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The impact of instructional strategy based on the triplet model of content representation on elimination of students' misconceptions regarding inorganic reactions

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Abstract: Recently we reported on the efficient teaching instruction based on integration of macroscopic, submicroscopic and symbolic levels of knowledge representation, from the standpoints of performance and mental effort. Based on obtained results a goal of this study was set – to identify misconceptions in the group of students trained in traditional manner and to determine whether the same misconceptions occur among students in the treatment group in the field of inorganic reactions. A two-tier test was used in the research, administered by 189 second grade high school students. Analysis was performed by calculating the frequencies of choosing distractors in the tasks. Results revealed a total of nine misconceptions in the group of students trained in traditional manner, while only one misconception remained in the treatment group, after implementing the intervention program. It can be concluded that the applied intervention strategy proved to be very efficient in elimination of majority of misconceptions in the examined group of students.

Keywords: macroscopic; submicroscopic; symbolic; two-tier test; intervention strategy.

INTRODUCTION

The existence of students' home-made and school-made misconceptions has been widely described in the literature. Namely, in the last 30 years researchers have extensively worked on identification of common misconceptions among students at various levels of education.[1–8] As a result, the extensive material on students' misconceptions for almost every area of chemistry has been collected. Beside their identification, it has been worked on the collection of information about their features such as persistence. For instance, similar misunderstandings about thermal phenomena occur among adolescents, adults and natural scient-

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ists,[9] while well-known misconception that boiling water bubbles consist of air is present among students of different ages. Thus, Papageorgiou and Johnson[10] reported previously mentioned misconception for the age 10–11, Johnson[11,12] for the age 11–14, Hatzinikita and Koulaidis[13] for the age 10–18, Goodwin[14] for post-graduate science students, Chang[15] for trainee teachers.

Allen[16] states that misconceptions are likely to form a conceptual network, which contributes significantly to their persistence. Accordingly, removal of miconceptions is very slow and lengthy process and development of effective teaching models that could lead to the elimination of misconceptions, thus presents a significant challenge for educational researchers. It is worth noting that attempts to replace students' misconception with scientifically accepted ideas met with partial success.[16] On the other hand, development of such models is essential, since only by correcting misconceptions, existing knowledge structures can be further upgraded in scientifically acceptable form.

According to Posner *et al.*,[17] in order to transform misconceptions into scientifically acceptable concepts, there must be dissatisfaction with the existing concepts, or the inability to use them to explain new problems or situations. Furthermore, to be adopted, new concepts have to be more sensible, plausible and fruitful than the existing concepts.

The teacher and teaching methods, including chemical models and representations play an important role in finding explanations for abstract concepts. Nowadays, it is well-known and widely accepted that teaching which is based on the inter-correlation of levels of content representation represents a very important component of a meaningful understanding of chemical concepts.[18]

The first was Johnstone[19] who suggested a model of three levels of chemistry representation of matter, later referred to as: chemistry triplet, triplet relationship or Johnstone's triangle. These three levels are commonly named: *macroscopic* (perceptually available observations), submicroscopic (particles inaccessible to direct sensory observations) and symbolic level (representation of macroscopic or submicroscopic level). An ability to move between different levels presents an essential skill necessary for understanding natural phenomena.[20] The chemistry triplet represents one of the most extensively investigated areas in chemistry education, however, it should be mentioned that most research studies in this field were concerned mainly with identifying problems and misunderstandings, primarily in the submicroscopic level of content representation,[21–23] while a much smaller number of studies was devoted to finding effective strategies for their elimination. In relation to that, Georgiadou and Tsaparlis[24] proposed the so-called three-cycle method, which is based on a separate study of three levels of content representation. One-half of the total available teaching time is devoted to the macro-cycle, and then the second and the third cycle (symbolic and submicroscopic levels) are gradually introduced in the teaching process. In this research, it was showed that the greatest positive effect in the teaching process had a group of students trained by using this particular model. Bunce and Gabel[25] examined how the performance of students would be affected by the instruction based on three levels of representation of matter compared to instruction whereas only two representations were used (macroscopic and symbolic). It was obtained that students' achievements on the selected topics were greatly affected by the use of particulate nature of matter, that is, submicroscopic level. One of the teaching models that is based on the idea of Johnstone's triangle suggests that students first in the most basic form should study chemical concepts parallel in all three levels, and then following a rule of the spiral curriculum, teaching contents should be built up in all three levels, from grade to grade. According to this model, more students learn in the three levels of representation, more they will be able to connect information into a meaningful whole.[26] Jaber and BouJaoude[27] and Milenković, Segedinac and Hrin[28] suggest that carefully planned instruction based on macro–submicro–symbolic teaching significantly increases students' performance.

