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Examination of Secondary School Students' Ability to Transform among Chemistry Representation Levels Related to Stoichiometry

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Abstract

The aim of this qualitative case study was to explore secondary students' ability to transfer among representation levels in relation to stoichiometry. In the study, 40 students in the 11th grade from two classes of an Anatolian high school in the east part of Turkey were selected as sample group. The data were collected by using a questionnaire consists of ten questions designed specifically target the transformation from macroscopic to symbolic, from symbolic to submicroscopic, and from submicroscopic to symbolic level. The analysis of the data was carried out both deductively and inductively by content analysis method. The results indicate that many students were unable to establish an appropriate link among chemical representation levels regarding stoichiometry.

Keywords: Chemistry Education, Representations, Stoichiometry, Submicroscopic Level, Symbolic Level

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INTRODUCTION

Chemistry is an abstract discipline of science in nature (Talanquer, 2011; Taber, 2013). Although the basis of chemistry investigates the change of matter through observation, chemistry relies on explanations of observations through behaviors and interactions of invisible submicroscopic particles (Chittleborough & Treagust, 2007; Gkitzia, Salta & Tzougraki, 2011; Taber & García-Franco, 2010; Thadison, 2011). Since it is difficult to observe particles directly, chemistry is seen as difficult and complex (Cardellini, 2012; Krajcik, 1991; Nakhleh, 1992). Moreover, chemistry contains a language of symbols or formulas to represent the submicroscopic world. Johnstone (2000) proposed that chemistry is multi-representational in nature and it requires the use of three representations at macroscopic, submicroscopic and symbolic level. The macroscopic level can be characterized as visible chemistry in which changes in properties of matter can be described directly through senses (e.g., changes in state, color and temperature). The submicroscopic level is associated with the behavior and motion of very small units such as atoms, ions and molecules. It refers to explanations of macroscopic level in the form of molecular models, diagrams or particulate drawings. The symbolic level refers to representation of macroscopic and submicroscopic phenomena symbolically using mathematical and chemical equations, formulas of molecules, diagrams, etc. (De Jong &Taber, 2007; Johnstone, 1993, Kern, Wood, Roehrig, & Nyachwaya, 2010; Treagust, Chittleborough & Mamiala, 2003).

For conceptual understanding of concepts and problem solving in chemistry, the ability to understand and interpret three levels representations and the ability to establish a link between all levels of representations have been explicitly highlighted (Arasasingham, Taagepera, Potter, & Lonjers, 2004; Cooper, Stieff, & DeSutter, 2017; Johnstone, 2000; Head, Yoder, Genton, & Sumperl, 2017; Mocerino, Chandrasegaran & Treagust, 2009; Santos & Arroio, 2016; Sunyono, Yuanita, & Ibrahim, 2015; Talanquer, 2011; Treagust et al., 2003). Santos and Arroio's (2016) literature review of the studies related to the representational levels revealed that the submicroscopic level is the most challenging for learners to comprehend. Moreover, ability of many secondary and college students are poor to establish a link between levels of chemical representation and to transfer among them simultaneously (Arasasingham et al., 2004; Gabel, 1998; Kern et al., 2010; Sanger, 2005; Sim and Daniel, 2014; Treagust et al., 2003).

Stoichiometry, the topic of this study, is fundamental part of chemistry. Although changes in matter, the focus of chemistry, are either classified as physical or chemical change, chemistry depend heavily on chemical changes, that is, chemical reactions. Chemical reactions involve the rearrangement of atoms. Therefore, chemistry first requires understanding the relationship between products and reactants. For this, it is necessary to understand how to balance the reactions. In other words, since students will have to work chemical equations through almost all chemistry subject, writing a chemical equation is the first and one of the most important steps in all types of chemistry problems. Moreover, they should learn ways of representing molecules and how molecules react. Since stoichiometry pertains to chemical reaction, it can be described the heart of chemistry. Poor understanding of stoichiometry will make it much harder to solve chemistry problems and understand other chemistry topics (e.g., acids and bases, chemical kinetics, and chemical equilibrium). Stoichiometry studies amounts of substances that are involved in reactions. The literature review has shown that research studies generally focus on secondary and college students' understanding of chemical representations, especially at submicroscopic level in relation to stoichiometry (Davidowitz, Chittleborough, & Murray, 2010; Kern et al, 2010).

Regarding the relational understanding of the chemistry triplet, many studies focused on students' ability to transform submicroscopic level to symbolic level or vice versa (Davidowitz et al., 2010; Kern et al., 2010; Sanger, 2005). Few studies explored students' ability to make connections among all levels of chemical representation in relation to stoichiometry (Arasasingham et al., 2004; Sunyono & Ibrahim, 2015; Trivic & Milanavic, 2018). Since many of them were conducted with university students, relatively little is known about the ability of secondary students to transition among all representational levels. To address this gap, this study aimed to explore the degree which secondary students' ability to transfer among representation levels.

