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Identifying and Analyzing the Misconceptions Associated with the Concept of Chemical Equation

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Abstract

Education research results point to frequent misconceptions of basic chemical concepts among students at all levels of education. One reason for this is the abstract nature of the subject, which requires higher cognitive abilities of students in the learning process. Considering these insights, research was conducted with the aim to identify and analyze students' misconceptions associated with the concept of chemical equation. The results served to design and implement a quasi-experiment aiming to enhance teaching of the mentioned concept, which is presently under way. The research, conducted in December 2013, included 357 eighth grade students from several primary schools. Multiple-choice questions were used in assessing the ability of associating two different ways of presenting a chemical reaction, namely chemical equation and particulate drawing. Analysis of the collected data revealed different misconceptions associated with insufficient understanding of the concepts of atom and molecule, stoichiometric number and index, reaction system and elementary reaction, and difficulties in applying the law of conservation of mass. The research results emphasize the value of particulate drawing as a teaching tool whose application in assessing knowledge enables an analysis of the conceptual understanding of the chemical equation.

Key words: *basic chemical concepts; chemical equation; misconception; particulate drawing.*

Introduction

Given the complexity and abstract nature of the majority of basic concepts in chemistry, special attention should be paid to their teaching and acquisition as early as in primary school. The study and teaching of chemistry should occur at three levels: the macroscopic, the submicroscopic (particulate) and the symbolic level (Johnstone, 1990). The majority of teachers teach chemical changes using student or demonstration experiments (macroscopic level) which is then explained at the symbolic level with chemical symbols, formulas and chemical equations, omitting the association of these two levels with the particulate level (Lee, 1999). Insufficient representation of the particulate level in chemistry teaching is one reason why misconceptions occur. They can be observed in different areas of chemistry, including *properties of matter* (Barke, Hazari & Yitbarek, 2009, Sanger, 2000; Stains & Talanquer, 2000, Taber, 2002), *chemical bonds* (Coll & Treagust, 2003; Taber, 1994), *chemical reactions* (Kern, Wood, Roehrig, & Nyachwaya, 2010; Nyachwaya, Mohamed, Roehrig, Wood, Kern, & Schneider, 2011) and *acids and bases* (Devetak, Drofenik Lorber, Juriševič, & Glažar, 2009; Nakhleh & Krajcik, 1994).

Previous research has shown that beginning chemistry students already have many preconceived notions of the nature surrounding them. These preconceptions, which are based on previous physical experience and social surroundings, differ from the concepts taught by the existing scientific theory and practice. It happens that a student does not associate new knowledge with previously acquired experiential knowledge. As a result, one way of thinking is applied when solving scientific problems and another in everyday life. If new and old knowledge are not connected in one's memory, new information is easily and quickly forgotten. Frequent repetition and application of new concepts is what anchors them in the existing knowledge. Teachers often use metaphor or analogy in an attempt to vividly explain a concept to their students. However, metaphorical language depends on students' sophisticated language skills, the absence of which can contribute to the emergence of misconceptions (Taber, 2002). Sometimes students change the meaning of the teacher's words in order to fit them into their existing conceptual frame, and neither side is aware of this before knowledge assessment (Talanquer, 2006, p. 811). Misconceptions often emerge from wrong or inadequate representations in chemistry textbooks (Taber, 2002). It should be noted that teachers are not "immune" to misconceptions either, and this can significantly influence student understanding of chemical concepts (De Jong, Acampo, & Verdonk, 1995; Papageorgiu & Sakka, 2000).

The mentioned issues often occur in teaching of the particulate nature of matter, an abstract and fundamental chemical concept underpinning the understanding of other chemical concepts (Ben-Zvi, Eylon, & Silberstein, 1986). As we are not able to see atoms, molecules and ions, their relationships and interactions, we rely on models when describing and explaining the particulate nature of matter (Bridle & Yezierski, 2012). Models are not an ideal reflection of reality but a means focused on important segments relevant for the demonstration of some phenomenon. Because of their limitations, they should be carefully used in teaching and combined with other teaching tools and models. In this way students can get a comprehensive and scientifically established insight into a chemical occurrence.

In teaching chemistry, teachers use particulate drawings, two-dimensional models that help students visualize the invisible world of particles. Prillman (2014) emphasizes that the teacher must familiarize students with the limitations of the particulate drawing as they often view it as true copy of reality. For the purpose of this research particulate drawing was used as a tool in identifying and analyzing the misconceptions of chemical equations among eighth grade students of primary school.

Chemical equation represents a fundamental concept whose understanding is not possible unless acquired from a number of other concepts. Numerous studies confirm students' difficulties in understanding the concept of chemical equation. Difficulties are manifested in the inability to differentiate an atom and a molecule (Wood & Breyfogle, 2006), differentiation of an index and a stoichiometric number (Mulford & Robinson, 2002; Sanger, 2005; Yarroch, 1985), and in the interpretation of symbols (Kelly, Barrera, & Mohamed, 2010; Kern et al., 2010; Wood & Breyfogle, 2006). Furthermore, it was observed that the majority of students who manage to write a correct chemical equation using algorithmic laws are still unable to predict the products of the chemical reaction or draw an accurate particulate drawing representing it (Davidowitz et al., 2010; Hinton & Nakhleh, 1999; Nyachwaya et al., 2011).

Taking into consideration the above-mentioned findings and the lack of data on the situation among Croatian students regarding their understanding of the said concept, a comprehensive study was devised aiming to identify, analyze and improve the teaching of the concept of chemical equation. In this paper the diagnostic part of research is presented, offering an answer to the following research question:

What are the most frequent misunderstandings of eighth grade students related to the concept of chemical equation?

Methods

Participant Sample

The sample in this research was not random, but a convenient sample of eighth grade students in primary schools. The research was conducted in eight primary schools in Croatia (Table 1) with a total number of 357 participants. The majority of participants were students of varied socio-economic status living in urban areas. Gender representation was balanced, with 173 boys and 184 girls.

