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From Symbolic Representation to Submicroscopic One: Preservice Science Teachers' Struggle with Chemical Representation Levels in Chemistry

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Abstract

Being able to move between different representations levels (macroscopic, sub-microscopic, and symbolic) is important to understand a chemical phenomenon meaningfully. The current study investigated how pre-service science teachers moved from symbolic representation to sub-microscopic representation. A total of 205 pre-service science teachers, first, balanced the three chemical reactions and then drew the reactions' sub-microscopic views if they were able to observe them. The findings revealed that pre-service science teachers are most successful at the symbolic level. Yet, this is not a valid conclusion for the sub-microscopic representation level. The drawings were analyzed concerning atomic size and molecular geometry and found that pre-service science teachers have common alternative concepts. Furthermore, they mostly have a superficial knowledge of the molecular geometry of chemical compounds. In conclusion, because pre-service science teachers will teach in their future careers, it is important to encourage them to comprehend chemical phenomena at each representation level and shift between them to prevent alternative concepts they may have.

Introduction

It is common to find alternative conceptions in all areas of science education (Taber, 2002), especially in chemistry education. Topics in chemistry education are usually related to or based on the structure of matter (Sirhan, 2007), which are mostly impossible to be observed by a naked eye, which makes it difficult for students. It is important to learn such abstract concepts since further learning might be difficult if these basic ones are not been understood well (Batır & Akçay, 2022; Özalp & Kahveci, 2011; Unlu Sinnett & Akçay, 2021; Zoller, 1990). Furthermore, chemistry education includes some other content learning difficulties (Sirhan, 2007). For example, in a chemistry class, it is usual to talk about mathematical chemistry problems (Bunce & Gabel, 2002). This situation also increases trouble for students' meaningful learning. In another respect, many students are able to solve mathematical chemistry problems successfully but indeed, they do not need to use their chemistry knowledge for these problems (Bunce & Gabel, 2002) which shows that students may seem successful without gaining real understanding (Boo, 1998). The current study investigated how pre-service science teachers (PSTs) balanced the chemical reactions and how they drew the sub-microscopic representations of the reactions if they were able to observe them. In particular, it was focused on how PSTs moved from symbolic representation to sub-microscopic representation. The topic was chosen as chemical reactions because it involves mathematical and chemical knowledge together. In other words, it is a kind of topic that includes symbolic and sub-microscopic representations simultaneously and commonly.

Fundamental Representation Levels in Chemistry

Understanding the relationship among the three levels and how they relate to each other is required for students to understand explanations of chemical phenomena (Kern et al., 2010). Johnstone (2007) states that macroscopic representations should be used until students have formed new concepts. After that explanations based on sub-microscopic and symbolic levels can be used. In other words, whereas the macroscopic observable chemical phenomena are the basis of a chemistry course, explanations of these phenomena usually rely on the symbolic and sub-microscopic level of representations (Treagust, Chittleborough, & Maimala, 2003). Yet, in a traditional chemistry course, particulate diagrams, that not only address the interaction of atoms, ions, and/or molecules but also may involve chemical symbols and mathematical equations, are not used much (Bunce & Gabel, 2002). There can be several reasons for this outcome. For example, students mostly focus on the course while macroscopic representations are being used since it is usually possible to observe the changes in physical properties (Kern et al., 2010). However, it is difficult to maintain attention while using sub-microscopic and symbolic representations (Harrison & Treagust, 2003). That is why teachers may don't want to use sub-microscopic and symbolic representations so as not to disturb students' attention. Also, the sub-microscopic level is the most problematic level for learners to understand (Chittleborough & Treagust, 2007) because students are not able to see this representation level, which causes difficulty to comprehend (Kern et al., 2010). Another reason can be that teachers are not much aware of (moving between) these representation levels. This is one of the focal points of this study. It is necessary to move between these representation levels in order to fully understand a chemical phenomenon (Gilbert & Treagust, 2009; Talanquer, 2011; Taber, 2013; Keiner & Graulich, 2020).

Alternative Concepts

Students develop their own ideas and beliefs about natural events before they start their formal education and come to class with those ideas and beliefs (Palmer, 1999). Most of the time such ideas and beliefs do not compatible with scientific explanations and affect students' subsequent learning negatively (Barke, Hazari, & Yitbarek, 2009; Garnett, Garnett, & Hackling, 1995; Hewson & Hewson, 1984; Karpudewan, Zain, & Chandrasegaran, 2017). These ideas can be called misconceptions, alternative concepts, intuitive beliefs, alternative frameworks, preconceptions, children's science, spontaneous reasoning, and naïve beliefs (Karpudewan et al., 2017). The sources of alternative concepts can be prior knowledge, the complexity of the chemical concepts, personal experiences, interactions with friends and textbooks, and even teachers (Chiu, 2007; Devetak, Vogrinc, & Glazar, 2010; Dhindsa & Treagust, 2014; Johnstone, 2010; Sanger & Greenbowe, 1999; Taber, 2002; Wu, Krajcik, & Soloway, 2001). Barke et al. (2009) state that alternative concepts are mostly constructed by teaching methods and materials which are called school-made misconceptions and offer an efficient way to deal with such misconceptions as preparing pre-service teachers qualified about alternative concepts.

