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INVESTIGATING THE PRESENCE OF MISCONCEPTIONS OF 8TH GRADE STUDENTS THROUGH MULTIPLE-CHOICE QUESTIONS AT NATIONAL CHEMISTRY COMPETITION TESTS

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A study was conducted to test the level of conceptual understanding of certain chemistry concepts defined in the national curriculum in Macedonia among 8th grade students who participated in the National chemistry competition in the 2016/17 school year. The students were tested on the following topics: state of matter, metals and non-metals, elementary substances, compounds and mixtures, chemical reactions and introduction to organic chemistry. An analysis of the multiple-choice questions was performed in order to categorize students' achievements in four areas of conceptual understanding (satisfactory conceptual understanding, roughly adequate performance, inadequate performance, and quite inadequate performance) according to the percentage of students who correctly answered the test items. Furthermore, the findings revealed three misconceptions and several vague and erroneous notions present in students' minds.

Keywords: conceptual understanding; lower-secondary education; misconceptions; multiple-choice questions; National chemistry competition

ИСТРАЖУВАЊЕ НА ЗАСТАПЕНОСТА НА МИСКОНЦЕПЦИИТЕ КАЈ УЧЕНИЦИ ОД 8-МО ОДДЕЛЕНИЕ ПРЕКУ ПРАШАЊА СО ПОВЕЌЕКРАТЕН ИЗБОР НА ДРЖАВНИОТ НАТПРЕВАР ПО ХЕМИЈА

Ова истражување беше спроведено за да се испита степенот на концептуално разбирање на одредени хемиски концепти застапени во наставната програма во Македонија кај ученици од 8-мо одделение кои учествуваа на Државниот натпревар по хемија во учебната 2016/17 година. На тестот беа застапени следниве поглавја: состојби на материјата, метали и неметали, елементарни супстанци, соединенија и смеси, хемиски реакции и вовед во органска хемија. Беше направена анализа на прашањата со повеќекратен избор за да може да се класифицираат постигнувањата на учениците во четири области на концептуално разбирање (добро, задоволително, недоволно и целосно неприфатливо) врз основа на процентуалната застапеност на учениците кои дале точен одговор на прашањата на тестот. Понатаму, наодите од истражувањето открија три мисконцепции и неколку нејасни и погрешни претстави кај учениците.

Клучни зборови: концептуално разбирање; основно образование; мисконцепции; прашања со повеќекратен избор; Државен натпревар по хемија

1. INTRODUCTION

Chemistry is one of the most complex sciences due to the abstract nature of many studied concepts. It is based on concepts which need to be presented and explained in an adequate way by chemistry teachers in their teaching practice. Chemistry teaching aims at the development of understanding the concepts, facts, principles, theories and laws that describe the physical and natural world.

The conceptual understanding of chemistry can be challenging to both teach and learn. Students are faced with abstract concepts from the very beginning of their chemistry education [1] which implies a development of their abstract thinking and, in many cases, applying a submicroscopic level of understanding [2]. Students are often put in a position to draw logical conclusions and develop skills to solve chemistry problems [3, 4], but also to use other mechanisms to create their own understanding and reinforce their critical thinking [5, 6].

Assessment is another key issue related to education in general. The term *assessment* has many meanings and interpretations. In its broadest sense, it can be used for two main purposes to evaluate students: (a) for grading, tracking or to provide comparisons between student sets, locally, nationally or internationally (summative assessment); or (b) as a diagnostic to give feedback (both to the student and the teacher) on the achievement of learning outcomes (formative assessment) [7]. Assessment and evaluation are essential components of the educational process. The purpose of evaluation is to record the progress of the students, focusing on what they have learned, rather than on what they have not learned.

