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Students' Metaphors on Formation of Molecules from Atoms

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Abstract

Chemistry as a discipline in general incorporates abstract concepts, which should be visualized through experiment- and application-oriented methods. It is a well-known fact in Turkey that chemistry class offered by simple and traditional methods cannot be understood by students at a satisfactory level. Such chemical subjects as atoms, molecules, and compounds include abstract concepts of this kind. The visualization of these structures is as strenuous as their teaching. Among the most arduous subjects is the teaching of the mechanism by which atoms form molecules, compounds, and many other structures by means of chemical and physical bonds. Students cannot conceptualize and understand such aspects as atom, molecule, compound, and mixture. The data were collected in a case study, a qualitative research design, to investigate the metaphors that were produced by 169 students of associate degree and bachelor's degree programs to refer to the formation of molecules from atoms. 167 students produced acceptable metaphors, which were categorized into eight themes. All the created metaphors incorporate positive connotations. It can be proposed based on the metaphors that the subjects at stake can be metaphorized and thematized for the concretization thereof. Thus, learning becomes more permanent and effective.

Keywords: Atom, Molecule, Students' Views, Metaphor, Formation of Molecules From Atoms

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Introduction

Humans are born, grow up, and live as thinking and reasoning beings. Since they have the ability of thinking, they can pass down their accumulated body of knowledge on upcoming generations. The ability to think can be given shape by education and environment. Thinking, in other words reasoning, is closely associated with our accumulated body of knowledge. “If we had an able repertoire of concepts and idioms applicable to thinking operations, then the resultant intellectual products would doubtlessly be far more different than those in reality. Since we would be able to define and make our statements explicitly and clearly, there would remain no dark spot in the information sets we have produced and in the propositions where these sets are externalized” (Uygur, 1962, 125). A better understanding and appreciation of the world can only be achieved by means of a competent reserve of concepts and idioms. Thinking plays a decisive role in an individual’s sensing and making sense of the world. “Because a great number of concepts that matters for us are abstract or not clear in our experiences (emotions, ideas, time, etc.), we attempt to understand them through other concepts that we can make sense of in clearer terms (spatial orientations, objects, etc.). This results in metaphor-based depictions in our conceptual system” (Lakoff and Johnson, 2003: 115). This holds true regardless of the field in which accumulation is performed; it could be in either social or natural sciences. The quality and quantity of the repertory of concepts and idioms plays a critical role in the way we understand the world. "Our everyday conceptual system, by which we think and act, is basically metaphorical in nature” (Lakoff and Johnson, 2003: 3). Therefore, views and thoughts individuals have developed in relation to a given subject matter and statements reflecting these views and thoughts are highly important. What is crucial here is teaching a subject by relying on individuals’ accumulated knowledge or determining their awareness of the subject. Knowing about the previously gained knowledge and awareness thanks to educational and instructional tasks allows for an easier and effective implementation of what is intended.

Metaphor refers to the expression of personal thoughts on a specific matter, situation, or happening. “Metaphors consist of nouns and nouns refer to beings. Besides, words created with nouns express our thoughts as well as representing beings. Then, metaphors comprising nouns and words too represent beings. Metaphors literally re-create beings through transfers between beings and nouns” (Ekinci, 2018, 164). Metaphors by individuals are significant data sources of human training and education to assess the immediate condition and produce solutions based on the assessments. Metaphors can be employed to determine students’ readiness in educational studies and can serve as viable educational tools to help them make sense of and perceive abstract concepts. “Since the mid-twentieth century, philosophers have manifested that metaphors are not simply teaching tools but are fundamental to human thought and provide a basis for mental leaps. Metaphors capacity to contribute to cognitive learning has attracted the attention of the science educators” (Niebert, Marsch, and Treagust, 2012: 2). Metaphors can prove useful in teaching hard-to-learn abstract concepts in science

teaching and determining how these concepts are perceived. "There are two principles for science education when considering experientialism as a theory of understanding and implementing it in science teaching. The first one is to help students create direct conceptions: As direct conceptions entail first-hand experience, teachers are expected to offer students opportunities to experience the phenomena to be taught. It can be performed via explorations or experiments. The second principle is to allow students to produce imaginative conceptions: Metaphors enable students to link between their conceptions and the phenomena at stake. This aspect looks appropriate for phenomena impossible to experience directly" (Niebert, Marsch and Treagust, 2012, 6).