METHOD

Research design

This study is a qualitative research aiming to determine the level of understanding of students' chemical representation levels about stoichiometry. Moreover, case study is preferred as a qualitative research method which offers gathering rich information about a case (such as a person, event, situation etc.) by facilitating the in-depth investigation of the subject of research (Yıldırım & Şimşek, 2008). The situation examined in this research is students' ability to transform among chemical representations. This case study allows us to detect the diversity of students' relational understanding among chemical representations in the context of stoichiometry.

Participants

The participants were 40 high school students (24 female, 16 male) from two classes of an Anatolian high school in Van, Turkey. Participants of the study were in the second semester of their 11th grade and their age was 16-17. Chemistry is taught as a separate and obligatory course in the 9th and 10th grade of all Anatolian high schools. Before the Grade 11, the all students are required to take many courses such as Math, Physics, Chemistry, Biology, Turkish, English, Second Foreign Language, Social Studies, Sports. At the end of 10th grade students need to decide which areas they wish to specialize in: science, social sciences, Turkish-Mathematics and foreign language. All students in this study had selected science as specialization areas. Therefore, the weight of the chemistry course they have is higher. They were introduced stoichiometry at the beginning of the 10th grade and were taught types of chemical reactions, balancing chemical equations and calculations with chemical equations (e.g., determination of composition of substances, amounts of substances, percentage yield). They also used their knowledge about stoichiometry while learning other chemistry topics (e.g., chemical equilibrium) during the 11th grade. All the students participated in the study voluntarily. Regarding the issue of confidentiality, all students were informed that their names would not be reported anywhere and the accessible data would be seen only by the researcher.

Data collection

A questionnaire was used to reveal students' relational understating among chemical representation regarding stoichiometry. The questionnaire consists of ten questions designed specifically target the three categories for transformation among representations: i) ability to transform from macroscopic to symbolic, from symbolic to submicroscopic, and from submicroscopic to symbolic. Most of the questions were developed by the researcher and some of them adapted from chemistry sources in the literature (Davidowitz et al.,2010). On the questionnaire, students were required to

a) write the balanced chemical equations based on a written explanation including the name of reactants and products, and their macroscopic properties such as color and state of matter (three questions)

b) convert sub-micro drawings into chemical equations

- sub-micro drawing provided representation of reactants only (two questions)
- sub-micro drawing provided representation of reactants and products (three questions)

c) draw the submicroscopic image of the reaction at the beginning and at the end of the reaction based on a given balanced chemical equation (two questions).

The questionnaire was administered to 40 high school students during a 40-minute lesson. It should be noted that since no further explanation on drawings and written chemical equations was collected from each participant it is not known about what ideas underline the students' responses.

Data analysis

The data were analyzed both deductively and inductively. First, the students' responses to each question were examined and coded by the author. At the beginning of the data analysis, literature were reviewed and categories used in the previous research (e.g., chemical equation but not lowest whole number, drawings with formula mismatch) lead the author (Davidowitz et al., 2010; Kern et al., 2010). During the data analysis, a new category was created when a response did not fit an existing category, and existing categories were reviewed and improved as necessary. Periodically, all previously categorized answers were checked to see if they could be placed in a newer or different category. After the author analyzed the data, a chemistry educator examined the data for the validation of the identified categories. To ensure trustworthiness of the study, except students' responses to Q3 and Q9 (students' drawings at submicroscopic level), different examples of responses that were revealed for each question were shared with him to check whether them belongs to the related category. Moreover, the chemistry educator checked the categories associated with the drawings of five randomly selected students for Q3 and Q9. The inter-rater reliability was found to be .88 (Reliability=agreement/agreement + disagreement), indicating a good level of agreement (Miles and Huberman, 1994). The discrepancies emerged were resolved by discussion and all previously categorized responses were reviewed. The final version of the categories with the percentage of students were presented in the following part. Furthermore, to establish the reliability of the research, the analysis process was explained in detail and all different examples of responses for each category were provided in the results section.

RESULTS

The ability to convert macroscopic level to symbolic representation

Regarding the ability to transfer from macroscopic to symbolic representation, students were asked to write the balanced chemical equations based on a written explanation about three different type chemical reaction (Combustion [Q1], Decomposition [Q4], Double substitution [Q7]). In the explanations, students were provided the name of reactants and products, and their macroscopic properties such as color and state of matter. The analysis of the student responses to the questions (Table 1) indicate that their ability to convert the written explanation to symbolic representation as a form of balanced chemical equation differs according to different types of chemical reactions. The most correct answer was obtained in the question 4 (62.5%). Although some students wrote a correct equation (7.5% for Q1 and 10% for Q7), it was unbalanced. Regarding the incorrect responses, most of the errors were made in the formulas of the reactants and products. Especially for Q7, %52.5 students made error about the subscripts in chemical formulas of the one or more reactants and products. For example, some students wrote silver chloride as $AgCI_{2,}$ calcium chloride as CaCl and calcium nitrate as $CaNO_3$. Moreover, 40% of students for Q1 wrote iron and oxygen in the form of ions in the chemical equation as Fe^{2+} and O^{2-}. Furthermore, nine students for Q4 identified reactants and products incorrectly. Although students wrote reactants and products incorrectly in the chemical equation, most of them did not considered that the total number of atoms in the reactants and products is equal to each other. In other words, the chemical equations were unbalanced.