Therefore, from all the above described studies it can be clearly noted that processing the contents in three levels of representation with special emphasis on the submicroscopic level is necessary for a meaningful understanding of chemical concepts and formation of a flexible system of chemical knowledge.

METHODOLOGY

Aim of research

The main goal of this research was to identify misconceptions in the field of inorganic reactions among students trained in traditional manner and to examine whether the same misconceptions occur among students trained with the use of multiple levels of knowledge representation, *i.e.*, to determine whether the described intervention strategy provides the elimination of misconceptions among treatment group of students.

Sample

The primary study sample included 195 high school students (10^{th} school year), from 8 intact classes from two public urban general type grammar schools in Novi Sad, Serbia. The age range of the participants was 16–17 years. Upon applying the initial test for group equalization by students' performances achieved on the test, classes were divided into four experimental and four control classes thus forming two statistically equivalent groups *i.e.* E (experimental) and C (control) group ($t_1 = 4.70 > t(\alpha = 0.1) = 1.29$; $t_2 = 2.40 > t(\alpha = 0.1) = 1.29$). A total of 189 students (46.6 % male; 53.4 % female) were subjected to final testing while 6 students (1 from E and 5 from C group) were not present on the day of the final testing. Students from 8 classes were instructed by two licensed chemistry teachers. Each of the teachers taught in two experimental and two control classes. These two teachers participated in the study on a voluntary basis and were selected by authors of this research for possessing the following required competences: *i*) similar teaching experience, *ii*) achievement of optimal educational results and *iii*) familiarity with the concept of multiple levels of knowledge representation. Before conducting the research, the authors have had several meetings with selected teachers to make them additionally informed about the levels of knowledge representation and its application in the teaching process, but also to ensure that selected teachers are competent and motivated to participate in demanding and complex research. The selected teachers are very committed to improvement of teaching process. They are active participants of numerous seminars for teachers of chemistry, while as mentors-practitioners participate in the practical training of students, future teachers of chemistry.

In order to provide additional validity of the study, all classes, both experimental and control, were performed under supervision of one of the authors of the paper.

Data collection

In the Republic of Serbia grammar school education takes four years following a compulsory eight-year primary education. In general type grammar school chemistry is obligatory subject for all students. They are studying chemistry for four years (school year 9–12), with 2 classes (90 min) per week. During the first year, students are studying general chemistry, during the second year inorganic chemistry, during the third year organic chemistry, and during the fourth, final year, biologically important organic compounds. Practical training (laboratory practice) is not separately presented within curriculum, but it is an integral part in each teaching unit in a form of demonstration experiments performed by teacher.

This study was largely based on demonstration experiments which are predicted by the national curriculum. The research was conducted during the 2012−2013 school year. During the first semester both E and C groups were trained in the traditional manner with identical obligatory demonstration experiments. In this phase of the study, authors had no impact on the work of selected chemistry teachers. At the end of the first semester, the previously mentioned initial testing was conducted, with the goal of group equalization, and formation of experimental and control classes. In the next phase of the research, students in C group were trained in unchanged manner, while E groups students had been demonstrated identical experiments as their peers in C group, however, their analysis and discussion flowed taking into account multiple levels of knowledge representation. Students in group C were trained in traditional manner, which is characterized by weak inter-correlations among levels of representations. In group E, upon demonstration, teacher encourages students to present their observations (formation of gas, colored compounds, sedimentation, sound effect etc.), and then encourages them to explain the observed changes at the level of particles. At that point, teacher has a task to guide students toward correct response helping them to find the path to the correct answer. To achieve that, teacher uses molecular models, three-dimensional representations, charts and drawings and asks questions to held discussion at the level of particles. The additional role of teacher is to activate as many students as well as to involve them in active discussion. When students manage to realize the connection between visible and particulate, teacher directs them towards symbolic level, requesting them to represent the observed changes in form of chemical equations. In doing so, teacher helps students to understand the meaning of the symbols and to realize the symbolic relation with the macroscopic and submicroscopic level.