Metaphors are used in educational research and studies. "Metaphors are used to determine perceptions, points of view, or attitudes of individuals towards abstract concepts. Studies on metaphors are frequently carried out in teaching mathematics and natural sciences, which students have difficulty learning because they contain abstract concepts. It was observed that metaphor studies in this field in Turkey were frequently carried out to determine participants' perceptions of a particular subject or concept, especially after the 2000s, and the number of these studies has substantially increased since 2012 and the highest number (25.31%) was observed in 2016. Metaphor's being used as a teaching tool in almost all of the analyzed studies (94.94%) substantiates this proposition (Pırasa, Şadoğlu, and Kuvvet, 2018, 697). It was observed that studies on the use of metaphors in science teaching, such as Minas and Gündoğdu (2013), Derman (2014), DönmezUsta and Ültay (2015), Aygün, Durukan, and Hacıoğlu (2015), Bıyıklı, Başbay, and Başbay (2014), Buyruk and Korkmaz (2016), Çelik (2016),Anılan (2017), Arslan and Zengin (2017) , were intended for some specific concepts in science teaching classes. Research is available on the use of metaphors in science teaching, i.e. Soysal and Afacan (2012), DemirciGüler (2012). Çilingir (2014), Aktamış and Dönmez (2016), Ekici (2016), Çetin (2016), Arık and BenliÖzdemir (2016).

One should start teaching the basic concepts of a field at stake in the initial steps of education, be it in natural or social sciences. "Going beyond the teaching of simple literacy and arithmetic, one of the most important missions of education is to enable students to understand the ways of thinking of the various disciplines, particularly disciplines such as the physical sciences and mathematics" (Vosniadou, 2007, 47). Whatever the field of study is, its principal concepts, theories, and laws should be learned, through which students can be helped acquire the thinking ways thereof.

Chemistry is a concept occurring in all walks of life. Among the first concepts to be taught in chemistry classes are atoms and formation of molecules from atoms. Hence, students' experience-induced views of chemistry and of atoms and formation of molecules from atoms as chemistry's fundamental concepts are greatly important. In a regular and planned manner, chemistry education should be offered starting at elementary school. "Even though chemistry is an inseparable part of everyday life, students have problems with concretizing many chemical concepts" (Yadigaroğlu,

Demircioğlu, and Demircioğlu, 2017, 797). According to the data from the previous research, while a student is able to solve a mathematical problem regardless of its level of difficulty, he/she cannot understand very simple theoretical and conceptual matters (Case and Fraser, 1999; Masson and Vazquez-Abad, 2006). The analysis of the studies on chemistry - of fundamental natural sciences - has revealed that students do not fully understand a concept of the theory of a subject whose cognitive representation a student of chemistry generates (Nakhleh, 1992). There are numerous studies on a great many concepts of natural sciences - as well as of chemistry education (Çalık and Ayas, 2005; Mirzalar Kabapınar, 2008; Nakhleh and Krajcik, 1994; Özmen, Demircioğlu and Demircioğlu, 2009). These basic concepts generated by scientists as a result of long experiences and longitudinal research should be taught effectively. Otherwise, students may suffer from grave problems with upcoming subjects. To exemplify, while teaching chemical bonds - one of the basic subjects -, interactions including weak bonds are taught as well. However, as solids and liquids in the following subjects are offered, the concept of weak interaction in their minds is likely to confuse students. As understood from the analysis of the sample subjects concerning chemical bonds to form molecules and compounds, the potentially difficult concepts are as follows: interatomic bonds originate from the interelectronic static attractive force. Among the concepts that students have difficulty comprehending are the causes of the interactions between atoms and molecules and the mechanism whereby they are formed (Nicoll, 2001). In a compound which incorporates lithium and hydrogen atoms, the bond between two atoms is called ionic bond (Atasoy, Kadayıfçı, and Akkuş, 2003). There exist no chemical bond and intermolecular attractive forces in the formation mechanism of a solid. Gases form as a result of repulsion of atoms therein (Brook, Briggs, and Driver, 1984). The conception that a molecule's chemical structure is determined thanks to the nonbinding electrons on atoms is another difficulty (Peterson, Treagust, and Garnett, 1989). Ignoring the presence of the octet structure in Lewis electron dot formulae and confusing ionic bond forming interatomic bonds with covalent bond is another difficulty (Taber, 1994). The content of the chemical bonds needed for the formation of molecules involve abstract concepts, and students encounter difficulty understanding this subject (Coll and Taylor, 2002; Levy Nahum, Mamlok Naaman, Hofstein and Taber, 2010; Özmen, 2004). The content of the physical and chemical bonds and interactions between atoms and molecules are taught by using abstract concepts, which makes it difficult for students to comprehend the subject (Griffiths and Preston, 1992). According to Ruth Ben-Zvi, Bat-Sheva Eylon, and Judith Silberstein (1986), the atomic model plays a central role in the study of chemistry and is generally offered very early in the curriculum. Therefore, it is important to examine the mental pictures of the atomic model created by students at an early stage. This is because misunderstanding the model is likely to prevent meaningful learning at later stages. These researchers have conducted a three-stage study: A diagnostic investigation of students' views about structure in chemistry, development and implementation of a