Tablo 1 The analysis of the student responses to Q1, Q4 and Q7

	Q1	n	%	Q4	n	%	Q7	n	%
Correct balanced equation	$2Fe+3/2O_2 \rightarrow Fe_2O_3$ $4Fe+3O_2 \rightarrow 2Fe_2O_3$	11	27.5	$PbCO_3 \rightarrow CO_2 + PbO$ $PbCO_3 + \text{ısı} \rightarrow CO_2 + PbO$	25	62.5	$2AgNO_3 + CaCI_2 \rightarrow 2AgCl + Ca(NO_3)_2$	13	32.5
Unbalanced equation	$3Fe + O_2 \rightarrow Fe_2O_3$ $Fe+O_2 \rightarrow Fe_2O_3$	3	7.5				$AgNO_3 + CaCI_2 \rightarrow AgCl + Ca(NO_3)_2$ $AgNO_3 + CaCI_2 \rightarrow 2AgCl + Ca(NO_3)_2$	4	10
Incorrect responses – formula mismatch	$2Fe+O_2 \rightarrow 2FeO$ $Fe_2 +3O_2 \rightarrow 2FeO_3$ $Fe+ O_2 \rightarrow FeO$ $Fe + 3O_2 \rightarrow FeO_3$ $3Fe + O_2 \rightarrow Fe_3O_2$ $2Fe + 3O \rightarrow Fe_2O_3$	7	17.5	$Pb + CO_3 \rightarrow CO_2 + PbO_2$ $Pb_2(CO_3)_2 \rightarrow 2CO_2 + 2PbO$ $PbCO_3 \rightarrow Pb_2 + (CO_2)_2$ $Pb(CO_3)_2 \rightarrow CO_2 + Pb_2O$	5	12.5	$2AgNO_3 + CaCI_2 \rightarrow AgCl_2 + Ca(NO_3)_2$ $AgNO_3 + CaCI \rightarrow AgCl + CaNO_3$ $AgNO_3 + CaCI_2 \rightarrow AgCl_2 + CaNO_3$ $AgNO_3 + CaCI_2 \rightarrow AgCl_2 + NaNO_3$ $AgNO_3 + CaCI \rightarrow AgCl_2 + Ca(NO_3)_2$ $AgNO_3 + CaCI_2 \rightarrow 2AgCl + CaNO_3$ $AgNO_3 + CaCI_2 \rightarrow AgCl_2 + Ca(NO_3)_2$	21	52.5
Incorrect responses- inappropriate reactant or product	$4Fe^{3+}+3O_2 \rightarrow 2Fe_2O_3$ $4Fe^{3+}+3O_2^{2-} \rightarrow 2Fe_2O_3$ $2Fe^{3+} + 3O^{2-} \rightarrow Fe_2O_3$ $Fe^{3+} + O^{2-} \rightarrow Fe_2O_3$	16	40	$PbCO_3 + CO_2 \rightarrow PbC_2O_5$ $Pb_3 + (CO_3)_2 \rightarrow Pb_2O$ $PbCO_3 + O_2 \rightarrow PbO + CO_2$	9	22.5			
No answer or illegible		3	7.5		2	5		2	5

The ability to convert submicroscopic level to symbolic representation

Regarding the ability to transfer from submicroscopic to symbolic representation, students were required to convert the data provided by sub-micro drawings into symbolic in the form of an equation. In Q2, Q5, and Q10, students were asked to create balanced equations based on the sub-micro drawings representing before and after the reaction by providing both reactants and products. While one of the sub micro drawings depict a reaction in which all reactants are converted into products (Q5), two of them include the reagent in excess (Q2 and Q10). In order to answer to Q5 students had to identify the product as CO_2 and H_2O. For a balanced equation, students are expected to apply the rule to chemical equations that reactants and products are always written using the smallest whole number ratios. The analysis of the student responses to Q5 (Table 2) indicate that only two students were able to write an appropriate balanced equation [$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$]. Although 85% of students generated the correct equation, they did not convert the coefficients to the small whole numbers [$3CH_4 + 6O_2 \rightarrow 3CO_2 + 6H_2O$]. In other words, they translated the numbers of reactants and products given in the drawings directly into a chemical reaction. In addition, two students were not able to answer the question and the remaining made errors on identification of the products correctly (one students) and writing the balanced equation (one students).

For Q2 and Q10, students had to identify the product and realize that the drawing contains one of the reagents excessively but will not be written in the chemical equation. The analysis of the student responses indicates (Table 2) while five students (12.5%) were able to write an appropriate balanced equation for Q2, only one student was able to write correct balanced equation for Q10. Most students (65%f or Q2 and 87.5% for Q10) translated the drawing directly into a chemical equation including the reagent in excess. For Q2, although four students were able to identify reactants and products correctly, they could not to write a balanced equation. In addition, three students made errors in subscripts of reactants or products [$2O_7 + 2H_5 \rightarrow 5H_2O + 2H_2$]. Moreover, small number of incorrect responses to these questions (5% for Q2 and 7.5% for Q10) include errors related to formula of reactants or products and one student were not able answer the question 10.