It is an indisputable fact that teachers' beliefs are resistant to change and they reflect these beliefs and ideas in their courses (Kagan, 1992). If their views are incompatible with scientific knowledge, they can mislead their students. That is why it is important to resolve teachers' alternative concepts if they have one. One of the effective solutions might be diagnosing PSTs' alternative concepts and correcting them with scientifically acceptable ones. In other words, PSTs should learn science concepts accurately and with confidence (Tekkaya, Çakıroğlu, & Özkan, 2004) to enable their students to have successful science learning.

To prevent alternative concepts, it is crucial to diagnose and cure them as early as possible. There are several methods to determine and prohibit alternative concepts. Köse (2008) lists some of these methods as open-ended questions, two-tier diagnostic tests, concept mapping, prediction-observation-explanation, interviews about instances and events, interviews about concepts, word association, and drawing. Other than these methods, Nyachwaya et al. (2011) offered an alternative method which is an open-ended drawing tool and aims to demonstrate students' answers through particulate diagrams in order to reveal their understanding at the sub-microscopic level. Although drawings are usually used to reveal students' conceptions about subjects, recent studies in chemistry education have focused on learner-generated particulate drawings as an evaluation tool (Davidowitz et al., 2010; Kern et al., 2010; Nyachwaya et al., 2011). One of the common features of diagnosing/measuring instruments used in literature is usually based on the symbolic level such as mathematical calculations, choosing one of the multiple choices, or explaining in a verbal form. Yet, the use of particulate drawings addresses the sub-microscopic level that reveals understanding beyond the symbolic level (Nyachwaya et al., 2011).

Chemical Reactions, Atomic Size, and Molecular Geometry

To understand most of the basic concepts and processes in chemistry, chemical reactions have vital importance to be understood (Barke et al., 2009). There are many studies in the literature that reveal students' alternative concepts about chemical reactions and equilibrium (Cheng & Gilbert, 2010; Eilks, Moellering, & Valanides, 2007). Some common alternative concepts found in these studies are given in Table 1.

Table 1. Some Common Alternatives for Chemical Reactions and Equilibrium

- The concentrations of all chemical substances are equal at equilibrium.
- The rate of forwarding reaction increases with time from mixing the reactants until equilibrium is established.
- In equilibrium the sum of the amount of matter (concentration) of reactants is equal to the sum of the amount of matter (concentration) of the products.
- In equilibrium the amounts (concentrations) of all substances which are involved in equilibrium are the same.
- Large values of equilibrium constant imply a very fast reaction.
- The sum of the amounts of matter (concentrations) remains the same during a reaction.

Chandrasegaran, Treagust, and Mocerino (2007) concluded their study by stating high school students have a limited understanding of multiple representations of chemical reactions. The studies done by Kern et al. (2010), Davidowitz et al. (2010), and Nyachwaya et al. (2011) support this conclusion. For example, Kern et al. (2010) reached that a large number of high school students were able to balance the equation correctly but were unable to show the appropriate particulate representation. Similar studies were done by Davidowitz et al. (2010) and Nyachwaya et al. (2011) with undergraduate students and reached the same results as Kern et al. (2010). The general view based on findings of the studies in related literature shows that students are successful in balancing and understanding chemical equations concerning stoichiometric coefficients, mass conservation, and limiting reagents. However, they have limited understanding due to the invisible nature of chemical reactions on a particulate level and the particulate nature of matter (Garnett et al., 1995). The literature, in general, agrees that a complete understanding of chemical reactions requires “a sound grasp of sub-micro representations” (Cheng & Gilbert, 2017, p. 1177).

The concepts related to atomic size are also crucial for meaningful chemistry learning since they are connected to other chemistry topics like chemical bonding, properties of the elements in the periodic table, and ionization energy (Eymur, Çetin, & Geban, 2013). Although the topic of the size and shape of atoms have great importance, students have a lot of alternative concepts related to it (for more see Cokelez, 2012). Eymur and colleagues (2013) state that the abstract nature of an atom and inappropriate instructions to teach the relevant concepts are the main reasons for these alternative concepts.

Molecular geometry is another important topic for chemistry education because it constitutes a basis for organic chemistry, orbital hybridization, and molecular polarity (Ibrahim & Harun, 2019). Furthermore, the topic has a great impact on the physical and chemical properties of a molecule because such properties are determined by the arrangement of its atoms (Chang & Overby, 2019). One of the significant reasons to learn molecular geometry is that it enables learners to construct a three-dimensional image of the molecule by using a two-dimensional representation of the molecule (Ibrahim & Harun, 2019). In other words, students can create a three-dimensional structure of the molecule in their minds by using chemical formulas and Lewis structures (Brown et al., 2018). Nevertheless, students mostly face difficulties comprehending the topic of molecular geometry due to its abstract nature (Erlina, Cane, & Williams, 2018) and many studies investigated the alternative concepts related to molecular geometry held by students (for more see Uyulgan, Akkuzu, & Alpat, 2014). As a consequence, intangible and complex structures of chemical concepts, and the difficulties moving among the three representation levels of chemistry are two fundamental reasons for students to understand and comprehend chemical concepts meaningfully (Gabel, 1999; Johnstone, 1993; Nakhleh, 1992; Rogers, Huddle, & White, 2000).