Table 1
Overview of participant count per school

Primary School	Number of students
Primary school Split 3-Split	68
Primary school Mertojak-Split	41
Primary school Sućidar-Split	92
Primary school Mejaši-Split	20
Primary school Spinut-Split	61
Primary school Silvije Strahimir Kranjčević-Lovreć	11
Primary school Trilj-Trilj	25
Primary school Đurmanec-Đurmanec	39
Total	357

Instrument and Procedure

The research was conducted as a non-experimental investigation of students' current knowledge. In the Republic of Croatia, the concept of chemical equation is taught to students in the introductory year of chemistry (7th grade of primary school). In the framework of this research teachers selected the didactic strategies for their lessons in accordance with the teaching methodology recommendations from the Croatian National Education Standard (HNOS) and the National Curriculum (PiP), which were issued in 2006 by the Croatian Ministry of Science, Education and Sports. Teachers did not use particulate drawings in their lessons or in the knowledge assessment phase.

The instrument used for data collection in December 2013 was a written test of knowledge (*Written assessment of chemical equation comprehension using particulate drawing*), which contained two conceptual multiple-choice tasks designed by the authors of this study and one multiple-choice task published in education literature. The test was peer-reviewed by three primary school chemistry teachers, one university professor of chemistry teaching methodology and one university professor of chemistry. The multiple-choice tasks tested students' ability to associate two manners of presenting chemical change, one being a symbolic inscription of the chemical equation (the most frequent representation) and the other a particulate drawing (visualization of the submicroscopic level of chemical change). The distractors were selected based on students' misconceptions described in previous literature.

The analysis of misconceptions covered descriptive data of selected answers within a task. Based on the results of multiple-choice tasks, it is possible to establish the presence of misconceptions and the level of conceptual understanding of particular concepts. According to literature (Dhindsa & Treagust, 2009; Gilbert, 1977; Milenković, 2014), a distractor is considered a misconception if more than 20% of test takers select it between four or more answer options in a task. The correct answer can be used as an indicator of sufficient understanding of a concept if chosen by 75% or more participants. A somewhat satisfactory effect is ascribed to the frequency of correct answers in the 50-74% range. If the correct answer in a given task is chosen by only 35-49% test takers, the learning effect is considered to be rather poor. Furthermore, if the correct answer is chosen by less than 25% of test takers, the effect is poor (Gilbert, 1977).

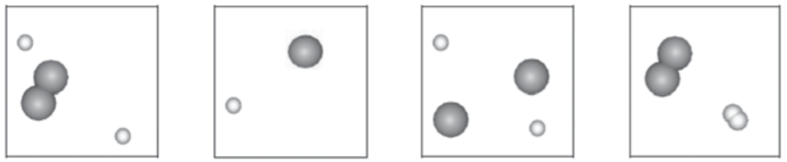
Results

In the first task, students were asked to indicate the particulate drawings of reactants and reaction products after the synthesis of hydrogen chloride from elementary substances as described in the chemical equation (Figure 1).

Hydrogen chloride is a product of a hydrogen and chlorine reaction. The described change is represented by the chemical equation: $\mathbf{H_2 + Cl_2 \rightarrow 2\ HCl}$

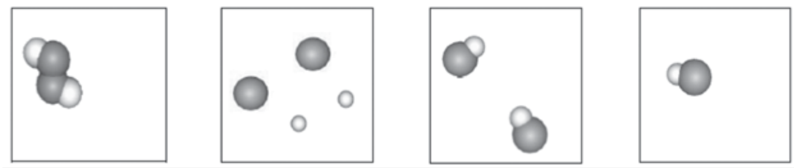
Legend: ○ model of a hydrogen atom; ● model of a chlorine atom

TASK 1. A Which particulate drawing accurately shows the reactants from the above mentioned chemical equation? Circle the letter next to the correct drawing.



A B C D

TASK 1. B Which particulate drawing accurately shows the products from the chemical equation shown above? Circle the letter of the correct drawing.



A B C D

Figure 1. Conceptual multiple-choice task, symbolic and particulate representation of chemical change in the preparation of hydrogen chloride from elementary substances

Task 1. A

Based on the frequency of selecting the correct answer D in this task, we can conclude that students have a satisfactory conceptual understanding (*f*>75%). The percentage of students' selection of distractors in this item is significantly under 20%, which indicates an absence of misunderstandings (Table 2).

Selection of incorrect answers A, B and C by a smaller percentage of students points to their incomprehension of the concepts of atom and molecule, as well as failure to differentiate between a stoichiometric number and an index. Drawing A shows the correct number of reactant atoms, but an incorrect symbolic inscription H_2. Drawing B presents the molecules of elementary substances incorrectly, and drawing C, while giving the correct number of reactant atoms, does not match the symbolic inscription of the chemical equation, showing molecules of elementary substances as reactants.

Table 2

Distribution of selected answers for tasks 1A and 1B

Task	n	Number (%) of answers				
		A	B	C	D	No answer
1.A	357	8(2.3)	15(4.2)	36(10.1)	**295(82.6)**	3(0.8)
1.B	357	91(25.5)	20(5.6)	**221(61.9)**	12(3.4)	13(3.6)

Task 1.B

A high percentage of students selected the correct answer, C, based on which we can conclude that conceptual understanding of content is nearly sufficient (Table 2). Distractor A, indicating the failure to differentiate between a stoichiometric number and an index, was selected by more than 20% of students, thus signifying a misconception. Answer A shows an agglomerate H_2Cl_2 instead of 2 HCl, two molecules of hydrogen chloride.

