorrect response, they said that the water level would rise because oxygen is consumed. To explain the result of the experiment

would indicate that your explanation is wrong, it is usually stated that the water level will be lower than in the first case. Numerous researchers have dealt with the problem of this experiment (Lawson, 2010; http://www.math.harvard.edu/~knill/pedagogy/waterexperiment/). The explanation given in Lawson's research is as follows: If oxygen is consumed creating a partial vacuum, and it causes a vacuum in which the water is sucked, then the water level should rise, which it does. Therefore, the hypothesis is supported (Lawson, 2010).

For Experiment 2, 41.6% of respondents correctly answered, and most often, as an incorrect response, they stated that there was no change in mass either in the first or the second measurement. In explaining the result of the experiment, it would be best to show that explanation 2 is probably wrong, in an equal percentage, it is said that during the second measurement of the weight of the bag, a smaller mass will be obtained than during the first measurement, that is, during the second measurement, the volume of the bag will decrease.

The obtained values indicate that in the majority of students the hypothetical-deductive reasoning is not fully developed. Since most students are not yet at this stage of reasoning, their correct understanding of abstract concepts that are studied in the course of physics is questioned. The obtained result is in agreement with Wason and Johnson-Laird and Lunzer and coworkers, shown in the paper Bady (1979). These researchers have been provided that at the level of college students and high school seniors, the majority of tested students show a lack of understanding of the logic of hypothesis testing. Similarly, it was obtained in the research Stepanović (2004a). In her research, it is stated that respondents are not on sub-stadia within the stage of formal surgery, and are not fully trained in correcting hypotheses involving observable causal agents (Lawson, Banks, Logvin, 2007). The obtained data indicate that students do not interpret the implications correctly and/or they do not understand the nature of science itself. The obtained data point to the problem of the educational system and pose an important issue of the efficiency of the applied teaching instructions that are necessary to process in the next research.

In the research Stepanović (2004a), there was a trend of growth, that is, with increasing age, the number of pupils reaching this level increases. Therefore, the dependence on the age and achievement of students is examined. The single-factor analysis of variance showed that there was a statistically significant difference in student achievement, depending on the age of the student, F ($df = 2$, $N = 653$) = 14.934, $p = 0.000$, $\eta^2 = 0.044$. The value of the eta-square of the coefficient indicates the small to the mean influence of the age on the degree of hypothetical-deductive reasoning. Scheffe's posthoc test showed statistically significant differences between students of the fourth grade $M = 2.14$, $SD = 1.25$, and students of the second $M = 1.53$, $SD = 1.27$ and the third grade $M = 1.71$, $SD = 1.17$, while the differences between pupils of the second and of the third grade were not statistically significant. Table 1 shows the dependence of the age of the respondents and the achievements on the scientific reasoning test.

Table 1 The proportion of correct answers

	0%	25%	50%	75%	100%
II grade	19.5%	43.1%	15.3%	9.2%	13.0%
III grade	15.8%	30.1%	30.1%	15.3%	8.7%
IV grade	9.6%	21.5%	31.6%	19.6%	17.7%

As can be seen from Table 1, more students of the second grade than students of the third and fourth grade did not give any correct answer, while more students of the fourth than the students of the second and third grade correctly answered all the questions.

Gender as an independent variable was not statistically significant, $F (df = 1, N = 653) = 3.466$, $p = 0.063$. The study found that the boys won $M = 1.88$, $SD = 1.29$, while the girls got almost the same, $M = 1.70$, $SD = 1.22$. The lack of full difference was also obtained in the research Stepanović (2004a).

4. CONCLUSIONS

The task of modern education is increasingly related to self-education, i.e. training for self-learning and the development of critical and creative thinking. It is precisely in this context that critical thinking, problem-solving and decision making are recognized as 21st-century skills. The development of these skills can best be seen by improving students' scientific reasoning abilities. Within the scientific reasoning, it is possible to distinguish several categories. One of them is hypothetical-deductive reasoning that is defined as the cognitive process used to generate a hypothesis, devise an appropriate experiment to test the hypothesis, deduce a prediction, and determine the agreement of the evidence with the prediction. Hypothetical-deductive cutting relates to the highest stage of cognitive development of students and is characterized by the ability of abstract thinking of students. Students who have developed this way of reasoning can "operate" statements, establish complex relationships among them, and combine them in a systematic way, coming to the set of all possible combinations. Recognizing all possible relationships between statements is particularly important when formulating and testing hypotheses. It is therefore important that students properly develop all the abilities they need to properly understand the entire teaching material, and especially the experimental data obtained within the relevant teaching subjects. As physics is defined as an experimental science, in order to properly understand physical concepts and processes, it is important to encourage students to critical thinking and to achieve the highest levels of scientific reasoning.

The results of the research have shown that most of the students are not at the level of hypothetical-deductive reasoning. Only about a seventh of students correctly answered all the questions, while the majority of students correctly answered a quarter or half of the questions. In order to improve the results obtained, it is necessary to train teachers to work with pupils by encouraging the critical thinking of students, then, the curriculum and the curriculum, to define the number of hours required for this type of teaching instruction. The results of the study have shown that there is a statistically significant dependence between the age of the student and the achievement of the test. It was found that older high school students more than the younger high school students gave the correct answers to the questions asked. Gender as an independent variable was not statistically significant.

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ISPITIVANJE I EVALUACIJA HIPOTETIČKO-DEDUKTIVNOG REZONOVANJA KOD UČENIKA U REPUBLICI SRBIJI

Cilj istraživanja je ispitivanje stepena razvijenosti hipotetičko-deduktivnog rezonovanja kod gimnazijalaca u Republici Srbiji. Hipotetičko-deduktivno rezonovanje predstavlja jednu od kategorija naučnog rezonovanja koja se može meriti Losonovim testom. Glavna karakteristika ovog rezonovanja je ukazivanje na stepen razvijenosti apstraktnog mišljenja kod adolescenata. Adolescenti koji su razvili ovaj način rezonovanja umeju da „operišu" iskazima, uspostavljaju složene odnose među njima i kombinuju ih na sistematičan način dolezeći do seta svih mogućih kombinacija. Hipotetičko-deduktivno rezonovanje je posebno izraženo prilikom izvođenja eksperimenata u nastavi fizike. Stoga je važno ispitati koliko učenika je dostiglo ovaj nivo rezonovanja, kao i naći način kako povećati nivo naučnog rezonovanja učenika. U istraživanju je učestvovalo 654 gimnazijalaca iz Novog Sada i Bačke Palanke. Rezultati istraživanja su pokazali da je oko 13% gimnazijalaca tačno odgovorilo na sva pitanja vezana za hipotetičko-deduktivno rezonovanje. Dobijeni podatak ukazuje da kod većine učenika nije razvijeno hipotetičko-deduktivno rezonovanje. U radu je predstavljen način na koji se može razviti ili podstaći hipotetičko-deduktivno rezonovanje.

Ključne reči: *hipotetičko-deduktivno rezonovanje, nastava fizike, učenici, eksperimenti*.