One important part of formative assessment is a diagnosis of pre-concepts, misconceptions and other erroneous notions that are present among students. The misbeliefs and ideas of children developed before and during their early school years are referred to as pre-concepts, and those that originate from the teaching process are known as school-made misconceptions [8]. Misconceptions are powerful, extremely persistent and highly resistant to change, thus creating obstacles to further learning [9, 10]. Misconceptions might stem from the specific chemical terminology, ideas about particles of which substances are composed of or chemical symbols used for their representation and other content from textbooks, as well as from teachers. Therefore, although the teaching process is aimed at acquiring knowledge and understanding chemistry concepts, in some cases it may mislead students and contribute to the formation of misconceptions. That is why special consideration should be paid in the way in which teachers teach and assess students' knowledge. A recent study in this field in Macedonia [11] shows that conceptual questions are of great importance, both in teaching and learning processes. Therefore, more attention is needed when designing an instruction focused to developing higher-order thinking skills rather than promoting low-level knowledge [13].

As stated before, conceptual questions are important in the teaching and learning process. Thus, teachers need to have the ability to ask questions to test the students' knowledge and their acquired skills. In designing a lesson, teachers should try to think of higher-order questions that stimulate thinking and test understanding [14]. These kinds of questions ask students to apply their chemistry knowledge to solve chemistry problems and explain real phenomena.

Conceptual questions are a necessary part of chemistry competitions that are organized in Macedonia. Competitions are an important part of the education process and an effective way of motivating students in a particular subject. Students compete with their classmates in the classroom, but also with students from all over the country at National competitions. Therefore, it is important to develop intrinsic motivation; that is, motivation to do something for its own sake, to learn to enjoy, and to meet the challenge rather than to win a prize and defeat someone else [15]. Competitions also provide students with feedback and give them an opportunity for self-evaluation and comparison to their peers. The availability of good competitions is beneficial for education in almost any discipline [16]. A good competition should challenge the participants to give their best.

There are three levels of chemistry competition in Macedonia: municipal, regional and national. The National chemistry competition test is composed of three parts: 1) multiple-choice questions that test, more or less, all levels of cognitive tasks, 2) conceptual questions and problems of different types, and 3) imagined experiments.

2. EXPERIMENTAL SECTION

2.1. *Methodology*

2.1.1. *Objectives of the study*

The main objective of this study was to obtain insight into students' knowledge about the chemistry topics defined in the 8^{th} grade national curriculum in Macedonia [17]: state of matter; metals and non-metals; elementary substances, compound and mixtures; chemical reactions; and introduction to organic chemistry (only alkanes are considered as well as fossil and alternative fuels). Furthermore, the study was aimed to investigate misconceptions present among students.

2.1.2. *Research sample*

The research sample comprised 64 8th grade students (≈ 13 years old) participating at the National chemistry competition in the 2016/17 school year. Students were tested according to the adopted curriculum of the Cambridge International Examination Center introduced by the Bureau for the Development of Education in the academic year 2014/2015 and the suggested textbook [18].

2.1.3. *Research instrument*

The National chemistry competition test was used for this research. All test items were revised by two university professors and verified by a national chemistry counselor from the Bureau for the Development of Education. The test itself consisted of three parts – the first part comprised ten multiple-choice questions covering concepts within all of the mentioned topics, while the second and third parts dealt with different types of questions involving short-answer questions, classification-type questions, fill-in-the-gap questions, open-ended questions seeking arguments for a given answer, etc. For the purpose of this study, only the first part (multiple-choice questions) was analyzed (Supplementary file, Appendix 1).

2.1.4. *Data analysis*

Each correct answer scored 2 points, so the maximum score for the test was 20. The test scores ranged from 8 to 20 points. Students were asked to answer properly by circling the letter in front of one of the offered answers. They were clearly informed that they would receive 0 points if they used pencil, circled two or more answers or crossed-out an answer.

The first part of the analysis was oriented to the percentage of correct responses by students. According to the literature [19], the percentage of students who correctly answered the test items can serve as an indicator of conceptual understanding. Thus, for the multiple-choice questions, four areas of conceptual understanding have been set:

1) satisfactory conceptual understanding (SCU) if the correct answer is given by 75 % or more of the students;
2) roughly adequate performance (RAP) if this percentage is in the range from 50–74 %;
3) inadequate performance (IP) for the percentage range 25–49 %, and
4) quite inadequate performance (QIP) if the obtained frequency is less than 25 %.