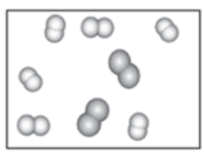
Answer B represents the product in atomized form and indicates a misunderstanding of the concept of the chemical compound molecule. Answer D shows one instead of two molecules of hydrogen chloride, which does not comply with the law of conservation of mass for the observed chemical equation. Furthermore, this answer indicates lack of understanding of the concept of stoichiometric number.

Task 2

The second task (Figure 2) required students to relate the particulate reaction system[1] drawing prior to the change with the symbolic inscription of the elementary reaction. They were also asked to identify the particulate drawing of the situation after the chemical reaction. This task is considered to be conceptually more demanding because the reaction system in its initial stage numbers twice as many reactant molecules as the number indicated in the chemical equation.

The particulate drawing shows **reactants**, N_2 and H_2 in a closed container.

Legend: ● model of a nitrogen atom ○ model of a hydrogen atom;



Assume that the matter presented above reacted entirely according to the chemical equation:

$$N_2(g) + 3\,H_2(g) \rightarrow 2\,NH_3(g)$$

Which of the particulate drawings **A–E** accurately shows the number and type of particles **after the reaction**?

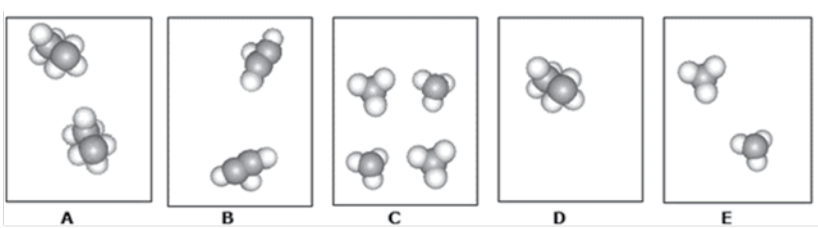


Figure 2. Conceptual multiple-choice task, the number of molecule reactants in the particulate drawing of the reaction system is sufficient for two elementary reactions described with the corresponding chemical equation

[1] A reaction system presented in a particulate drawing represents only the type and numerical ratio of particles present in the real system.

Only 14.3% of students selected the correct answer, C (Table 3). The very poor result indicates students' failure to comprehend the content conceptually. A large number of participants (*f*>20%) selected the distractors A and E, which can therefore be considered as misconceptions.

Table 3
Distribution of selected answers in task 2

n	Number (%) of answers					
	A	B	**C**	D	E	No answer
357	97(27.2)	42(11.8)	**51(14.3)**	36(10.1)	109(30.5)	22(6.1)

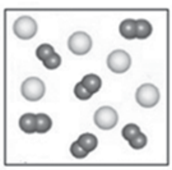
The selection of answers A, B and E, which respectively represent two molecules of the product as written in the chemical equation, reveals that students fail to understand the chemical equation inscription as a representation of an elementary reaction occurring many times in a reaction system. The majority of students opted for answer E, indicating they were guided by the number of product molecules in the chemical equation inscription, and not by the "number of reactive particles in the system". Answer D is indicative of a thinking pattern congruent to the one in answer E, but with an additional misconception related to stoichiometric number and its role in the chemical equation. Although answer D shows a non-existing particle N_2H_6, 10.1% of students selected that answer. The selection of answers B, D, and E indicates that 52.4% of students fail to apply the law of conservation of mass correctly.

Task 3

The most demanding conceptual task in the written assessment of knowledge was taken from the test by Mulford and Robinson (2002) and examines the concept of the limiting reactant (Figure 3). Although this concept is not included in the primary school curriculum, students are expected to successfully solve the task, provided they understand the chemical equation as a representation of an elementary reaction, which can occur more than once in a reaction system. After applying the law of conservation of mass, students should note that sulphur is the reactant in excess and oxygen the limiting reactant.

The particulate drawing represents **reactants**, S and O_2 in a closed container.

Legend: ◯ model of a sulphur atom ● model of an oxygen atom;



Assume that the presented particles reacted according to the chemical equation:

$$\mathbf{2\,S + 3\,O_2 \rightarrow 2\,SO_3}$$

Which of the particulate drawings **A-E** accurately shows the number and type of particles **after the reaction?**

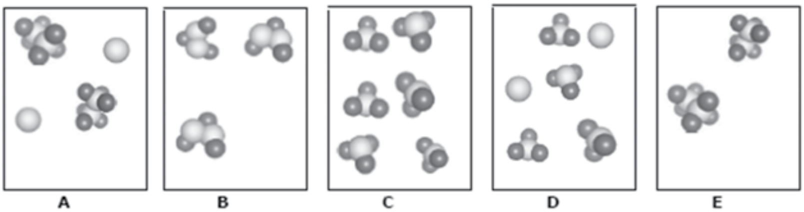


Figure 3. Conceptual multiple choice task involving the concept of limiting reactant in a reaction system

Similarly to the second task, the frequency of the correct answer D (19.1%) indicates a lack of conceptual understanding of the content (Table 4).

The correct answer in this task was chosen by 11.0% of students in a study by Mulford and Robinson (2002) and by 10.3% in research conducted by Wood and Breyfogle (2006). In a more recent study by Kimberlin and Yezierski (2016) 14.1% of students selected the correct answer.

Table 4

Distribution of selected answers in Task 3

n	Number (%) of answers					
	A	B	C	**D**	E	No answer
357	79(22.1)	25(7.0)	30(8.4)	**68(19.1)**	119(33.3)	36(10.1)

Answers A and E include representations of two molecules of the product (non-existing particles S_2O_6 as a false equivalent of the chemical inscription 2 SO_3), which correspond to the stoichiometric number 2 in the chemical equation and are the key reason for the frequent choice of the two answers. Students who selected answer A also observed that sulphur is the reactant in excess.

The least represented answer was distractor B. Choice of the non-existent product 3 S_2O_3 indicates the failure to differentiate between a stoichiometric number and an index.