program designed to prevent some of the misconceptions identified in the first stage, and an evaluation of the new program.

There are studies on this issue. Ayas and Demişbaş (1997) have investigated the introductory concepts, such as element, compounds, mixture, and physical and chemical changes) as a result of instruction based on the currently used chemistry textbooks in Turkish secondary schools. Several studies on the formation of molecules from atoms and on atoms and molecules are available in the related literature. The study carried out by Sağlam (1998) on 210 students has found that more than 50% of the students cannot understand some basic chemical concepts in the Grade 5 science textbook. In the study by Nakiboğlu, Karakoç, and Benlikaya (2002), the participating students have been asked to draw the atomic model. İyibil and Sağlam-Arslan (2010) have investigated whether prospective teachers can develop mental models in consideration of scientific knowledge and have roughly reported that prospective teachers hold no knowledge of such mental models. Gökulu and Geban (2014) have conducted a study to research the effects of the instruction based on conceptual change approach supplemented by analogies on seven graders' understanding of atom, molecule, ion, and matter and they have shown that the students having been informed about the subject are more successful in the subjects concerning atom, molecule, ion, and matter than the other students. In "Assessing the Ways 7th Grade Students of Secondary School Follow in Forming the Atomic and Molecular Model", Bilge and Bahçeci (2017) have found that students' ability to choose the materials suitable for their mental models and the studied subject affect the instruction of a given subject.

Purpose of the Research

In the present study, the participating students were asked to create metaphors on how atoms are formed from molecules. The study was conducted on the students at different educational stages in different fields. The obtained metaphors were grouped into themes for the purpose of the study. The students take chemistry-focused or -related classes at 9th, 10th, 11th, and 12th grade and in post-secondary programs and they learn many abstract concepts, such as atomic modeling and its relevance to chemistry, formation of molecules and compounds from atoms, intramolecular and intermolecular bonds and interactions. This research study was conducted due to students' low level of success in this subject. It aims to determine what should be done while learning and teaching process by concretizing their thoughts on the formation of molecules from atoms. The study attempts to answer the following questions in view of the aim above:

1. What are the metaphors the students created in relation to the formation of molecules from atoms?

2. In what themes can the metaphors the students created in relation to the formation of molecules from atoms be classified?

Method

Research Model

This case study attempted to identify and analyze the thoughts of the students who were offered the concept of molecule formation from atoms either for a short or long while in the course of formal education. “Case study is a research method similar to qualitative research designs and among the research approaches adopted by individuals, decision-makers, or institutions to gain in-depth insight into a phenomenon and sometimes to account for a theory’s accuracy and context-bound efficacy” (Saban and Ersoy, 2017, 174).

Sampling

The maximum variation sampling method, a type of purposive sampling, was adopted to create the sample consisting of the students in associate and bachelor’s degree programs in a faculty of education, a faculty of arts and sciences, and a vocational school in western Turkey. “In purposive sampling, a population is divided into groups for the purpose of the study. Of these groups, the one considered the best fit for the research is adopted as the sample” (Şahin, 2014, 125). The students of associate degree and bachelor’s degree programs who were thought to have created diagrams or atoms of how molecules are formed from atoms in the life science class of primary education and chemistry class of secondary education were purposefully included in the study. 116 students from the faculty of education, 23 from the faculty of arts and sciences, and 30 from the vocational school participated in the study, which was carried out in the spring semester of the 2018-2019 academic year.