Importance of the Study and Research Questions

Most of the findings in Table 1 were usually based on questionnaires that involve students’ explanations in verbal form or multiple-choice questions depending on mathematical calculations. This study is different from others concerning gathering data instrument that is used in a few studies (Davidowitz et al., 2010; Kern et al., 2010; Nyachwaya et al, 2011). This study is also distinctive from these studies because the current study participants are PSTs who will teach the topic in their future careers. That is why diagnosing PSTs’ alternative concepts about chemical reactions and equilibrium, and correcting them with scientific ones is crucial. Within this respect, the research questions were determined as follows:

- How do pre-service science teachers balance chemical equations?
- How do pre-service science teachers represent the molecular geometry of the atoms/ions or molecules in the process of chemical reactions at the sub-microscopic level?
- How do pre-service science teachers represent the size of the atoms/ions or molecules in the process of chemical reactions at the sub-microscopic level?

Method

Participants

The study was done with a total of 205 pre-service science teachers, 56 of them were first-year students, 35 of them were second-year students, 51 of them were third-year students, and 63 of them were fourth-year students. The Council of Higher Education determines the curriculums of programs in the faculties at universities in Turkey. That is why every science education program at universities in Turkey has the almost same quadrennial curriculum, in which PSTs take two chemistry courses (General Chemistry I & II) in their first year and also take another two chemistry courses (Analytical Chemistry & Organic Chemistry) in their second year. In addition, the curriculum also involves pedagogical courses such as introduction to education, educational psychology, principles and methods of instruction, science curriculum and planning, teaching methods, classroom management, and teaching practice. The advantage of determining PSTs from the first year to the fourth year enabled us to see the effects of courses about chemistry and education on participants' alternative concepts.

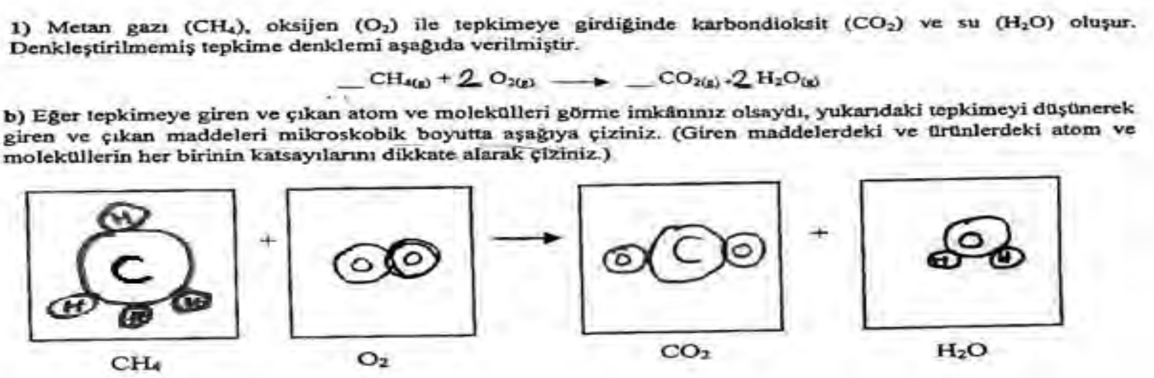
Data Collection

Questionnaire

The open-ended drawing response questionnaire developed by Nyachwaya et al. (2011) was used in the study. The instrument involves a broader range of chemical reactions to have rich data about students' conceptual understanding of the particulate nature of matter. The chemical reactions in the questionnaire cover covalent compounds (combustion of methane), ionic compounds (precipitation reaction), and a reaction with both covalent and ionic compounds. The original form of the questionnaire involves two steps. In the first step, PSTs balance the equations mathematically, and in the second step, they draw the reaction at the sub-microscopic level concerning what they could see if they were able to observe the particles of chemical components in the chemical reactions. The instrument was translated into Turkish and two instructors from the Department of Chemistry Education checked in terms of the understandability of questions and another instructor assessed the instrument about its translation. The study was done at the end of the spring term of the school year. That is why it was assumed that the first-year PSTs took the two chemistry courses (General Chemistry I & II) and two pedagogical courses (Introduction to Education & Educational Psychology); the second-year PSTs took another two chemistry courses (Analytical Chemistry & Organic Chemistry) and another two pedagogical courses (Principles and Methods of Instruction & Science Curriculum and Planning); the third year PSTs took pedagogical courses (Teaching Methods) other than the first and second year PSTs. Lastly, the fourth-year PSTs took other pedagogical courses such as classroom management and teaching practice. The questionnaire was administered as a quiz in a chemistry laboratory session.