Regarding the ability to transfer from submicroscopic to symbolic representation, Q6 and Q8 required students to write a balanced equation based on sub-micro drawings provided reactants only and explanations including the products name. While sub-micro drawing related to Q6 include no excess reactant, that for Q8 include excess reactant. The analysis of the student responses to Q6 (Table 3) indicate only five students were able to write an appropriate balanced equation although all of them not used whole numbers. 45% of students wrote a correct equation without converting the coefficients to the small whole numbers [$6H_2O \rightarrow 6H_2 + 3O_2$]. Although formula of reactants and products are correctly symbolized in the equation, nine chemical equations provide by the students are not balanced and they involve errors related to coefficients. In addition, some incorrect responses to Q6 (15%) include errors related to formula of reactants or products. In fact, Hydrogen or Oxygen gases were not symbolized as diatomic in the chemical equation.

Tablo 2 The analysis of the student responses to Q2, Q5 and Q10

	Q2	n	%	Q5	n	%	Q10	n	%
Correct balanced equation	$H_2 + 1/2O_2 \rightarrow H_2O$ $2H_2 + O_2 \rightarrow 2H_2O$	5	12.5	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	2	5	$AB_2 + 1/2B_2 \rightarrow AB_3$	1	2.5
Correct equation but not lowest whole numbers -				$3CH_4 + 6O_2 \rightarrow 3CO_2 + 6H_2O$	34	85			
Unbalanced equation	$10H_2 + 7O_2 \rightarrow 10H_2O$ $10H_2 + 7O_2 \rightarrow 5H_2O$ $10H_2 + 5O_2 \rightarrow 7H_2O$	4	10	$3CH_4 + 3O_2 \rightarrow 3CO_2 + 6H_2O$	1	2.5			
Chemical equation including the reagent in excess	$7O_2 + 10H_2 \rightarrow 10H_2O + 2O_2$	26	65				$6AB_2 + 5B_2 \rightarrow 6AB_3 + 2B_2$	35	87.5
Incorrect responses – error in subscripts	$2O_7 + 2H_5 \rightarrow 5H_2O + 2H_2$	3	7.5						
Incorrect responses – formula mismatch	$H + O_2 \rightarrow H_2O$ $H_2 + O \rightarrow H_2O$	2	5	$CH_4 + O_2 \quad CO_2 + 2H_2$	1	2.5	$AB_2 + B_2 \rightarrow AB_4$ $2AB_2 \rightarrow 2AB_3 + B_2$ $3AB_2 \rightarrow 6AB_3$	3	7.5
No answer or illegible					2	5		1	2.5

Tablo 3 The analysis of the student responses to Q6 and Q8

	Q6	n	%	Q8	n	%
Correct balanced equation	$2H_2O \rightarrow 2H_2 + O_2$ $H_2O \rightarrow H_2 + 1/2O_2$	5	12.5	$N_2 + 3H_2 \rightarrow 2NH_3$	3	7.5
Correct equation but not lowest whole numbers -	$6H_2O \rightarrow 6H_2 + 3O_2$	18	45			
Unbalanced equation	$6H_2O \rightarrow 3H_2 + 4O_2$ $6H_2O \rightarrow 3H_2 + 3O_2$	9	22.5	$4N_2 + 9H_2 \rightarrow 8NH_3$	5	12.5
Chemical equation including the reagent in excess				$4N_2 + 9H_2 \rightarrow 6NH_3 + N_2$	30	75
Incorrect responses– formula mismatch	$6H_2O \rightarrow 6O_2 + 12H$ $H_2O \rightarrow H + O_2$ $6H_2O \rightarrow 6H_2 + 6O$	6	15	$4N_2 + 8H_2 \rightarrow 8NH_2$	2	5
No answer or illegible		2	5			

Unlike to Q6, sub-micro drawing in Q8 refers to a reaction with excess reactant. Table 3 indicates only three students could provide a correct balanced equation. In addition, five students wrote a balanced equation without converting the coefficients to the small whole numbers [$4N_2 + 9H_2 \rightarrow 8NH_3$]. Most of the students wrote an incorrect equation. 75% of them translated the drawing directly into a chemical equation including the reagent in excess [$4N_2 + 9H_2 \rightarrow 6NH_3 + N_2$]. In addition, two incorrect responses to Q8 include errors related to formula of product, ammonia.

The ability to convert symbolic level to submicroscopic representation

Regarding the ability to transfer from symbolic to submicroscopic representation, students were required to convert the data provided by an equation into sub-micro drawings. The analysis of student responses to Q3 and Q9 (Table 4) indicate almost half of the students (42.5% for Q3 and 40% for Q9) drew a suitable submicroscopic representation of reactants and products. It is seen that most of them (32.5% for Q3 and 40% for Q9) limited the number of reactants and product in their drawings to the coefficients in the balanced equation. Although some students draw more molecules than represented as coefficient in the equation for Q3, some of submicroscopic representations are unbalanced. 15% of students for Q3 and 12.5% of students for Q9 did not considered that the total number of atoms in the reactants and products is equal to each other. Moreover, almost half of the students (42.5%) drew incorrect submicroscopic representation including one or more molecule not matching the correct molecular formulae. In other words, students' responses revealed that the number of atoms in the molecule did not match the subscripts in the given equation. For example, some students depicted MgO as being composed of three particles (one Mg and two oxygen atoms) and represented $FeCI_2$ by one Fe and one Cl atom. Moreover, it is seen that some students confused the meaning of coefficients and subscripts since 2HCl was represented by two hydrogen atoms bonded to one chlorine atom in their drawings for Q9.