Slightly more frequent was answer C, which gives an accurate representation of the molecule of the product SO_3, but in it no consideration is taken of oxygen as the limiting reactant, and sulphur as the reactant in excess.

A high percentage of students (48.7%) selected answers B, C and E, in which the law of conservation of mass was not applied.

Discussion

Students' answers to selected tasks provide a good insight into their ability to relate symbolic representations of chemical changes in a chemical equation with the representation at submicroscopic level of the same change using particulate drawings.

Students attempt to link the symbolic representation and particulate drawing using wrong algorithms. Based on the frequency of answers A and E in tasks 2 and 3, a similar pattern of misconceptions related to some aspects can be observed. Students lack proper understanding of the stoichiometric number (i), the index in the chemical formula (ii) and the chemical equation representing unit transformation in the reaction system (iii). Similar percentages of answers 2E and 3E indicate that almost one third of students do not understand the entry (iii). Answer 3E alone could not lead to this conclusion, because it does not rule out the possibility of students having problems only with entries (i) and (ii). Answer 3E alone could not lead to this conclusion, because it does not rule out the possibility of students having problems only with entries (i) and (ii) as answers 2A and 3A. Comparative results of identified misconceptions are shown in Table 5.

Table 5

Misconceptions identified in the written assessment of knowledge

Task	Misconception	%
1B	Failure to differentiate between an index and a stoichiometric number	28.9
2	Failure to differentiate between an index and a stoichiometric number	49.1
	Incorrect application of the law of conservation of mass	52.4
	Failure to differentiate between a chemical equation and a reaction system	69.5
3	Failure to differentiate between an index and a stoichiometric number	62.4
	Incorrect application of the law of conservation of mass	48.7
	Failure to differentiate between a chemical equation and a reaction system	55.4

Failure to differentiate between an index and a stoichiometric number is identified in all three tasks. This misconception is often reflected in the representation of molecules in the form of aggregates. The tendency of students towards such a representation of the chemical reaction was observed in previously conducted research with similar conceptual tasks. Davidowitz, Chittleborough, and Murray (2010) report in their paper that 12.8% of first year natural sciences students presented molecules of water as aggregates (H_4O_2 instead of 2 H_2O), and 19% of them grouped molecules of ammonia (2 NH_3) into one particle, N_2H_6. The same pattern of thinking was observed in studies conducted by Mulford and Robinson (2002) and Kimberlin and Yezierski (2016). More than half of the students in their assessment chose the symbolic representation S_2O_6 instead of SO_3. Increased task complexity results in a higher percentage of wrong answers, indicating student failure to differentiate between an index and a stoichiometric number. In such tasks students need to apply more complex concepts such as the limiting reactant, and to differentiate between the chemical equation and the reaction system. As concepts (i) and (ii) are not yet fully grasped by learners, they fail to choose the right answers.

The percentage of students failing to apply the law of conservation of mass in the tasks is high and constant. This misconception is not recognized in the first task, where all distractors represent an equal number of particles both in the chemical equation and the reaction system. Mulford and Robinson (2002) found that 65.0% of students in their research selected answers in which the law of conservation of mass was not applied.

The dominant misconception in the second and the third task is the failure to differentiate between the chemical equation and the reaction system. Particulate drawing served as a useful tool in identifying this.

A quasi-experiment was carried out on another sample of eighth grade students in the pre-test phase and prior to the implementation of the selected teaching strategy. Its results completely correspond to the results of this diagnostic research (Šimičić & Mrvoš-Sermek, 2016).

Conclusion

The manner in which knowledge is constructed in students' minds is a process that rarely enfolds according to our expectations. This leads to the necessity of seeking and developing more appropriate tools for the purpose of testing and analyzing chemical concepts and diagnosing misconceptions. In this research issues were observed in establishing associations between the symbolic inscription representation of chemical change and the particulate drawing showing the same change at submicroscopic level. Algorithmic knowledge alone applied by students when writing a chemical reaction equation is not enough for them to conceptually understand the chemical changes at particulate level. Students showed satisfactory conceptual understanding in the task where the number of particles in the symbolic inscription matched their number in the particulate drawing at submicroscopic level. On the contrary, tasks in which this was not the case revealed students' failure to understand the chemical equation as unit transformation, which can occur more than once in a reaction system or, more precisely, as many times as determined by the limiting reactant. Issues identified in this study pertain to the misunderstanding of the concepts of atom and molecule, failure to differentiate between a chemical equation and a reaction system, as well as between a stoichiometric number and an index, and lastly, failure to apply the law of conservation of mass. The findings correspond to the issues identified in previous research: the same misconceptions were observed among participants who were taught using various didactic strategies in various education systems. The misconceptions identified here are very long-lasting and deep-rooted: they are developed in the initial learning phase and are often retained even after years of formal chemistry education. The results of this research emphasize the value of the particulate drawing as a teaching tool, which enables the analysis of conceptual understanding of the chemical equation in student knowledge assessment. Furthermore, the results indicate a necessity of adjusting the teaching strategies so as to improve students' conceptual understanding of the basic chemistry concepts. As such, they serve as a foundation for further research in developing the procedures and methods for the purpose of improving both teacher competencies and student operational knowledge with the use of particulate drawings.

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Kako prepoznati i analizirati pogrešna shvaćanja povezana s konceptom jednadžbe kemijske reakcije?