Data Analysis

Descriptive statistics were used to analyze the PSTs' drawings. They were analyzed based on the two themes, molecular geometry, and atomic/ionic size, by using content analysis. For molecular geometry, if a PST drew all the atoms, molecules, or ions in the reaction correctly, then his/her drawing was counted as correct. If s/he had one or more wrong drawing(s), then the drawing was counted as false. Correct drawings were calculated as percentages. For the atomic size, similarly, if a PST drew all of the atoms, molecules, or ions by considering its size, then it was counted as correct. If there were one or more wrong drawings related to atomic/molecular size, then the drawing was considered false. And, again, correct drawings were calculated as percentages. Two researchers coded 25% of the participants' responses separately and then compared their results. The inter-rater reliability was found at 96.4%. Any disagreements between researchers were discussed and arrived at a consensus. Then, one of the researchers coded the remaining data set. Figures 1a, 1b, and 1c indicate one of the PSTs' drawings showing sub-microscopic representations of chemical reactions that are considered correct.

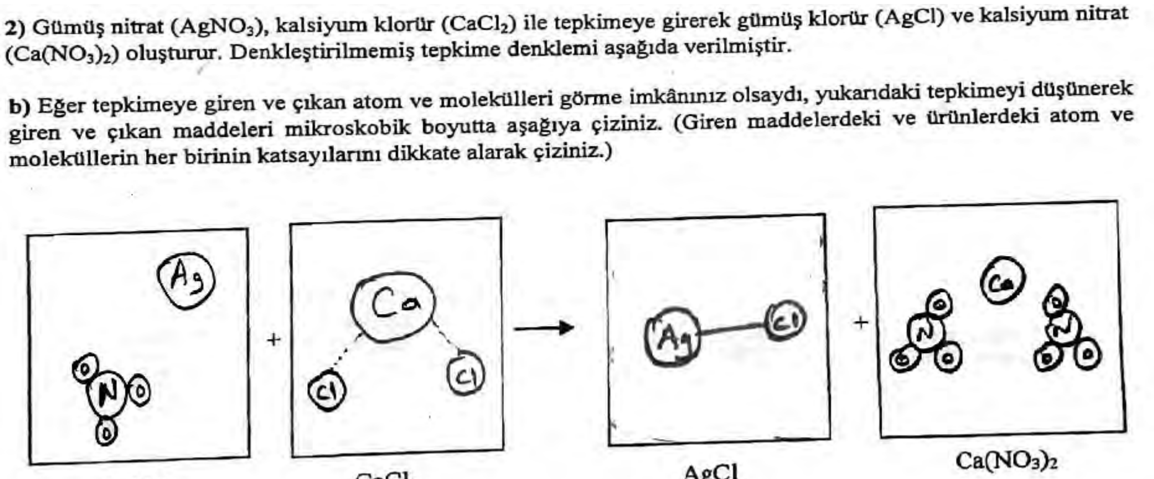


1) Metan gazı (CH_4), oksijen (O_2) ile tepkimeye girdiğinde karbondioksit (CO_2) ve su (H_2O) oluşur. Denkleştirilmemiş tepkime denklemi aşağıda verilmiştir.

$$\_\_\ CH_{4(g)} + 2\ O_{2(g)} \longrightarrow \_\_\ CO_{2(g)} + 2\ H_2O_{(g)}$$

b) Eğer tepkimeye giren ve çıkan atom ve molekülleri görme imkânınız olsaydı, yukarıdaki tepkimeyi düşünerek giren ve çıkan maddeleri mikroskobik boyutta aşağıya çiziniz. (Giren maddelerdeki ve ürünlerdeki atom ve moleküllerin her birinin katsayılarını dikkate alarak çiziniz.)

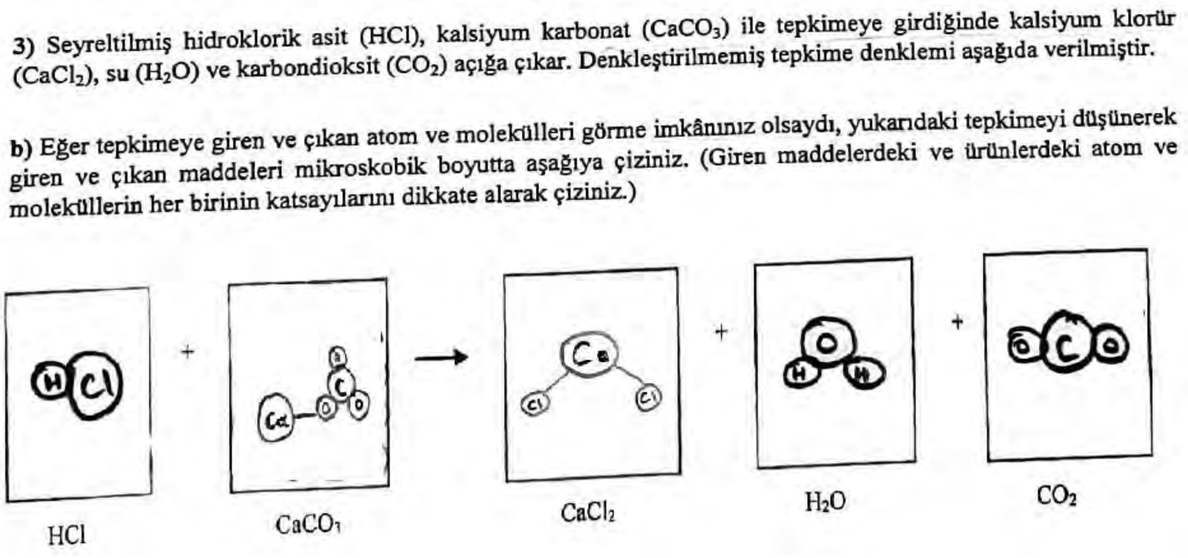
Figure 1a. Sub-Microscopic Representations of the Chemicals in the Combustion Reaction