At the end of the second semester the final testing was conducted, and the results of that test are presented in this paper.

Diagnostic instrument

Multiple-choice questions (alone or in combination with other methods) are very popular technique for identifying students' misconceptions.[29-31] However, the effect of guessing the correct answer in these tasks is non-negligible, for instance, in the tasks with four options, the possibility of guessing the correct answer is 25 %. Therefore, in recent decades, researches have increasingly begun to apply the so-called two-tier diagnostic tests with tasks that comprise two parts.[32-37] First part of the task contains a question related to a problem statement (macroscopic or symbolic level), while other part provides possible explanations (submicroscopic level). In this research, final test contained 15 two-tiered tasks, each part of which comprised four offered answers, only one of which is correct. Thereby, the possibility of guessing the correct answer was reduced to only 6.25 %.

The items on the final test were related to experiments suggested by national curriculum that belong to the following topics: *i*) group 14 elements, *ii*) group 15 elements, *iii*) group 16 elements, *iv*) group 17 elements and *v*) transition metals. Preparation of the final test items required a prior detailed analysis and evaluation of students' responses obtained by initial testing upon which the authors classified the distractors with high choosing frequency to define areas of conceptual difficulties. Identified problems were related to poor understanding of the properties and behavior of submicroscopic particles resulting in the projection of visible macroscopic properties to submicroscopic particles, then poor understanding of the process of oxidation, but also with literal and incorrect interpretation of chemical symbols and formulas. On that basis, tasks on the final test were prepared to contain mentioned misunderstood concepts.

Items were evaluated for both correct and incorrect response combinations selected. On the basis of incorrectly chosen answers, possible misconceptions have been considered.

Criteria for evaluation of conceptual understanding

Within the analysis of misconceptions, frequency of selecting the individual answers have been considered. According to the literature, a response represented as a distractor can be considered a misconception if it is chosen by more than 20 % of the respondents.[33,38,39] On the other hand, correct answers given by approximately 75 % of the students (for items with four options) can serve as an indicator of the satisfactory conceptual understanding (SCU). Frequency of choosing the correct answer in a range 50–74 % represent a roughly adequate performance (RAP). Furthermore, 25–49 % frequency indicates inadequate performance (IP), while obtained frequency less than 25 % represents quite inadequate performance (QIP).[40]

Test psychometrics

According to the data available in literature, test assurance parameters were evaluated on the combined sample (N = 189) and included calculations of: Cronbach α, item-total correlations, item difficulty and item discrimination indices. Since two-tier items were considered as paired items, mentioned parameters were calculated for a total of 15 items, and data were converted to binary data (1 point for both tiers correct and 0 points for incorrect or partially correct tiers).

The collected data were processed in Microsoft Office Excel and IBM SPSS Statistics 20. The reliability of the applied test was examined by two methods: *i*) internal consistency using Cronbach α parameter and *ii*) item-total correlation, using the Pearson's correlation coefficient. The obtained Cronbach α value (α = 0.89) exceeded benchmark of 0.70,[41] indicating very good reliability. Results of item-total correlation (r is in a range 0.31–0.70) indicate that all items contribute to the reliability of the test. Namely, based on values obtained for Pearson correlation coefficient, two tasks (14 and 15) could be described as appropriate ($0.30 < r < 0.39$), while the remaining thirteen as quite appropriate ($r > 0.40$) for further analysis.