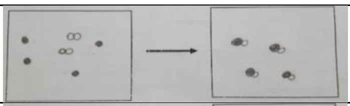
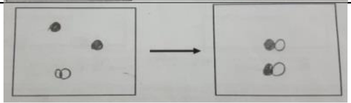
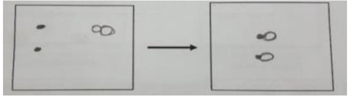
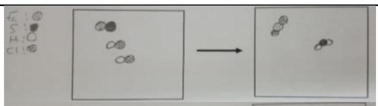
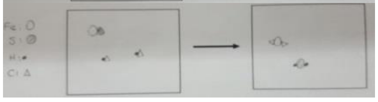
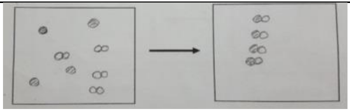
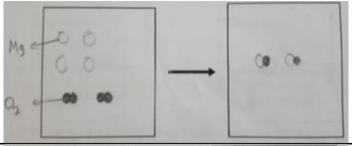
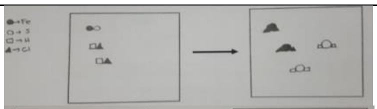
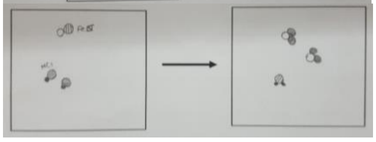
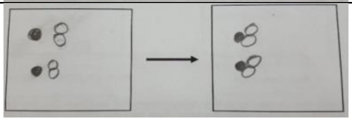
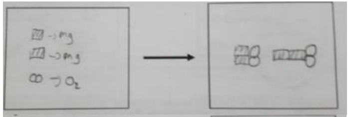
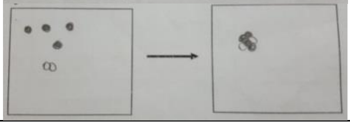
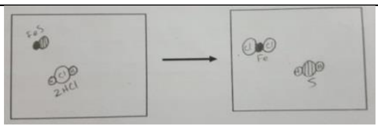
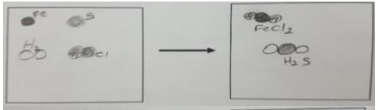
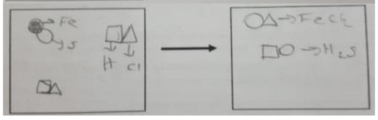
DISCUSSION AND CONCLUSION

Students' responses to ten questions allow us to examine their relational understanding among chemical representations regarding chemical equation and stoichiometry which is an important aspect of competence in school chemistry. The literature emphasized students had difficulty in translation of chemical representations from one level to another in relation to various chemistry concepts (Devetak, Urbančič, Grm, Krnel, & Glažar, 2004; Farida, Widyantoro, & Sopandi, 2010; Tan, Goh, Chia, & Treagust, 2009; Tarkın-Çelikkıran & Gökçe, 2019). The findings of the study also indicate many students were unable to establish an appropriate link among chemical representation levels regarding stoichiometry.

Regarding the ability to transfer from macroscopic to symbolic representation, the findings of the study reveal that some students made error in writing a chemical equation from a written explanation since they had difficulty in writing formula of reactants and products. The difficulties of the students in this area have been revealed in previous studies in the literature. According to the review study focused on students' use and understanding of chemical formulas (Taskin and Bernholt, 2014), many research studies presented that students have difficulties in deriving the formula from a given compound name. Baah and Ampiah (2012) also found that the senior high school students presented poor performance on translating written statement about a chemical reaction into a chemical equation using symbols. Beside inability to writing correct chemical formula, the results of this study present that many students have misunderstanding about writing a chemical equation. Whether correct or incorrect chemical equation, most of the chemical equations written by students were unbalanced. In other words, many of the students ignored the equality of total number of atoms in the reactants and products.

In this study, student showed inability to convert the data provided by sub-micro drawings into symbolic in the form of an equation as in the other studies (Davidowitz et al., 2010; Sanger, 2005; Sunyono et al., 2015). Many students did not use the lowest whole numbers with correct ratio while balancing the chemical equation. In this case, students wrote the equation based on the image directly without balancing the equation with simplest ratio of the entities. Similar to Trivic and Milanovic (2018), these students did understand that coefficients in a chemical reaction represent the stoichiometric ratios.