Furthermore, we were interested in discovering possible misconceptions present among students. Thus, the second part of our analysis was directed towards diagnosing misconceptions. All wrong answers (distractors) chosen by more than 20 % of the students were considered misconceptions [12].

3. RESULTS AND DISCUSSION

3.1. *Part I: Analysis of correct answers*

The percentage of chosen options for each test item is given in Table 1. The areas of conceptual understanding are given according to the correct answers (which are given in bold in the table). It can be seen that there is sound understanding of the tested concepts in the 2nd, 6th and 7th test items (denoted as SCU). RAP was observed in five test items (numbered 1, 3, 4, 8 and 9). The results also show IP of students for the 5th and the 10th test items. QIP was not reported for any test item. This study includes students who are not only high-achievers in chemistry but the best students in the country, so high outcomes and performances are to be expected.

Table 1

Information on students' answers

Option	**Test item No.**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
A	12.5	3.1	14.1	**70.3**	**25.0**	9.4	**95.3**	18.8	21.9*	17.2
B	14.1	0.0	**71.9**	6.3	4.7	0.0	1.6	**68.8**	1.6	39.1*
C	0.0	**89.1**	0.0	7.8	56.3*	0.0	1.6	3.1	**62.5**	9.4
D	**73.4**	3.1	3.1	3.1	12.5	**85.9**	0.0	7.8	1.6	7.8
E	0.0	4.7	10.9	12.5	0.0	4.7	0.0	0.0	10.9	**26.6**
Two answers	0.0	0.0	0.0	0.0	1.6	0.0	1.6	1.6	1.6	0.0
Area of conceptual understanding	RAP	SCU	RAP	RAP	IP	SCU	SCU	RAP	RAP	IP

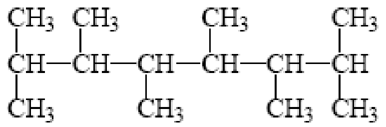
3.2. *Part II: Analysis of misconceptions and other incorrect responses*

In Table 1, the options that represent misconceptions are marked with an asterisk. The three misconceptions that were detected are:

1) During the electrolysis of water that contains a small amount of diluted sulfuric acid, the reactant(s) is/are water and sulfuric acid.

2) The decomposition of plant material is one of the sources of carbon dioxide.

3) The correct IUPAC name of the following compound



is 1,1,2,3,4,5,6,6-octamethylhexane.

In addition to these misconceptions, other incorrect responses by students are interesting to analyze and comment on, in particular those detected in more than 10% of participants (see Table 1).

In the first test item (see Supplementary file, Appendix 1), such responses are represented by options A and B. This item tests knowledge about laboratory equipment, specifically about laboratory funnels. These are used both for filtration and transferring liquids. Actually, students who circled options A or B have a partial understanding of the role of funnels in the laboratory, as both options are combined in option D (the correct option).

The third test item was about gaseous ammonia. In fact, students were supposed to distinguish between pure substances (elementary substances or compounds) and mixtures, to be acquainted with the type of particles it is composed of, and to be familiar with the concept of diffusion in order to apply their knowledge in the example of ammonia gas. The confusion between options A and B is obvious. It seems that students have problems with understanding the differences between distinct particles and cannot determine the difference between a pure substance and a mixture. This kind of problem was noted by many researchers [20–22]. It is clear, in our case, that option A represents a pure substance and option B a mixture. Also, few students did not have firm awareness about the process of diffusion.

The fourth test item refers to characteristic chemical reactions by which the presence of a certain element can be confirmed. Most students performed well on this item, but some confused the brick-red color of the pure copper metal to the color characteristic in the flame-test identification of calcium metal.

The fifth test item was rather problematic for 75 % of the students who did not know the correct answer. More than half of the students did not appreciate the role of sulfuric acid as a means to speed up the electrolysis process, thus not having any effect on the nature of the products (misconception No. 1). Surprisingly, 12.5 % of students could not tell the difference between the reactants and the products or had no understanding of the electrolysis process at all.