In addition, the mean difficulty index for 15 items is 0.39, while item difficulty indices range from 0.18–0.56. Difficulty index values for three items are less than 0.30 which characterize them as difficult, while remaining 12 items have difficulty index ranging from 0.30–

–0.56 and therefore can be considered as moderately difficult. Discrimination index was calculated using 27 % cut-off. For the index of test discrimination, a value of 0.70 has been obtained, indicating very good discrimination. For individual tasks, it varies in the range of 0.33 to 0.96. According to Towns,[42] discrimination index greater than 0.40 is an indicator of excellent item with high discrimination. In this test, 13 tasks meet this criterion. Discrimination indices in the range 0.20–0.40 indicate that the item is good and there are two such tasks on the test. Item analysis showed that this test does not contain items with $0.00 < Id < 0.20$ (the tasks that are unacceptable and need to be discarded or revised), nor the tasks with the negative value of index discrimination (the tasks that are flawed or not keyed correctly).

Item validity was established through expert validation. The expert group consisted of seven experts: 2 university professors and 3 researchers in the field of chemical education, 1 university professor of pedagogy and 1 chemistry teacher in secondary education.

RESULTS AND DISCUSSION

The percentage of correct answers on the final test (for E and C group) only for the first tier and combined for both tiers are shown in Table I. As can be observed from the table, achievements of E group students were significantly higher in comparison to the achievements of C group students regardless of whether only the content results were considered ($t = 10.15$; $p = 0.00$) or results for both tiers ($t = 7.41$; $p = 0.00$). On the other hand, it is important to note that students' achievements in the content part are higher than the achievements for both tiers in both examined groups.

TABLE I. The percentage of choosing the correct answers for both tiers

Task	E		C	
	First tier	Both tiers	First tier	Both tiers
1.	74.47	72.34	41.05	31.58
2.	81.91	61.70	50.53	30.53
3.	86.17	77.66	49.47	34.74
4.	63.83	60.64	43.16	16.84
5.	72.34	58.51	45.26	23.16
6.	68.09	45.74	40.00	14.74
7.	85.11	68.09	31.58	15.79
8.	75.53	71.28	37.89	31.58
9.	72.34	56.38	41.05	25.26
10.	88.30	74.47	48.42	22.11
11.	68.09	51.06	36.84	11.58
12.	80.85	79.79	34.74	18.95
13.	45.74	35.11	25.26	9.47
14.	87.23	26.60	31.58	9.47
15.	92.55	27.66	33.68	10.53
Mean	76.17	57.80	39.37	20.42

Identification of misconceptions

Table II summarizes all identified misconceptions, with specified distractor choosing frequencies, which indicate the existence of misconception.

TABLE II. Comparative review of misconception by groups

Misconception	Task	Distractor indicating a misconception	Frequency of choosing distractors, %		Frequency of choosing correct answer, %		Evaluation of understanding	
			E	C	E	C	E	C
Attributing macroscopic properties to submicroscopic particles	1	Chloride ions are green	8.5	24.2	80.9	48.4	SCU	IP
	4	Collisions of molecules in the solid phase are explosive	10.6	21.1	63.8	38.9	RAP	IP
	6	Micropores of activated carbon contain gas molecules of which have an unpleasant odor	12.8	26.3	66.0	34.7	RAP	IP
	12	Potassium ions are blue	10.6	21.1	81.9	38.9	SCU	IP
Oxidation-reduction reactions	3	In the burning process, red phosphorus molecules decompose to atoms	5.3	26.3	80.9	47.4	SCU	IP
	13	Permanganate ion readily loses an electron in an alkaline environment	26.6	30.5	47.9	25.3	IP	IP
Interpretation of symbolic representations	9	Molecules of hydrogen	12.8	24.2	60.6	37.9	RAP	IP
	5	are formed in reaction	13.8	24.2	70.2	34.7	RAP	IP
Particles	8	Molecule of potassium permanganate is stable at increased temperatures	2.1	23.2	77.7	45.3	SCU	IP

The first type of misconceptions involved attributing macroscopic properties to submicroscopic particles. This type of misconception arises in the tasks: 1, 4, 6 and 12.

The first task was related to the chemical reaction of calcium carbonate and dilute hydrochloric acid. In the first tier of the task, students were expected to recognize a visible change that occurs during the reaction, while in the second tier they were expected to choose a logical explanation for the visible change selected in the first tier.