Tablo 4 The analysis of the student responses to Q3 and Q9

	Q3 $2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(k)}$	n	%	Q9 $FeS_{(s)} + 2HCl_{(aq)} \rightarrow FeCl_{2(s)} + H_2S_{(g)}$	n	%
Correct representation		4	10			
Correct representation – based on coefficients in balanced equations	 	13	32.5	 	16	40
Incorrect representation-unbalanced	 	6	15	 	5	12.5
Incorrect representation - inappropriate reactant or product (Formula mismatch)	  	17	42.5	  	17	42.5
No answer or illegible					2	5

Moreover, when sub-micro drawing includes excess reactant, many students showed the excess reactant in the chemical equation. The idea that writing a chemical equation from submicroscopic representations directly depends on the number of particles in the drawing has been observed by other researchers (Arasasingham et al., 2004; Davidowitz et al., 2010; Sunyono et al., 2015). Similar to findings revealed in Sunyono et al. (2015), some students failed to identify the reaction products with correct formula in this study. Furthermore, three students for Q2 represented the number of particulates for each reactant as subscript while the number of atoms in the molecule as stoichiometric coefficient (e.g. using $2O_7$ instead of $7O_2$ and $2H_5$ instead of $5H_2$). It is seen that these students have misunderstanding about the meaning of stoichiometric coefficient and subscript. Trivic and Milanovic (2018) found that some students confuse the meaning of these terms. In their study, it was revealed that some students thought that the coefficient shows how many atoms there are. Similarly, in this study, some students represent the number of atoms in the molecule as stoichiometric coefficient. To help students enhance their relational understanding of the chemistry triplet, teacher should differentiate the meaning of stoichiometric coefficient and subscript and focus on the relationship between submicroscopic representation and chemical equation referring symbolic level. While using submicroscopic representation, teachers should associate the number of sub-micro entities in the diagram with its chemical equation (Cheng & Gilbert, 2014).

While students move from symbolic level to submicroscopic level, they generally imaged the number of particles in the reagents and products as much as the stoichiometric coefficient in the balanced equation. Students might have misunderstanding about the meaning of stoichiometric coefficient. Research studies revealed that students do not understand the coefficients as the stoichiometric ratios of reactants and products (Trivic & Milanovic, 2018; Marais & Jordaan, 2000). In the study of Trivic and Milanovic (2018), one of twelve students interviewed said that coefficients represent how many molecules there are [e.g., 3H2O means there are three molecules of water]. The drawings of some students in the current study indicate that these have the same viewpoint for the coefficients in a chemical reaction. In addition, some students could not represent the chemical formula of reactants or products in their drawing correctly. There was a mismatch between the numbers of atoms in the molecule in students' drawings and subscripts in the given equation. For example, some students represented 2MgO as the structure for the molecular formula Mg_2O_2 or $2MgO_2$. As observed in the previous studies, students have difficulty in representing the right number of atoms and molecules in their drawings and the correct linkage of atoms in molecules (Arasasingham et al., 2004). Moreover, some students did not consider that the total number of atoms in the reactants and products is equal to each other in their drawings. Similar to previous studies, students had difficulty in representing molecules with the correct number and connectivity of constituent atoms (Arasasingham et al., 2004; Davidowitz et al., 2010; Kern et al., 2010). Some studies indicated that students may associate the coefficients in the chemical equation only with the first atom of the subsequent chemical formula (Smith and Metz, 1996). Similar to this idea, some participants of this study represented 2HCl by two hydrogen atoms bonded to one chlorine atom. Use of visualization tools for submicroscopic representation with establishing link to other representation levels can enhance students' understanding of submicroscopic level and its association with other levels (Farida et al., 2010; Herga, Cagran & Dinevski, 2016; Wu, Krajcik & Soloway, 2001).

Students' ability to transform representational levels into each other tied to teaching process in classrooms and textbooks. To be able to transform from one level to another, student should be trained by using multiple representations with highlighting their inter-connectedness (Adadan, 2012; Baptista, Martins, Conceiçao, & Reis, 2019; Devetak, Vogrinc, & Glazar, 2009; Head et al., 2017; Jaber & BouJaoude, 2012; Mocerino et al., 2009; McBroom, 2011; Russell et al. 1997; Sunyono et al., 2015). Chemistry teachers should integrate three levels of representations in their teaching and explicitly emphasize association of each representation level with other levels (Demirdöğen, 2017; Farida et al., 2010; Santos & Arroio, 2016). In addition to teacher use of chemical representations, students should be enrolled in activities including different representation levels and transitions between them (Farida et al., 2010; Santos & Arroio, 2016). Sunyono et al. (2015) reported that before using multiple representation method students were less able to interpret all chemical representations. At the end of the implementation of multiple representation method, it was seen that there has been an improvement of their ability to interpret the representation levels and transform among them in relation to stoichiometry. However, some students still had problems on interpretation of the submicroscopic representation and its association with symbolic and macroscopic level. Therefore, students should be regularly informed about interpretation and transformation of representation levels during chemistry courses.