2) Gümüş nitrat ($AgNO_3$), kalsiyum klorür ($CaCl_2$) ile tepkimeye girerek gümüş klorür ($AgCl$) ve kalsiyum nitrat ($Ca(NO_3)_2$) oluşturur. Denkleştirilmemiş tepkime denklemi aşağıda verilmiştir.

b) Eğer tepkimeye giren ve çıkan atom ve molekülleri görme imkânınız olsaydı, yukarıdaki tepkimeyi düşünerek giren ve çıkan maddeleri mikroskobik boyutta aşağıya çiziniz. (Giren maddelerdeki ve ürünlerdeki atom ve moleküllerin her birinin katsayılarını dikkate alarak çiziniz.)

Figure 1b. Sub-Microscopic Representations of the Chemicals in the Reaction

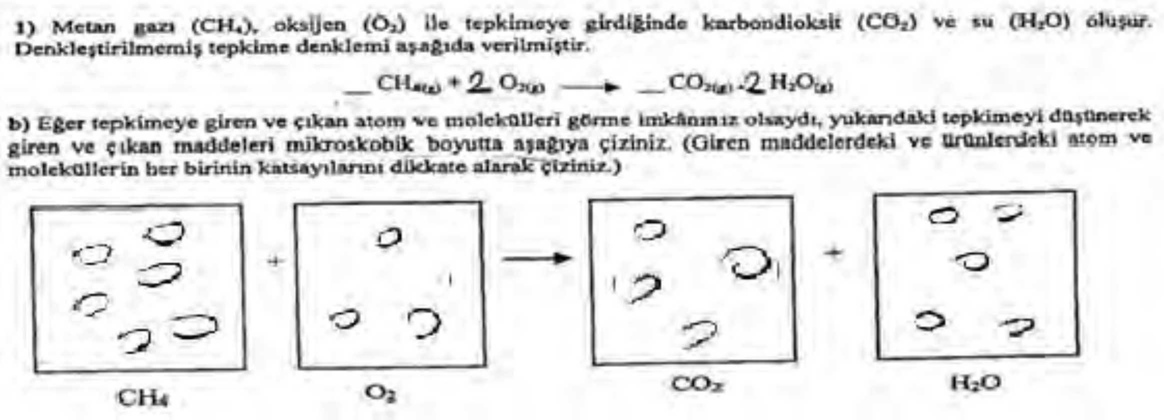


3) Seyreltilmiş hidroklorik asit (HCl), kalsiyum karbonat ($CaCO_3$) ile tepkimeye girdiğinde kalsiyum klorür ($CaCl_2$), su (H_2O) ve karbondioksit (CO_2) açığa çıkar. Denkleştirilmemiş tepkime denklemi aşağıda verilmiştir.

b) Eğer tepkimeye giren ve çıkan atom ve molekülleri görme imkânınız olsaydı, yukarıdaki tepkimeyi düşünerek giren ve çıkan maddeleri mikroskobik boyutta aşağıya çiziniz. (Giren maddelerdeki ve ürünlerdeki atom ve moleküllerin her birinin katsayılarını dikkate alarak çiziniz.)

Figure 1c. Sub-Microscopic Representations of the Chemicals in the Acid-Base Reaction

On the other side, Figures 2a, 2b, and 2c indicate another one of the PSTs' drawings showing sub-microscopic representations of chemical reactions that are considered wrong.