Based on the obtained results it can be noted that large percentage of C group students believe that chloride ions are green. On the basis of this response it can be assumed that students have transferred macroscopic property of chlorine gas to its submicroscopic particles (chloride ions). This is in a line with previous research,[26,31,43,44] which reported that students tend to attribute visible macroscopic properties of a substance to its submicroscopic particles in a number of examples. In contrast to the group C, the results show that the E group students do not possess the aforementioned misconception, but SCU of the examined content.

The task No. 4 was related to the obtaining ammonia by reaction of ammonium chloride and calcium hydroxide. In the C group there was a large percentage of students who believed that the collisions of molecules in the solid phase are explosive. It has been reported that students believe that molecules of solids are harder than molecules of liquids and gases, and larger in size (cited by Horton[45]) therefore, C group students in this study could believe that collisions of such particles are accompanied by the loud sound. E group students elected this distractor in significantly lower percentage.

The task No. 6 was related to the experiment "Testing the properties of activated carbon". In this task E group students achieved significantly higher achievement than their peers in the group C as well, showing RAP. On the contrary, a large percentage of C group students believed that the activated carbon in its micro-pores contains gas, molecules of which have an unpleasant odor. Four questions on the test were related to the experiment "Chemical chameleon" (the reaction of potassium permanganate and sucrose in an alkaline medium). In the first tier of the tasks students were expected to possess descriptive knowledge about colors observed at different stages of the experiment, while in the second tier they were expected to explain the observations by the existence of certain particles in solution.

In the task number 12, students were expected to relate purple color of potassium permanganate to the presence of permanganate ions. However, a large percentage of C group students did not have a satisfactory level of descriptive knowledge about the color of an aqueous solution of potassium permanganate, while in the second tier 21.1 % of the students stated that potassium ions are blue, which once again confirmed misconception observed in the task 1.

The following type of misconception referred to oxidation-reduction reactions. The third task was related to reaction of combustion of red phosphorus. A large number of students from the E group identified the correct answer that air oxygen oxidizes phosphorus, to form molecules of phosphorus(V) oxide, while a large number of C group students considered that in this reaction phosphorus molecules decompose into atoms. The explanation for this could be found in the fact that in the above reaction only one reactant (red phosphorus) is visible, while oxygen is not directly perceptually available. This is in line with the conclusions reached by Schmidt,[31] who examined misconceptions in the field of combustion reactions. Namely, the author has found that students believe that oxygen supports combustion process, but it does not participate. Besides, it is found that students consider combustion rather as process of releasing heat, which destroys the substance, than type of reaction (cited by Horton[45]). In the thirteenth task, which refers to the experiment "Chemical chameleon", a large percentage of both group students believed that oxidation of potassium permanganate takes place in the reaction. Based on obtained results it can be concluded that students of both groups did not sufficiently mastered the concept of oxidation-reduction reactions. A large number of research studies, which dealt with misconceptions in the field of oxidation–reduction reactions were primarily focused on the difficulties that students have in identifying the oxidation-reduction reaction.[46,47] According to Rosental and Sanger[48] the cause of such misunderstandings could be found in the existence of many definitions of oxidation-reduction reactions in chemistry textbooks and their application by teachers. The above-mentioned authors, state several definitions of oxidation and reduction, which can be considered the cause of misconceptions among students: *i*) method of electrons (oxidation – losing electrons, reduction – receiving electrons), *ii*) method of oxidation number (oxidation–oxidation number increases, reduction–oxidation number decreases), *iii*) method of oxygen (oxidation – number of oxygen atoms increases, reduction – number of oxygen atoms decreases) and *iv*) method of hydrogen (oxidation – number of hydrogen atoms decreases, reduction-number of hydrogen atoms increases), etc. Since the same problem is present within education system in the Republic of Serbia, it could be considered as one of the possible causes of poor performance in this task. The results showed that E group students have achieved IP in this area as well.

Difficulties related to the interpretation of symbolic representations were found in the tasks number 5 and 9. These tasks are related to the knowledge of chemical equations and require developed capacity of their interpretation. In the fifth task, it was necessary to identify the equation which describes the reaction of ammonium chloride and calcium hydroxide, and in the ninth task equation which describes thermal decomposition of potassium permanganate. In both tasks in the level of explanation a large percentage of C group students stated that molecules of hydrogen are product of the reaction, although in the task number 5 only a small percentage of students selected the equation in which H_2 was shown as product of reaction, while in the ninth task, H_2 was not even listed as a reaction product within the offered equations.