Data Collection

The students were invited to fill in the form “Metaphors by Students on Formation of Molecules from Atoms” and the contents of the collected forms were analyzed. The forms incorporate data on personal facts, metaphors on formation of molecules from atoms, and underlying reasons of the metaphors. The data were collected by asking the participants to fill in the statement “Formation of molecules from atoms is like ..... because .....”, following the section including the demographic items. The reliability of the form was assessed based on the views of three experts in the field and then the semi-structured interview was administered to the participants.

Data Analysis

The data were evaluated by content analysis. The main purpose of content analysis is to cluster data with similar characteristics around themes and to interpret them in a way that readers can understand (Yıldırım and Şimşek, 2006). The data were analyzed by means of theme coding and thematization/categorization. To ensure the validity and reliability of the data, verbatim/direct quotes from the data were used.

Creating Metaphors

After the students of associate degree and bachelor's degree programs created metaphors, they were digitalized to produce the table of metaphors. The metaphors by 169 students were examined by two data coders, after which the metaphors by two students were excluded from the study, but 167 were included in it.

Creating Metaphors

The students' metaphors were examined to discover commonalities. The two data coders derived eight categories based on the alpha-ordered table of metaphors and the categories into which the metaphors would be grouped were determined by the coders.

Testing Validity and Reliability

The data source (the participants herein) was diversified to achieve a higher level of construct validity. To increase the diversity of the participants, students of bachelor's degree programs from the faculty of education and of arts and sciences were included in the study, which also featured students from an associate degree program and other bachelor's degree programs. To promote the construct validity, the researcher triangulation was performed. A high level of construct validity was aimed by elaborately describing the process of data analysis, i.e how the eight categories were attained. To achieve internal validity in reporting the research, direct quotations from the participating students' answers were provided. Cohen's Kappa coefficient was calculated to assess reliability (Vierra and Garret, 2005). The Kappa values were calculated to be .96 for "whole-making", .90 for "changing - improving", .88 for "puzzle", .92 for "mystery", .90 for "matching", .90 for "family", .91 for "friendship", and .92 for "connection".

Findings and Interpretation

Table 1. Demographic Facts of the Students Creating Metaphors on Formation of Molecules from Atoms

		Gender				Total	
		Male		Female			
Educational status	Class	F	%	F	%	F	%
Faculty of education	3rd year	26	35	48	65	74	43.7
	4th year	17	40	25	60	42	24.8
Faculty of arts and sciences	4th year	7	30	16	70	23	13.6
Vocational school	1st year	12	40	18	60	30	17.7
Total		62	37	107	53	169	100.0

The participants were studying in associate and bachelor's degree programs. The bachelor's degree participants were third-year (43.7%) and fourth-year students (24.8%) from the faculty of education and fourth-year students (13.6%) from the faculty of arts and sciences. 17.7% of the participants were first-year students in a vocational school offering courses in natural sciences.

Table 2. Categories of the students' metaphors on formation of molecules from atoms

Themes	Frequency	%
Complementing	49	29.9
Changing - improving	46	27.2
Puzzle	34	20.11
Mystery	15	8.8
Matching	12	7.1
Family	5	2.9
Friendship	3	1.7
Connecting	3	1.7
Invalid metaphors	2	1.1
Total	169	100

Eight categories were harvested from the students' metaphors on formation of molecules from atoms. The invalid data account for 1.1% of the total data. These data were excluded from the analysis. The metaphors by 29.9% of the students were placed in the "complementing" category. Creswell (2012) classifies themes as ordinary, unexpected, hard-to-classify and major and minor themes/categories. In the evaluation of the obtained metaphors, 29.9% were classified as "complementing", 27.2% as "changing and improving", 20.11% as "puzzle", 7.1% as "matching", 2.9% as "family", 1.7% as "friendship", and 1.7% as "connecting", which can be called "ordinary themes". The metaphors in "mystery" (8.8%) can be listed as "unexpected themes/metaphors". It is highly interesting that all the metaphors by the students on formation of molecules from atoms were denotationally and connotationally positive. This finding shows that the students adopted a positive attitude toward formation of molecules from atoms and thought it to be a required and expected process/result.