Sažetak

Rezultati edukacijskih istraživanja ukazuju na učestalost pogrešnih shvaćanja temeljnih kemijskih pojmova kod učenika svih obrazovnih razina. Uzrok tome je i apstraktna priroda nastavnog predmeta koja od učenika zahtijeva više kognitivne sposobnosti pri usvajanju sadržaja. Uzimajući u obzir te spoznaje, provedeno je istraživanje čiji je cilj bio prepoznati i analizirati pogrešna shvaćanja učenika povezana s konceptom jednadžbe kemijske reakcije. Rezultati ovog istraživanja poslužili su za osmišljavanje i provedbu kvazieksperimenta s ciljem unaprjeđenja poučavanja navedenog koncepta, koje je u tijeku. U istraživanju koje je provedeno u prosincu 2013. godine sudjelovalo je 357 učenika osmih razreda osnovnih škola. Zadatcima višestrukog izbora provjeravana je sposobnost povezivanja dvaju načina prikaza kemijske promjene, jednadžbom kemijske reakcije i čestičnim crtežom. Analizom prikupljenih podataka uočena su različita pogrešna shvaćanja povezana s nerazumijevanjem pojmova: atom i molekula, stehiometrijski broj i indeks, reakcijski sustav i elementarna pretvorba, kao i poteškoće primjene zakona o očuvanju mase. Rezultati ovog istraživanja ističu vrijednost čestičnog crteža kao nastavnog alata čija uporaba pri provjeri znanja omogućava analizu konceptualnog razumijevanja jednadžbe kemijske reakcije.

Ključne riječi: *čestični crtež; jednadžba kemijske reakcije; pogrešna shvaćanja; temeljni kemijski pojmovi.*

Uvod

Većina je temeljnih kemijskih koncepata složena i apstraktna pa posebnu pozornost treba posvetiti njihovu usvajanju i razumijevanju već u primarnom obrazovanju. Učenje i poučavanje kemije trebalo bi se odvijati na tri razine: makroskopskoj, submikroskopskoj (čestičnoj) i simboličkoj razini (Johnstone, 1990). Poučavanje kemijskih promjena većina nastavnika temelji na učeničkom ili demonstracijskom pokusu (makroskopska razina) koji se potom objašnjava na simboličkoj razini primjenom kemijskih simbola, formula i jednadžbi kemijske reakcije pri čemu izostaje povezivanje tih dviju razina s čestičnom razinom (Lee, 1999). Nedovoljna zastupljenost te razine u nastavi jedan je od uzroka nastanka pogrešnih shvaćanja. Uočena su u različitim područjima kemije uključujući *građu tvari* (Barke, Hazari, i Yitbarek, 2009, Sanger, 2000; Stains i Talanquer, 2000; Taber, 2002), *kemijske veze* (Coll i Treagust, 2003; Taber, 1994), *kemijske reakcije* (Kern, Wood, Roehrig, i Nyachwaya 2010; Nyachwaya, Mohamed, Roehrig, Wood, Kern, i Schneider, 2011) i *kiseline i baze* (Devetak, Drofenik Lorber, Juriševič, i Glažar, 2009; Nakhleh i Krajcik, 1994).

Istraživanjima je utvrđeno da učenici započinju učenje kemije s mnogo unaprijed stvorenih predodžbi o prirodi koja nas okružuje. Te predodžbe proizašle iz prethodnog fizičkog iskustva i društvenog okruženja razlikuju se od onih koje nude postojeća znanstvena teorija i praksa. Događa se da učenik nove spoznaje ne povezuje s prethodno usvojenim iskustvenim znanjem, što za posljedicu ima da se učenik koristi jednim načinom razmišljanja u rješavanju znanstvenih problema, a drugim u svakodnevnom životu. Ako se nove spoznaje pohranjuju u memoriji odvojeno od starih, lako se i brzo zaboravljaju. Čestim ponavljanjem i uvježbavanjem novi se koncepti usidre u postojećem znanju. Nastavnici se često u želji da učenicima približe neki pojam koriste metaforom ili analogijom. Metaforički jezik ovisi o sofisticiranim jezičnim vještinama učenika i ako ih oni nemaju, metafore mogu doprinijeti nastanku pogrešnih shvaćanja (Taber, 2002). Ponekad učenik mijenja značenje nastavnikovih riječi kako bi se one uklopile u njegov postojeći konceptualni okvir, čega nisu svjesni ni učenik ni nastavnik do trenutka vrednovanja i ocjenjivanja znanja (Talanquer, 2006). Pogrešna shvaćanja nerijetko proizlaze i iz pogrešnih i neprikladnih prikaza u udžbenicima kemije (Taber, 2002). Važno je naglasiti da i nastavnici nisu „imuni” na pogrešna shvaćanja koja značajno utječu na učenikovo razumijevanje kemijskih koncepata (De Jong, Acampo, i Verdonk, 1995; Papageorgiu i Sakka, 2000).

Navedene poteškoće česte su pri usvajanju čestične prirode tvari, apstraktnog, temeljnog kemijskog koncepta koji podupire razumijevanje drugih kemijskih koncepata (Ben-Zvi, Eylon, i Silberstein, 1986). Budući da ne možemo vidjeti atome, molekule i ione, njihove veze i međudjelovanja, u opisivanju i objašnjavanju čestične prirode tvari potrebno se koristiti modelom (Bridle i Yezierski, 2012). Modeli nisu idealan odraz stvarnosti, već sredstvo koje se fokusira na važne odrednice potrebne za objašnjavanje nekog aspekta fenomena. Zbog njihovih ograničenja u nastavi se njima treba koristiti promišljeno i u kombinaciji s drugim nastavnim sredstvima ili modelima kako bi učenici dobili cjelovit i znanstveno utemeljen uvid u kemijsku pojavu.

U nastavi kemije koriste se čestični crteži, dvodimenzijski modeli koji pomažu učenicima da vizualiziraju nevidljiv svijet čestica. Prillman (2014) naglašava da nastavnik mora upoznati učenike s ograničenjima čestičnog crteža jer ga oni često doživljavaju kao egzaktnu kopiju stvarnosti. U ovom se istraživanju čestični crtež koristio kao alat pri otkrivanju i analizi pogrešnih shvaćanja vezanih uz jednadžbu kemijske reakcije učenika osmih razreda osnovne škole.