Textbooks are source of information for both students and teachers. Therefore, representations took place in textbooks can support students' and teachers' use of representations to explain a chemical phenomenon and transformation among them. Textbook review studies revealed that multiple and submicroscopic representations appear in a small number in chemistry textbooks (Demirdöğen, 2017; Gkitzia et al., 2011; Shehab & BouJaoude, 2016). In addition to providing chemical representations in books, how they are given is of great importance. Degree of relation and link to the text is important for students to understand what the representation represents (Demirdöğen, 2017; Gkitzia et al., 2011). Demirdöğen (2017) revealed that surface features of submicroscopic and multiple representations were generally implicit or ambiguous for readers to interpret the meaning of representations correctly. Therefore, chemistry textbooks should establish an appropriate link between representations and text.

Some recommendations can be presented to researchers for further studies. For example, how a student interprets chemical representations and converts them into each other can be examined in more detail through interviews. This study focused on students' ability to transform among chemical representations in the context of stoichiometry. However, similar studies can be carried out with different chemistry topics to learn more about the students' ability to transform among chemical representations. Moreover, correlational studies between students' relational understanding about chemical representations and teaching environment (e.g., teachers' ability to convert representations into each other and their use of them during chemistry teaching) can be conducted to reveal the factors affecting students' ability to transform among chemical representations.

REFERENCES

Adadan, E. (2012). Using multiple representations to promote grade 11 students' scientific understanding of the particle theory of matter. *Research in Science Education, 43*(3), 1079-1105.

Arasasingham, R. D., Taagepera, M., Potter, F., & Lonjers, S. (2004). Using knowledge space theory to assess student understanding of stoichiometry. *Journal of Chemical Education, 81*(10), 1517-1523.

Baah, R., & Ampiah, G. J. (2012). Senior high school students' understanding and difficulties with chemical equations. *International Journal of Scientific Research in Education, 5*(3), 162-170.

Baptista, M., Martins, I., Conceição, T., & Reis, P. (2019). Multiple representations in the development of the students' cognitive structures about the saponification reaction. *Chemistry Education Research and Practice, 20,* 760-771.

Cardellini, L. (2012). Chemistry: why the subject is difficult?. *Educación química, 23,* 305-310.

Cheng, M. M. W., & Gilbert, J. K. (2014). Teaching Stoichiometry with Particulate Diagrams – Linking Macro Phenomena and Chemical Equations. In Eilam, B & Gilbert, JK (Eds.), *Science Teachers' Use of Visual Representations*, p. 123-143. Cham: Springer

Chittleborough, G., & Treagust D. (2008). Correct interpretation of chemical diagrams requires transforming from one level of representation to another, *Res. Sci. Educ. 38,* 463–482.

Cooper, M. M., Stieff, M., & DeSutter, D. (2017). Sketching the invisible to predict the visible: from drawing to modeling in chemistry. *Topics in cognitive science, 9*(4), 902-920.

Davidowitz, B., Chittleborough, G., & Murray, E. (2010). Student-generated submicro diagrams: A useful tool for teaching and learning chemical equations and stoichiometry. *Chemistry Education Research and Practice, 11*(3), 154-164.

De Jong, O., & Taber, K. (2007). Teaching and learning the many faces of chemistry. In S. K. Abel & N.G. Lederman (Ed). *Handbook of Research on Science Education*, 631-652. Lawrence Erlbaum Associates.

Demirdöğen, B. (2017). Examination of chemical representations in Turkish high school chemistry textbooks. *Journal of Baltic Science Education, 16*(4).

Devetak, I., Vogrinc, J., & Glazar, S. A. (2009). Assessing 16-year-old students. Understanding of aqueous solution at submicroscopic level. *Research in Science Education, 39*(2), 157–179.

Devetak, I., Urbančič, M., Grm, K. S. W., Krnel, D., & Glažar, S. A. (2004). Submicroscopic representations as a tool for evaluating students' chemical conceptions. *Acta Chimica Slovenica, 51*(4), 799-814.

Farida, I., Widyantoro, D. H., & Sopandi, W. (2010). Representational Competence's Profile of Pre-Service Chemistry Teachers in Chemical Problem Solving. Paper presented at 4th International Seminar of Science Education, Bandung. 30 October 2010

Gkitzia V., Salta K., & Tzougraki C. (2011). Development and application of suitable criteria for the evaluation of chemical representations in school textbooks. *Chemistry Education Research and Practice, 12* (1), 5–14.

Head, M. L., Yoder, K., Genton, E., & Sumperl, J. (2017). A quantitative method to determine preservice chemistry teachers' perceptions of chemical representations. *Chemistry Education Research and Practice, 18*(4), 825-840.

Herga, N. R., Čagran, B., & Dinevski, D. (2016). Virtual laboratory in the role of dynamic visualisation for better understanding of chemistry in primary school. *Eurasia Journal of Mathematics, Science & Technology Education, 12*(3), 593-608.

Jaber, L. Z., & BouJaoude, S. (2012). A Macro–Micro–Symbolic Teaching to Promote Relational Understanding of Chemical Reactions. *International Journal of Science Education, 34*(7), 973-998.

Johnstone, A. H. (1993). The development of chemistry teaching: A changing response to changing demand. *Journal of Chemical Education, 70*(9), 701.

Johnstone, A. H. (2000). Teaching of chemistry-logical or psychological? *Chemistry Education Research and Practice, 1*(1), 9-15.