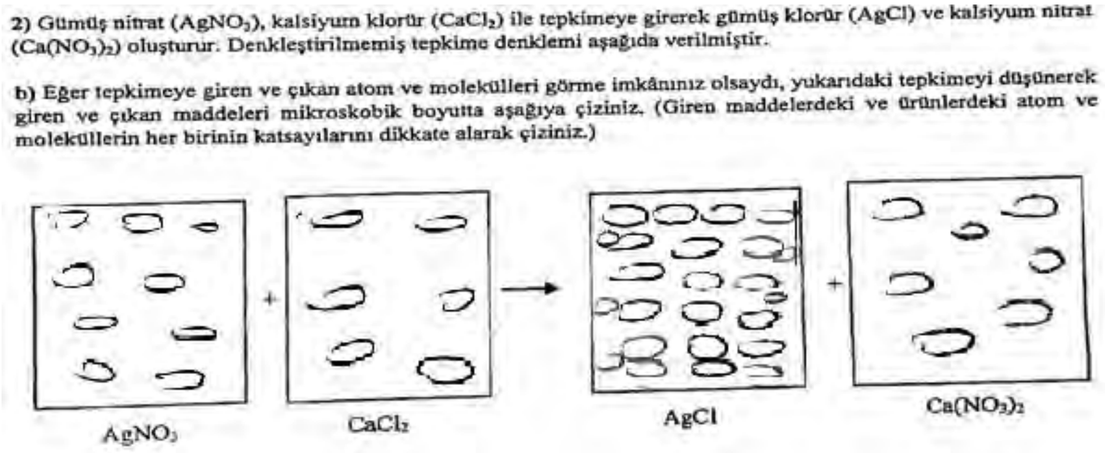


1) Metan gazı (CH_4), oksijen (O_2) ile tepkimeye girdiğinde karbondioksit (CO_2) ve su (H_2O) oluşur. Denkleştirilmemiş tepkime denklemi aşağıda verilmiştir.

$$\_\_\ CH_{4(g)} + 2\ O_{2(g)} \longrightarrow \_\_\ CO_{2(g)} \cdot 2\ H_2O_{(g)}$$

b) Eğer tepkimeye giren ve çıkan atom ve molekülleri görme imkânınız olsaydı, yukarıdaki tepkimeyi düşünerek giren ve çıkan maddeleri mikroskobik boyutta aşağıya çiziniz. (Giren maddelerdeki ve ürünlerdeki atom ve moleküllerin her birinin katsayılarını dikkate alarak çiziniz.)

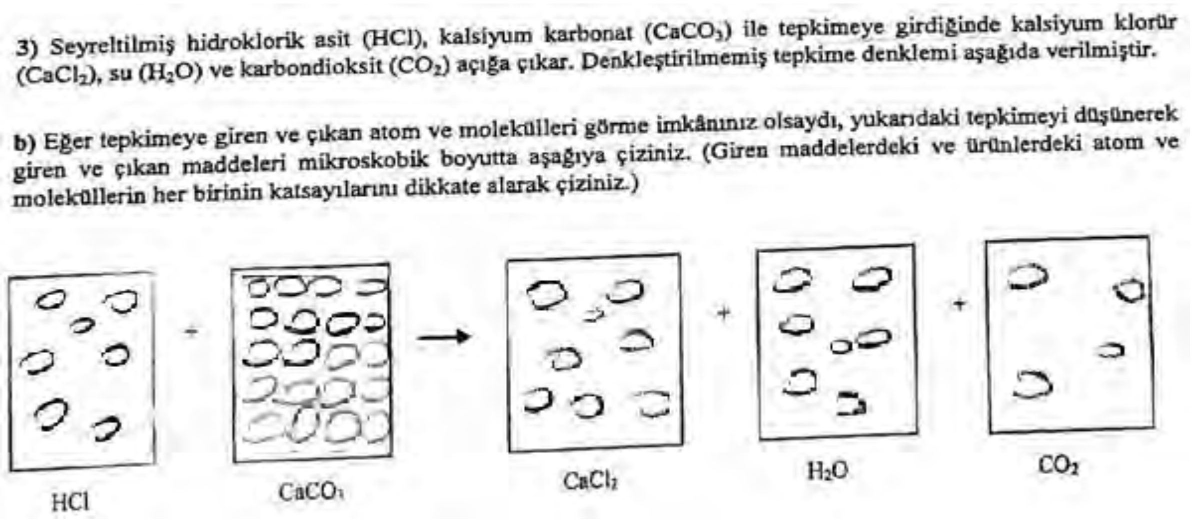
Figure 2a. Sub-Microscopic Representations of the Chemicals in the Combustion Reaction



2) Gümüş nitrat ($AgNO_3$), kalsiyum klorür ($CaCl_2$) ile tepkimeye girerek gümüş klorür (AgCl) ve kalsiyum nitrat ($Ca(NO_3)_2$) oluşturur. Denkleştirilmemiş tepkime denklemi aşağıda verilmiştir.

b) Eğer tepkimeye giren ve çıkan atom ve molekülleri görme imkânınız olsaydı, yukarıdaki tepkimeyi düşünerek giren ve çıkan maddeleri mikroskobik boyutta aşağıya çiziniz. (Giren maddelerdeki ve ürünlerdeki atom ve moleküllerin her birinin katsayılarını dikkate alarak çiziniz.)

Figure 2b. Sub-Microscopic Representations of the Chemicals in the Reaction



3) Seyreltilmiş hidroklorik asit (HCl), kalsiyum karbonat ($CaCO_3$) ile tepkimeye girdiğinde kalsiyum klorür ($CaCl_2$), su (H_2O) ve karbondioksit (CO_2) açığa çıkar. Denkleştirilmemiş tepkime denklemi aşağıda verilmiştir.

b) Eğer tepkimeye giren ve çıkan atom ve molekülleri görme imkânınız olsaydı, yukarıdaki tepkimeyi düşünerek giren ve çıkan maddeleri mikroskobik boyutta aşağıya çiziniz. (Giren maddelerdeki ve ürünlerdeki atom ve moleküllerin her birinin katsayılarını dikkate alarak çiziniz.)