Jednadžba kemijske reakcije predstavlja temeljni koncept čije razumijevanje također nije moguće ako nije usvojen niz drugih koncepata. Rezultati niza istraživanja potvrđuju da učenici imaju poteškoće u razumijevanju koncepta jednadžbe kemijske reakcije. Poteškoće se očituju u nerazlikovanju atoma i molekula (Wood i Breyfogle, 2006), nerazlikovanju indeksa i stehiometrijskog broja (Mulford i Robinson, 2002; Nyachwaya, Warfa, Roehrig, Wood, i Schneider, 2014; Sanger, 2005; Yarroch, 1985; Yitbarek, 2011) i interpretaciji značenja simbola (Kelly i sur., 2010; Kern i sur., 2010; Wood i Breyfogle, 2006). Također, uočeno je da većina učenika koji točno napišu jednadžbu kemijske reakcije koristeći se algoritamskim pravilima, nisu sposobni predvidjeti produkte kemijske reakcije ili nacrtati točan čestični prikaz reakcije (Davidowitz i sur., 2010; Hinton i Nakhleh, 1999; Nyachwaya i sur., 2011).

Uzevši u obzir navedene spoznaje i nepostojanje spoznaja o razumijevanju opisanog koncepta u populaciji hrvatskih učenika, osmišljeno je cjelovito istraživanje koje ima za cilj prepoznati, analizirati i unaprijediti poučavanje koncepta jednadžbe kemijske reakcije. U ovom radu opisan je dijagnostički dio navedenog istraživanja kao odgovor na sljedeće istraživačko pitanje:

Koja su najčešća pogrešna shvaćanja učenika osmih razreda povezana s konceptom jednadžbe kemijske reakcije?

Metode

Ispitanici

Uzorak u ovom istraživanju bio je neslučajan, prigodan uzorak učenika osmih razreda osnovnih škola. Istraživanje je provedeno u osam hrvatskih škola (tablica 1). Ukupan uzorak obuhvatio je 357 učenika. Sudionici su bili učenici različitog socioekonomskog statusa, pretežno urbane sredine. Ostvarena je ravnomjerna zastupljenost ispitanika prema spolu jer su u istraživanju sudjelovala 173 dječaka i 184 djevojčice.

Tablica 1

Instrument i procedura

Istraživanje je provedeno kao neeksperimentalno ispitivanje stanja. Koncept jednadžbe kemijske reakcije poučava se u Republici Hrvatskoj u prvoj godini učenja kemije (7. razred). Učiteljice su poučavale učenike po vlastitom odabiru didaktičkih strategija, a prema prijedlozima i preporukama za metodičku obradu iz HNOS-a[1] i PiP-a[2] propisanih od MZOS[3] 2006. godine. Tijekom poučavanja učiteljice se nisu koristile zadatcima s čestičnim prikazima pri usvajanju i provjeri znanja.

Instrument kojim su se prikupili podatci u prosincu 2013. bila je pisana provjera znanja (*Pisana provjera usvojenosti koncepta jednadžbe kemijske reakcije čestičnim crtežom)* koja je sadržavala dva autorska konceptualna zadatka višestrukog izbora i

[1] Hrvatski nacionalni obrazovni standard
[2] Plan i program
[3] Ministarstvo znanosti, obrazovanja i sporta

jedan zadatak višestrukog izbora objavljen u obrazovnoj literaturi. Test su recenzirale tri učiteljice kemije koje rade u osnovnoj školi, jedan metodičar nastave kemije i jedan sveučilišni profesor kemije. Zadatcima višestrukog izbora provjeravana je sposobnost povezivanja dvaju načina prikaza kemijske promjene, jednadžbom kemijske reakcije u simboličkom zapisu (najčešće korišten prikaz) s čestičnim crtežom (vizualizacijom submikroskopske razine kemijske promjene). Distraktori (ometači) su birani na temelju učeničkih pogrešnih shvaćanja opisanih u prije navedenoj literaturi.

U okviru analize pogrešnih shvaćanja razmatrani su deskriptivni podatci izabranih odgovora u zadatku. Na temelju rezultata u zadatcima višestrukog izbora moguće je utvrditi prisutnost pogrešnih shvaćanja i razinu konceptualnog razumijevanja pojedinih koncepata. Prema literaturi (Dhindsa i Treagust, 2009; Gilbert, 1977; Milenković, 2014), distraktor se može smatrati pogrešnim shvaćanjem ako ga izabere više od 20% ispitanika u zadatcima višestrukog izbora s četiri i više ponuđenih odgovora. Točan odgovor može se koristiti kao indikator zadovoljavajućeg konceptualnog razumijevanja ako ga izabere 75% ili više ispitanika. Približno dovoljnim učinkom smatra se frekvencija biranja točnog odgovora u rasponu 50 – 74%. Učinak je u velikoj mjeri nedovoljan ako točan odgovor u zadatku izabere 25 – 49% ispitanika. Nadalje, frekvencija biranja točnog odgovora manja od 25% ukazuje na nedovoljan učinak (Gilbert, 1977).

Rezultati

U prvom zadatku učenici su trebali prepoznati čestične crteže koji prikazuju reaktante i produkte reakcije nastanka klorovodika od elementarnih tvari opisane jednadžbom kemijske reakcije (slika 1).

Slika 1

Zadatak 1.A

Na temelju frekvencije biranja točnog odgovora D u ovom zadatku, možemo zaključiti da učenici posjeduju zadovoljavajuće konceptualno razumijevanje ($f > 75\%$). Postotak biranja distraktora u ovoj čestici znatno je manji od 20%, što ukazuje na nepostojanje pogrešnih shvaćanja (tablica 2).