It is disappointing to find that 18.8 % of our best students (this percentage is very close to the critical value of 20 % considered a misconception) presume that sodium chloride solution is an alkali one, thus changing the color of universal indicator to dark blue. It is our assumption that students are taking the word ‘sodium’ as a representative of something alkali, not bearing in mind the other words present and their meaning in the chemistry context.

As stated before, the ninth test item reveals one misconception (misconception No. 2). Analyzing this item, we found that 10.9 % of students thought that cattle farming is one of the sources of carbon dioxide, probably because they were not certain about the correct answer and this statement is mentioned in the same textbook but in another context.

The final item tested the knowledge about the rules of naming organic compounds (alkanes). A very small percentage of students had solid knowledge regarding organic nomenclature, applying the branching rules in order to give the correct name of the compound. The highest percentage of students (39.1 %) chose option B (misconception No. 3), considering the false main chain distracted probably by the symmetry of the given formula. Furthermore, 17.2 % of students made a mistake in naming the compound, this time taking the correct main chain, but confusing the position of the substituents on the chain.

Organic nomenclature has been a subject of interest for a long time [23]. Recently, many strategies to improve lessons and eliminate organic nomenclature misconceptions among students can be found in the literature [24, 25].

The overall knowledge shown by students in this study regarding organic chemistry is not satisfactory. This is perhaps due to the fact that this topic is the last one in the curriculum and students had the least time to prepare.

4. CONCLUSION

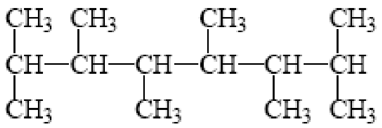
In this study, the conceptual understanding of 8th grade students who participated in the National chemistry competition in 2017 was examined. Students were tested on the following topics: state of matter; metals and non-metals; elementary substances, compound and mixtures; chemical reactions; and introduction to organic chemistry. The findings show that students had a solid understanding of concepts tested by most of the multiple-choice questions and were classified in the area of SCU or RAP. This was rather expected since participants were selected in a two-level competition process involving students from all parts of the country, and therefore had the biggest achievements in chemistry, along with interest and motivation in the subject which were at a very high level. The area of IP was noticed in two test items, whereas QIP was not present for any item.

Results indicated the presence of three misconceptions among students:

1) During electrolysis of water that contains small amount of diluted sulfuric acid, the reactant(s) is/are water and sulfuric acid.

2) The decomposition of plant material is one of the sources of carbon dioxide.

3) The correct IUPAC name of the following compound



is 1,1,2,3,4,5,6,6-octamethylhexane.

A few more incorrect responses by students were also analyzed. They addressed the usage of laboratory equipment, the distinction between pure substances and mixtures and the type of particles they are composed of, characteristic chemical reactions for identification, the electrolysis of water, pH and indicators and organic nomenclature. It is important that all of these erroneous notions be first perceived and addressed and then a process should be started to find a "cure", i.e. strategies for their correction and replacement with scientifically accepted concepts. This is especially important for younger students at the beginning of their chemical education, because their achievements in further education depend highly on the elimination of pre-concepts and early-stage misconceptions.

The test items used in this analysis are available to all lower-secondary school students and chemistry teachers in Macedonia [26] and we believe that both students and teachers will benefit in their future work. Organizing a good competition is a major challenge, requiring work and dedication, and we hope that we have succeeded in accomplishing our idea to motivate, educate and interconnect students from Macedonia, thereby increasing their interest in studying chemistry.

4.1. *Limitations and implications for future research*

The National competition test was restricted to only 10 multiple-choice questions. It was important to cover all learning material according to the curriculum, thus limiting the number of questions for certain topics. Therefore, in further research, a deeper and more detailed analysis should be undertaken in order to access and understand problematic concepts.

The questions were thoughtfully developed using meaningful distractors, bearing in mind that students could guess the correct answer. In the test, we provided more questions which required the use of complex cognitive processes to obtain the answer.

Furthermore, this study included students who showed the best results in previous levels of competition. A broader study, involving a larger sample of students from various backgrounds and knowledge levels, would be beneficial in obtaining better results and discovering more learning difficulties and misconceptions among students.

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