Table 3. Complementing category and metaphors

Themes	Frequency	%	Metaphors
Complementing	49	29.9	Mothers' embroidering (113), ashure (Noah's pudding) (62), ayran (diluted yogurt) (94), tree-planting (158), constructing a building (46, 143,154, and 162), raising a man out of a child (96), creating a man out of a child (96), raising a man (31), combining things (22), like marrying two lovers (7), individual (41), complementing (161), making a sentence (81), sentences (101), making a lake out of drops (153), embroidery (68), hammering hot iron (97), sea (88), making sentences with the words in our minds (55), staple (36), food (100), life (57, 116), country (43), world (117), education (76), living (123), KPSS (a state-administered exam) (52), getting 100 points in KPSS (42), lemonade (66), placing iron pieces around a magnet (156), putting marbles in a jar (56), bringing students together for an assignment (102), students' efforts to create an atmosphere in a class (132), teaching (as a profession) (40, 60), cake (89, 71), picnic basket (166), building a pyramid (157), painting (121, 151), writing a novel (65), dress (105), salting the sea (79), microbe (8).

29.9% of the participating students created metaphors of complementing. From these metaphors in the ordinary category, it can be inferred that the students regard formation of molecules

from atoms as the creation of a new whole, i.e. a new piece, from pieces, which is an expected way of thinking. For example:

"Formation of molecules from atoms is like a country because it incorporates people of different nationalities and beliefs." S. 43

In the "whole-making" category, S. 43 likens formation of molecules from atoms to a community of people with different nationalities and beliefs living in a harmonious ordered manner.

"Formation of molecules from atoms is like making ashure [Noah's pudding] because different kinds of ingredients together make an amazing taste." S. 62

This denotes that atoms are different from each other and these different structures come together to form an "amazing" new structure.

"Forming molecules from atoms is like a cake because ingredients come together to form a meaningful structure." S. 89

S. 89 likens formation of molecules from atoms to a cake to mean that atoms come together to more meaningful and useful new structures.

"Formation of molecules from atoms is like tailoring a dress because scientists creating molecules work like a tailor to produce molecules." S. 105.

This student uses the "dress" metaphor to liken it to a time-taking, strenuous practice of expertise.

"Formation of molecules from atoms is like mothers' embroideries because it entails effort and hard labor, and a small mistake messes up the embroidery." S. 113.

The student expresses that creating molecules requires hard labor and a small mistake will lead to undesired consequences.

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Table 4. Changing and improving category and metaphors

Themes	Frequency	%	Metaphors
Changing - improving	46	27.2	Growing up to become an adult (87), soup (144), acquire a new piece of knowledge (53), a new invention (3, 10, 70, 108, 28), food/cooking (13, 35, 37, 49,50, 51,64, 74, 93, 95,112, 124, 147, 167), sowing crops in a field (1), society (122), writing a poem (67, 69, 140), love (104), making a snowman (2), mixture (80), making a cake (110, 120, 149,160), sounds in our language like babbling (54), birth (59, 92, 106, 136), universe (135), recycling (98), dough (142), poppy-seed cookies (32), sculpturing (134), building a wall (9), making grape molasse (44).

The metaphors in the "changing and improving" category (27.2%) are expected as in Creswell (2012). 14 (30.4%) of the students were found to form the "cooking" metaphor. *"Formation of molecules from atoms is like making grape molasse because grapes are the essence like atoms and the molasse is the mixture like molecules."* S. 44

"Formation of molecules from atoms is like cooking because even though atoms are meaningful on their own, they create a totally different thing together." S. 50

"Formation of molecules from atoms is like cooking because it is like creating different tastes with the same ingredients." S. 74

"Formation of molecules from atoms is like cooking because different atoms come together to create a single molecule." S. 100

Moreover, they frequently used the "(an) invention" (5; 10%) and "birth" (4; 8.6%) metaphors. Some created the "poem" metaphor (3; 6.5%).