Considering task number 8, one misconception was observed. This task shows that students have ambiguities regarding structure of potassium-permanganate. Namely, similar to other studies[36,49] which found that students thought that sodium-chloride exists as molecules, this study showed that students believed that fundamental particles of potassium-permanganate are also molecules. According to Othman *et al.*[36] this is one of the prevalent conception that bonded substances are commonly in the form of molecules. This misconception was observed only in the group C, while E group students did not exhibit this misconception, on the contrary, they showed SCU.

At the end, we should briefly comment on tasks number 14 and 15 which, as mentioned earlier, refer to the experiment "Chemical chameleon". Namely, almost all offered distractors in these tasks, for both groups were selected with a percentage higher than the value which indicate the existence of a misconception. Thus, it can be concluded that examined students poorly mastered these concepts, because of which they were choosing answers randomly. Since guessing was most likely the method of selecting answers in these two tasks, they will not be commented in this paper.

However, based on overall results presented, it can be concluded that E group students have acquired better understanding of the tested contents.

CONCLUSIONS AND LIMITATIONS

Results of the study have indicated that the instruction based on the intercorrelation of levels of content representation were efficient in the elimination of a large number of misunderstandings commonly encountered among students trained in the traditional manner, in the field of inorganic reactions. These results suggested that students who were trained through the application of triplet model of knowledge representation were able to effectively cope with some abstract concepts that could be labeled as common misconceptions. However, it is important to note that certain misconceptions still retained among treatment group of students, and these are misconceptions related to the oxidation–reduction reactions. Therefore, further work with special emphasis on redox reactions is necessary.

Regarding the limitations of the study, it is important to mention the type of questions applied in the test. Namely, in this study exclusively multiple-choice tasks in the form of a two-tier tasks have been used. Although these tasks have a number of advantages over traditional multiple choice tasks, such as reduced possibility of guessing the correct answer and the introduction of an additional tier in the task with meaningful distractors, which assesses understanding of the content, one must take into account the fact that in such tasks answers are offered in advance, which can enable students to recall the correct response, instead of using complex cognitive processes, critical thinking skills and linguistic expression.

Finally, considering teaching practice, it is important that teachers become aware of the misconceptions that students possess and to devote more effort to apply appropriate methods and instructions suggested by various researchers to prevent misconceptions, which is of a great importance since proper formation of basic chemical concepts affects students' future learning.

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ИЗВОД

УТИЦАЈ ИНСТРУКЦИОНЕ СТРАТЕГИЈЕ ЗАСНОВАНЕ НА ТРИПЛЕТНОМ МОДЕЛУ РЕПРЕЗЕНТАЦИЈЕ САДРЖАЈА НА ЕЛИМИНАЦИЈУ УЧЕНИЧКИХ МИСКОНЦЕПЦИЈА ВЕЗАНИХ ЗА НЕОРГАНСКЕ РЕАКЦИЈЕ

ДУШИЦА Д. МИЛЕНКОВИЋ, МИРЈАНА Д. СЕГЕДИНАЦ, ТАМАРА Н. ХРИН и САША ХОРВАТ

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Недавно је извешћено о ефикасној наставној инструкцији заснованој на интеграцији макроскопског, субмикроскопског и симболичког нивоа репрезентације знања, са становишта перформанси и менталног напора. На основу добијених резултата, постављен је циљ овог истраживања, а то је да се идентификују мисконцепције код групе ученика обучаваних на традиционалан начин и утврди да ли се исте мисконцепције јављају и међу ученицима експерименталне групе у области неорганских реакција. У истраживању је коришћен тест који је решавало 189 ученика другог разреда гимназије. Анализа је спроведена рачунањем фреквенција бирања дистрактора у задацима. Резултати су указали на постојање укупно 9 мисконцепција у групи ученика обучаваних на традиционалан начин, док је само једна мисконцепција уочена у експерименталној групи, након спровођења интервентног програма. Може се извести закључак да се примењена инструкциона стратегија показала као веома ефикасна у елиминацији највећег броја мисконцепција код испитиване групе ученика.

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