Figure 2c. Sub-Microscopic Representations of the Chemicals in the Acid-Base Reaction

Results

For the first research question, it was found that almost all of the PSTs (except four third-year PSTs) balanced the three chemical equations correctly. Then drawing proper representations concerning the coefficients of the chemicals in the equations were checked. It was reached that four first-year PSTs (7.1%) drew their representations without considering the coefficients of the chemicals in the three equations. In addition, six first-year PSTs didn't draw the compounds correctly concerning the coefficients for the first chemical reaction. For the second chemical reaction, eight first-year PSTs and for the third chemical reaction, seven first-year PSTs did not pay attention to the coefficients of the compounds while drawing them.

For the second-year PSTs, four PSTs (11.4%) didn't consider the coefficients of the three chemical reactions when drawing the compounds. Moreover, three second-year PSTs didn't draw the compounds in the first chemical reaction while drawing them. Whereas ten second-year PSTs drew the compounds without considering the coefficients in the second reaction, seven second-year PSTs didn't draw the compounds in the third chemical reaction concerning the coefficients.

For the third-year PSTs, 13 PSTs (25.5%) didn't draw the compounds with respect to the coefficients in the three chemical reactions. Furthermore, nine third-year PSTs didn't take consider the coefficients while drawing the compounds in the first chemical reactions. Ten third-year PSTs didn't draw the compounds in the second reaction based on the coefficients. Last, eight third-year PSTs didn't pay attention to the coefficients of the compounds in the third chemical reaction while drawing them.

For the fourth-year PSTs, 11 PSTs (17.5%) didn't emphasize the coefficients of the compounds in the three chemical reactions. Besides five fourth-year PSTs didn't draw the compounds in the first chemical equation concerning the coefficients of the chemicals. In addition, 17 fourth-year PSTs didn't consider drawing the compounds concerning the coefficients in the second reaction. Once again, 9 fourth-year PSTs drew the compounds in the third reaction without considering the coefficients.

For the second and third research questions, PSTs' drawings were analyzed concerning the two main themes: molecular geometry and atomic/ionic size. Figure 1 shows the findings for the first theme which is the molecular geometry of ions and/or molecules. The findings revealed that 41.7% of PSTs drew the correct geometry of ions and/or molecules. Whereas the fourth-year PSTs mostly paid attention to the correct geometry of the ions and/or molecules, it had the lowest ratio for the second-year PSTs. Four out of ten first-year PSTs drew the correct geometrical shapes of the chemical compounds. For the third-year PSTs, it was reached that three out of ten depicted the geometrical shapes of ions and/or molecules correctly.

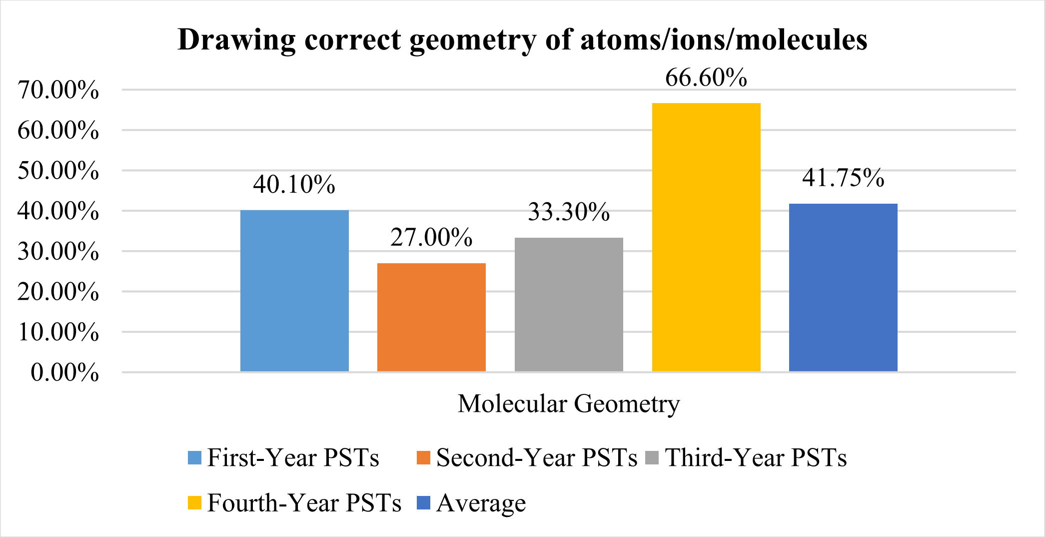


Figure 1. Drawing Correct Geometry of Atoms/Ions/Molecules by Grade Levels

Figure 2 indicates the results for the second theme which is atomic/ionic size. The findings show that 23.2% of PSTs presented the sizes of the atoms/ions without a problem. It was the highest percentage for the first-year PSTs and the lowest value for the third-year PSTs. In terms of the second-year and third-year PSTs, the results were also found relatively low (19.8% and 26.6%, respectively).