"Formation of molecules from atoms is like inventing [because] it combines already existing things to come up with a new formation". S. 28

"Formation of molecules from atoms is inventing [because] it displays the characteristics of the older parts but is no more like before." S. 108

"Formation of molecules from atoms is like birth because smaller pieces create a bigger thing." S. 136

"Formation of molecules from atoms is like a poem because we cannot use any atom to create molecules just as we meticulously pick words in poetry." S. 140

Table 5. Puzzle category and metaphors

Themes	Frequency	%	Metaphors
Puzzle	34	20.11	Jigsaw (6, 26, 30, 34, 58, 75, 82, 84, 103, 129, 131, 137, 141, 155, 163, 164), Lego (145, 148, 111, 29), puzzle (4, 5, 16), My life (165, 168), playing 101 [a board game] (21), Brainbox (146), making a wooden table (169), education (91), replacing missing parts (25), mathematics (38), game (119), platonic love (138), playing PUBG (15).

In the “puzzle" category, the most frequently adopted metaphors are jigsaw (47.05%), Lego (11.76%), puzzle (8.8%), and my life (5.8%). While the other metaphors are related to games, as in Brainbox, game, playing 101, playing PUBG, the participants formed various other metaphors, such as making a wooden table, education, replacing missing parts, mathematics, and platonic love.

“Formation of molecules from atoms is like a riddle because it is hard to solve.” S. 4

“Formation of molecules from atoms is like a jigsaw because together they add up to a complete object”. S. 6

“Formation of molecules from atoms is a jigsaw because atoms come together to form a meaningful thing, a molecule.” S. 58

“Formation of molecules from atoms is like a jigsaw because it is complicated.” S. 84

“Formation of molecules from atoms is like a puzzle because each piece should be placed into the right spot.” S. 141

Table 6. Mystery category and metaphors

Themes	Frequency	%	Metaphors
Mystery	15	8.8	Magic (83, 90), seeing the glass in a mirror (127), going insane (73), creating out of nothing (78), creation (152), the zenith of the art of creation, sleep (12), calendar (33), teaching a person of social sciences integral/integration (139), miracle (14), making music (159), NATO (63), the Ottoman Empire (128), death (61)

Magic (13.3%) is the most frequently observed of the metaphors by the students on formation of molecules from atoms and it is followed by assorted metaphors. Significantly different metaphors (8.8%) were observed in the “mystery” category such as magic, seeing the glass in a mirror, going insane, creating out of nothing, creation, the zenith of the art of creation, sleep, calendar, teaching a person of social sciences integral/integration, miracle, making music, NATO, the Ottoman Empire, death.

“Formation of molecules from atoms is like a calendar because it has no time and [sic].” S. 33

“Formation of molecules from atoms is like death because they know nothing [about it].” S. 61

“Formation of molecules from atoms is like magic because they are too small to see; this is incredible.” S. 83

"Formation of molecules from atoms is like an elixir because you can create magical and miraculous things by mixing things." S. 90

"Formation of molecules from atoms is like being able to see the glass in a mirror because even though a mirror looks like a complete object, we miss the fact that it is made of glass." S. 127

Table 7. Matching category and metaphors

Themes	Frequency	%	Metaphors
Matching	12	7.1	Marrying (20, 85, 107, 114, 118, 133), lover (18, 19), two halves of an apple (125), matching one with the other (23), love between the snow flower and the sun (48), snowball (126)

The students accounted for formation of molecules from atoms by using the "marriage" and "being lovers" metaphors. The other metaphors in this category are concerned with uniting and harmony, e.g. two halves of an apple, matching one with the other, love between the snow flower and the sun, and snowball.

"Formation of molecules from atoms is like marrying because atoms get connected by coming together." S. 7

"Formation of molecules from atoms is like being lovers because molecules do not occur if atoms do not act in harmony." S. 19

"Formation of molecules from atoms is like marrying because someone comes in your life and you get connected with him/her." S. 20

"Formation of molecules from atoms is like the love between snowflakes [flower] and the sun because they are connected but also two different structures create a new bound." S. 48

"Formation of molecules from atoms is like marriage because water consists of two different atoms, which act together." S. 114

Table 8. Family category and metaphors

Themes	Frequency	%	Metaphors
Family	5	2.9	Family (17, 86, 99), father (130), uniting two siblings (24).