Birani netočni odgovori A, B i C upućuju kod manjeg dijela učenika na nerazumijevanje značenja pojmova atom i molekula elementarne tvari te nerazlikovanje stehiometrijskog broja i indeksa. Crtež A prikazuje točan broj atoma reaktanata, ali je netočno prikazan simbolički zapis H_2. Crtež B netočno prikazuje molekule elementarnih tvari, a crtež C prikazuje točan broj atoma reaktanata, ali nije u skladu sa simboličkim zapisom jednadžbe kemijske reakcije u kojoj su reaktanti molekule elementarnih tvari.

Tablica 2

Zadatak 1.B

Učenici su u velikom postotku izabrali točan odgovor C pa možemo reći da je konceptualno razumijevanje sadržaja približno dovoljno (tablica 2). Distraktor A, koji upućuje na nerazlikovanje pojmova stehiometrijski broj i indeks, izabralo je više od 20% učenika pa ga možemo smatrati pogrešnim shvaćanjem. Odgovor A prikazuje aglomerat H_2Cl_2 umjesto dvije molekule klorovodika 2 HCl.

Odgovor B nudi prikaz produkta u atomarnom obliku i upućuje na nerazumijevanje značenja pojma molekula kemijskog spoja. Odgovor D prikazuje jednu molekulu klorovodika umjesto dvije, što nije u skladu sa zakonom o očuvanju mase za razmatranu jednadžbu kemijske reakcije. Također, taj izbor upućuje i na nerazumijevanje značenja pojma stehiometrijski broj.

Zadatak 2

U drugom zadatku (slika 2) učenici su trebali povezati čestični crtež reakcijskog sustava[4] prije reakcije sa simboličkim zapisom jedinične pretvorbe i prepoznati čestični prikaz reakcijskog sustava nakon promjene. Taj zadatak je konceptualno zahtjevniji jer reakcijski sustav prije reakcije broji dvostruko više molekula reaktanata nego što je to zapisano u jednadžbi kemijske reakcije.

Slika 2

Točan odgovor C izabralo je samo 14,3% učenika (tablica 3). Vrlo slab učinak ukazuje na konceptualno nerazumijevanje sadržaja. Velik broj ispitanika (f > 20%) izabrao je distraktore A i E, pa ih možemo smatrati pogrešnim shvaćanjem.

Tablica 3

Izbor odgovora A, B i E, koji prikazuju dvije molekule produkta kao u jednadžbi kemijske reakcije, ukazuje na učeničko nerazumijevanje značenja zapisa jednadžbe kemijske reakcije kao jedinične pretvorbe koja se u reakcijskom sustavu dogodi mnogo puta. Najviše učenika izabralo je odgovor E, vodeći se brojem molekula nastalog produkta u zapisu jednadžbe kemijske reakcije, a ne „brojem čestica u reakcijskom sustavu koje su mogle reagirati". U odgovor D uključen je obrazac učeničkog razmišljanja koji je u skladu s odgovorom E, s dodatnim nerazumijevanjem značenja stehiometrijskog broja u jednadžbi kemijske reakcije. Iako odgovor D prikazuje nepostojeću česticu N_2H_6, izabralo ga je ukupno 10,1% učenika. Izbor odgovora B, D i E upućuje na to da ukupno 52,4% učenika ne zna primijeniti zakon o očuvanju mase.

Zadatak 3

Konceptualno najzahtjevniji zadatak pisane provjere preuzet jev iz testa Mulforda i Robinsona (2002) i ispituje koncept mjerodavnog reaktanta (slika 3). Iako taj koncept nije obuhvaćen nastavnim programom osnovne škole, očekuje se da učenici koji poimaju jednadžbu kemijske reakcije kao opis jedinične pretvorbe koja se u reakcijskom sustavu ponovi mnogo puta uspješno riješe zadatak. Primjenom zakona o očuvanju mase učenici trebaju uočiti da je sumpor reaktant u suvišku, a kisik mjerodavni reaktant.

[4] Reakcijski sustav prikazan čestičnim crtežom predstavlja samo vrstu i brojevni odnos jedinki u realnom sustavu.

Slika 3

Kao i u drugom zadatku, učestalost biranja točnog odgovora D (19,1%) upućuje na konceptualno nerazumijevanje sadržaja (tablica 4). Mulford i Robinson (2002) u svom istraživanju utvrdili su 11,0% točnih odgovora studenata, a Wood i Breyfogle (2006) 10,3% točnih studentskih odgovora. U najnovijem istraživanju, Kimberlin i Yezierski (2016) su izvijestili da je 14,1% studenata odabralo točan odgovor.

Tablica 4

Odgovori A i E uključuju prikaz dviju molekula produkta (nepostojeće jedinke S_2O_6 kao sinonim za kemijski zapis 2 SO_3), što odgovara stehiometrijskom broju 2 u jednadžbi kemijske reakcije i presudan je čimbenik za visoku učestalost odabira tih odgovora. Učenici koji su izabrali odgovor A, uočili su i da je sumpor reaktant u suvišku.

Najmanje je zastupljen distraktor B. Prikaz nepostojećeg produkta 3 S_2O_3 upućuje na nerazumijevanje razlike između stehiometrijskog broja i indeksa.

Neznatno je viši postotak odgovora C koji predstavlja točan prikaz molekula produkta SO_3, ali ne uzima u obzir da je kisik mjerodavni reaktant, a sumpor reaktant u suvišku.

Visok postotak učenika (48,7%) izabrao je odgovore B, C i E u kojima se ne primjenjuje zakon o očuvanju mase u reakcijskom sustavu.

Rasprava

Učenički odgovori u odabranom nizu zadataka pružaju nam dobar uvid u sposobnost povezivanja prikaza kemijske promjene jednadžbom kemijske reakcije u simboličkom zapisu s prikazom submikroskopske razine iste promjene čestičnim crtežom.