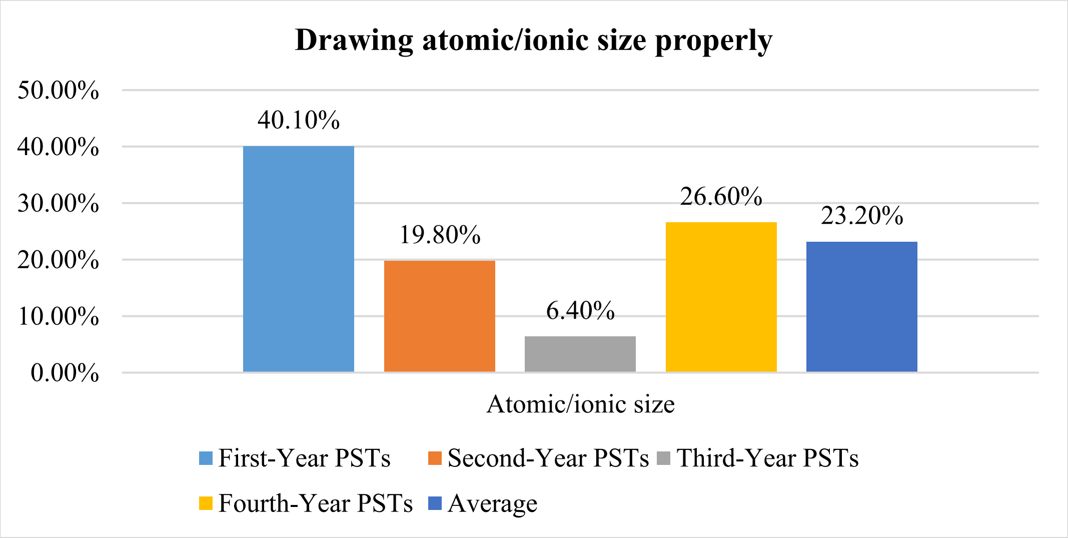


Figure 2. Drawing Atomic/Ionic Size by Grade Levels

Discussion and Conclusion

The current study examined PSTs' ability to shift from the symbolic representation to the sub-microscopic representation. The findings revealed that PSTs are most successful at the symbolic level because almost all of them balanced the chemical reactions correctly. This result is compatible with some other studies (Davidowitz et al., 2010; Kern et al., 2010; Nyachwaya et al, 2011). Nevertheless, the same success is not valid for the sub-microscopic representation level. PSTs are seriously unsuccessful at the sub-microscopic level.

Comprehending chemical phenomena at each representation level and moving between them is a way of meaningful understanding in chemistry (Gkitzia, Salta, & Tzougraki, 2020; Keiner & Graulich, 2020; Taber, 2013). However, in the current study, PSTs were not usually successful move from the symbolic level to the sub-microscopic level. They had alternative concepts about the molecular shapes of compounds and the size of molecules or ions. This result shows that PSTs may be successful at the symbolic level because of their achievements in math since although they were able to balance the equations in the chemical reactions, some of them did not consider even the coefficients of compounds or molecules while drawing them in the sub-microscopic level. It indicates that PSTs' understanding of chemical reactions at the symbolic level dominates more than the other two levels (Sinaga, 2022). It is possible that PSTs' success in presenting the chemical reactions at the symbolic level does not guarantee the ability to represent the given reactions at the sub-microscopic level (Putica, 2022).

Furthermore, fourth-grade PSTs drew the molecular geometry of ions or molecules better than the other grade levels. Pre-service teachers in Turkey must take an exam to be assigned as in-service teachers at public schools after graduation. That is why most pre-service teachers prepare for the exam in their last year. The exam includes both pedagogy and content knowledge. This can be a reason to have more correct molecular geometry drawing among fourth-grade PSTs. Although the fourth-grade PSTs were not the most successful ones for drawing the size of atoms, ions, or molecules, they were the second group after the first-grade PSTs. First-grade PSTs take General Chemistry I and II courses in their first year in the program, so their content knowledge may be better than the other grade levels, which can be a reason why the first-grade PSTs have better percentages than the second and third-grade ones.

This study revealed that although PSTs are able to balance the chemical reactions properly, they were not successful to draw them at the sub-microscopic level if they were able to observe it. Although the first and fourth-grade PSTs drew relatively better molecular geometry of ions or molecules and size of atoms, ions, or molecules than the other grade levels, these were not an expected level. Since PSTs will teach the topic in their future professional careers, they shouldn't have alternative concepts about the topic. If they have, then it is possible that their students might have similar alternative concepts about the topic, which can be labeled as school-made alternative concepts. In order to prevent such kind of conclusions, PSTs should be taught better about the sub-microscopic level of chemical representations. Recently, educational technologies present great opportunities for teacher educators or chemistry teachers in order to visualize the sub-microscopic level of chemical entities. They can be used in class. Moreover, the move between the representational levels can be emphasized more while teaching the topic. For example, PSTs should be able to observe and understand a molecule's, atom's, or ion's representation at each level and should be able to move between them easily and correctly. Consequently, an essential outcome of this study is to teach the representation levels in chemistry that should be emphasized more in classes, in which great responsibility falls on teacher educators and chemistry teachers.

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