Kern, A. L., Wood, N. B., Roehrig, G. H., & Nyachwaya, J. (2010). A qualitative report of the ways high school chemistry students attempt to represent a chemical reaction at the atomic/molecular level. *Chemistry Education Research and Practice, 11*(3), 165-172.

Krajcik, J. (1991). Developing students' understanding of chemical concepts. In S. Glynn, R. Yeany, & B. Britton (Eds.), *The psychology of learning science* (pp. 117–147). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc

Marais, P., & Jordaan, F. (2000). Are we talking symbolic language for granted? *Journal of Chemical Education, 77*(10), 1355 - 1357.

McBroom, R.A. (2011). Pre-Service Science Teachers' Mental Models Regarding Dissolution and Precipitation Reactions. Unpublished doctoral dissertation, North Carolina State University, Raleigh, North Carolina.

Miles M. B., & Huberman A. M., (1994). *Qualitative data analysis: an expanded sourcebook*. Thousand Oaks, CA: Sage.

Mocerino, M., Chandrasegaran, A. L., & Treagust, D. F. (2009). Emphasizing multiple levels of representation to enhance students' understandings of the changes occurring during chemical reactions. *Journal of Chemical Education, 86*(12), 1433.

Nakhleh, M. B. (1992). Why some students don't learn chemistry: Chemical misconceptions. *Journal of Chemical Education, 69*(3), 191.

Russell, J. W., Kozma, R. B., Jones, T., Wykoff, J., Marx, N., & Davis, J. (1997). Use of simultaneous-synchronized macroscopic, microscopic, and symbolic representations to enhance the teaching and learning of chemical concepts. *Journal of chemical education, 74*(3), 330-334.

Sanger M. J. (2005). Evaluating students' conceptual understanding of balanced equations and stoichiometric ratios using a particulate drawing, *J. Chem. Educ., 82*, 131-134.

Santos, V. C., & Arroio, A. (2016). The representational levels: Influences and contributions to research in chemical education. *Journal of Turkish Science Education, 13*(1), 3-18.

Shehab, S. S., & BouJaoude, S. (2016). Analysis of the chemical representations in secondary Lebanese chemistry textbooks. *International Journal of Science and Mathematics Education, 15*(5), 797-816.

Sim, J. H., & Daniel, E. G. S. (2014). Representational competence in chemistry: A comparison between students with different levels of understanding of basic chemical concepts and chemical representations. *Cogent Education, 1*(1), 991180.

Sunyono, Yuanita, L., & Ibrahim, M. (2015). Mental Models of Students on Stoichiometry Concept in Learning by Method Based on Multiple Representation. *The Online Journal of New Horizons in Education, 5*(2), 30-45.

Taber, K. S. (2013). Revisiting the chemistry triplet: Drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education. *Chemical Education Research and Practice, 14*(2), 156–168.

Taber, K. S., & García-Franco, A. (2010). Learning processes in chemistry: Drawing upon cognitive resources to learn about the particulate structure of matter. *The Journal of the Learning Sciences, 19*(1), 99-142.

Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry 'triplet'. *International Journal of Science Education, 33*(2), 179–195.

Tan, K. C. D., Goh, N. K., Chia, L. S., & Treagust D. F. (2009) Linking the Macroscopic, Sub-microscopic and Symbolic Levels: The Case of Inorganic Qualitative Analysis. In: Gilbert J.K., Treagust D. (eds) *Multiple Representations in Chemical Education. Models and Modeling in Science Education*, vol 4. Springer, Dordrecht.

Tarkın-Çelikkıran, A. & Gökçe, C. (2019). Kimya öğretmen adaylarının çözünürlük konusuna ilişkin submikroskobik seviyedeki anlama düzeylerinin çizimlerle belirlenmesi. *Pamukkale Üniversitesi Eğitim Fakültesi Dergisi, 46*, 57-87.

Taskin, V., & Bernholt, S. (2014). Students' Understanding of Chemical Formulae: A review of empirical research. *International Journal of Science Education, 36*(1), 157-185.

Thadison, F. C. (2011). Investigating Macroscopic, Submicroscopic, and Symbolic Connections in a College-Level General Chemistry Laboratory. Unpublished doctoral dissertation, The University of Southern Mississippi.

Treagust, D., Chittleborough, G., & Mamiala, T. (2003). The role of submicroscopic and symbolic representations in chemical explanations. *International Journal of Science Education, 25*(11), 1353-1368.

Trivić, D., & Milanović, V. D. (2018). The macroscopic, submicroscopic and symbolic level in explanations of a chemical reaction provided by thirteen-year olds. *Journal of the Serbian Chemical Society, 83*(10), 1177-1192.

Wu, H. K., Krajcik, J. S., & Soloway, E. (2001). Promoting understanding of chemical representations: Students' use of a visualization tool in the classroom. *Journal of Research in Science Teaching, 38*(7), 821-842.

Yıldırım, A., & Şimşek, H. (2008). *Nitel araştırma yöntemleri* (7. Baskı). Ankara: Seçkin Yayıncılık.