Učenici pokušavaju povezati simbolički zapis i čestični crtež reakcijskog sustava koristeći se pogrešnim algoritmima. Na temelju učestalosti odabira odgovora A i E u zadatku 2 i u zadatku 3 može se prepoznati istovrstan obrazac pogrešnog shvaćanja dijelova koncepta kao što su: (i) stehiometrijski broj, (ii) indeks u kemijskoj formuli i (iii) jednadžba kemijske reakcije kao jedinična pretvorba u reakcijskom sustavu. Podudarnost frekvencije biranja odgovora 2E i 3E navodi na zaključak da gotovo jedna trećina učenika ne razumije navod (iii). Samo na temelju učestalosti odgovora 3E to se ne bi moglo pretpostaviti jer on ne isključuje mogućnost da učenici imaju problem jedino s navodima (i) i (ii), što bi se moglo reći za učenike koji su birali odgovor 2A i 3A.

Usporedni rezultati prepoznatih pogrešnih shvaćanja prikazani su u tablici 5.

Tablica 5

U sva tri zadatka prepoznato je nerazlikovanje stehiometrijskog broja i indeksa. To pogrešno shvaćanje često se očituje u prikazivanju molekula u obliku aglomerata. Sklonost učenika takvom prikazivanju sudionika kemijske reakcije uočena je u prethodno provedenim i opisanim istraživanjima u kojima su se koristili slični konceptualni zadatci. Davidowitz, Chittleborough i Murray (2010) u svom su radu zvijestili da 12,8% studenata prve godine prirodnih znanosti prikazuje molekule vode u obliku aglomerata (H_4O_2

umjesto 2 H_2O), a 19% studenata molekule amonijaka (2 NH_3) grupira u jednu česticu, N_2H_6. Isti obrazac razmišljanja opažen je u istraživanjima Mulforda i Robinsona (2002) i Kimberlin i Yezierski (2016) u kojima je više od polovine studenata izabralo prikaz S_2O_6 umjesto prikaza 2 SO_3. Sa složenošću zadatka raste i postotak netočnih odgovora u kojima je iskazano nerazlikovanje stehiometrijskog broja i indeksa. Razlog tome je što u tim zadatcima učenici trebaju primijeniti složenije koncepte poput mjerodavnog reaktanta te razlikovati reakcijski sustav od jednadžbe kemijske reakcije, a dijelovi koncepata (i) i (ii) nisu u potpunosti usvojeni.

Visok i stalan postotak učenika ne primjenjuje u zadatcima zakon o očuvanju mase. To pogrešno shvaćanje nije prepoznato u prvom zadatku jer svi distraktori prikazuju jednak broj čestica u jednadžbi kemijske reakcije i reakcijskom sustavu. U istraživanju Mulforda i Robinsona (2002), 65,0% učenika je izabralo odgovore u kojima se ne primjenjuje zakon o očuvanju mase.

Dominantno pogrešno shvaćanje u drugom i trećem zadatku jest nerazlikovanje jednadžbe kemijske reakcije od reakcijskog sustava. Uporaba čestičnog crteža poslužila je kao koristan alat u njegovu prepoznavanju.

Rezultati poslije provedenog kvazieksperimenta na drugom uzorku učenika osmih razreda osnovne škole u predtestu kvazieksperimenta, a prije primjene odabrane nastavne strategije, potvrđuju u potpunosti rezultate ovog dijagnostičkog istraživanja (Šimičić i Mrvoš-Sermek, 2016).

Zaključak

Konstrukcija učeničkog znanja je proces koji se često ne odvija na očekivan način, iz čega proizlazi potreba razvijanja pogodnih alata za provjeru i analizu usvojenosti kemijskih koncepata i dijagnosticiranje pogrešnih shvaćanja. U ovom istraživanju uočeni su problemi povezivanja simboličkog prikaza kemijske promjene jednadžbom kemijske reakcije s prikazom submikroskopske razine iste promjene čestičnim crtežom. Algoritamsko znanje koje učenici primjenjuju u pisanju jednadžbe kemijske reakcije nije bilo dostatno za konceptualno razumijevanje kemijske promjene na čestičnoj razini. Učenici su pokazali zadovoljavajuće konceptualno razumijevanje u zadatku u kojem je broj čestica u simboličkom zapisu jednadžbe kemijske reakcije bio prenesen u čestični crtež submikroskopske razine. Nasuprot tome, zadatci u kojima to nije bio slučaj otkrili su učeničko nepoimanje zapisa jednadžbe kemijske reakcije kao jedinične pretvorbe koja se u reakcijskom sustavu događa mnogo puta ili točnije onoliko puta koliko to određuje mjerodavni reaktant. Prepoznata pogrešna shvaćanja odnose se na nerazlikovanje jednadžbe kemijske reakcije i reakcijskog sustava, nerazlikovanje stehiometrijskog broja i indeksa te poteškoće povezane s primjenom zakona o očuvanju mase. Navedeno je u skladu s literaturnim izvorima, ista pogrešna shvaćanja uočena su kod ispitanika koji su poučavani različitim didaktičkim strategijama u različitim obrazovnim sustavima. Prepoznata pogrešna shvaćanja u početnom poučavanju zadržavaju se često i nakon više godina formalnog kemijskog obrazovanja, što potvrđuje njihovu trajnost i ukorijenjenost.

Rezultati ovog istraživanja ističu vrijednost čestičnog crteža kao nastavnog alata čija uporaba pri provjeri učeničkog znanja omogućava analizu konceptualnog razumijevanja jednadžbe kemijske reakcije. Također, rezultati ukazuju na potrebu prilagodbe strategija poučavanja kako bi se postiglo bolje konceptualno razumijevanje temeljnih kemijskih pojmova i služit će kao temelj za daljnja istraživanja u osmišljavanju postupaka i nastavnih metoda kojima bi se uporabom čestičnih crteža unaprijedile kako nastavničke kompetencije tako i operativno znanje učenika.