The most common metaphors in the "family" category (2.9%) are father and sibling. Families are the smallest social groups, which merge to comprise a society.

"Formation of molecules from atoms is a family because different things come together to create good or bad values." S. 17

"Formation of molecules from atoms is a family because small pieces come together to create a meaningful whole." S. 86

"Formation of molecules from atoms is like a family because it continuously grows bigger, develops, and renovates itself. S. 99

"Formation of molecules from atoms is like a father because atoms come together to form molecules just as a father brings a family together." S. 130

Table 9. Friendship category and metaphors

Themes	**Frequency**	**%**	**Metaphors**
Friendship	3	1.7	Friendship/making friends (11, 27, 115)

1.7% of the participants developed metaphors in the "friendship" category. The metaphors created by the students in this category are friendship and making friends.

"Formation of molecules from atoms is like being friends because molecules do not occur if atoms do not act in harmony." S. 11

"Formation of molecules from atoms is like friendship because choosing the right friend is helpful to have a nice life and [social] environment." S. 27

"Formation of molecules from atoms is like friendship because multiple atoms come together to form a molecule". S. 115

Table 10. Connecting category and metaphors

Themes	Frequency	%	Metaphors
Connecting	3	1.7	DNA (72), RNA chain (150), swing (45)

The category consists of the expected metaphors concerning the students' thoughts on the subject matter. The metaphors in this category comprise the concepts, which are free of interpretation and imagination and with which they directly transfer their knowledge. Yet only 1.7% of the students thought of metaphors in the "connection" category, which were built not on interpretation and imagination but on knowledge.

"Formation of molecules from atoms is like a swing because they need to get connected" S. 45

"Formation of molecules from atoms is DNA because they get connected like genes." S. 72

"Formation of molecules from atoms is like an RNA chain because they consist of bases." S. 150

Discussion and Conclusion

The students primarily created metaphors on formation of molecules from atoms by foregrounding "complementing" (29.9%). Generally speaking, the metaphors by the participating students rely on simple physical concepts, for example "building" and "making sentences". "Metaphors based on simple physical concepts – up-down, in-out, object, substance, etc. – which are as basic as anything in our conceptual system and without which we could not function in the world – could not reason or communicate – are not in themselves very rich" (Lakoff and Johnson, 1980, 61).

27.2% of the metaphors were placed in the "changing and improving" category, which refers to the creation of a totally different and positive thing by bringing together materials with different structures and properties. It was observed that the students compared formation of molecules from atoms to food (i.e. meal and cake) – people's basic need – and to an invention, which is a new product that can be used for the good of people. Sarıkaya (2007) suggests that teachers, faculty members, and students should produce their own molecular models by using inexpensive and easily accessible materials (e.g. cardboard, playdough, and pins). It can be deduced from the students' metaphors that the subject can be presented and taught by exploiting such everyday materials as meals, cake, soup, etc., which is believed to help them understand the topic easily. Learning about Atoms, Molecules, and Chemical Bonds: A Case Study of Multiple-Model Use in Grade 11 Chemistry by Harrison and Treagust (1999) adopts the multiple-model approach. Their study has concluded that metaphors that students create in view of their previous experiences promote effectiveness of their learning chemistry subjects at stake with help of other models.

"Cooking" is the most common metaphor (30.4%) in the "changing and improving" category. By doing so, the students mostly mean that formation of molecules from atoms is a process that satisfies needs and whereby materials useful for people are produced. Liu and Owyong (2011) report that scholars supplement their research papers with visual-graphical items, i.e. photographs, scientific diagrams and tables. Thus, they suggest that metaphors and semiotic nature of scientific knowledge should be operationalized to achieve scientific literacy. In their study, formation of molecules from atoms are likened to many concepts of everyday life. The proposition by Liu and Owyong (2011) in their paper and the created metaphors were observed to overlap. The students in their study explained a chemistry subject by availing themselves of many objects, events and phenomena of everyday life by linguistic means.

The second most common metaphors (20.11%) were observed in the "puzzle" category. "It is a delusion of educators that students' misconceptions can be eliminated through traditional education, in other words "direct instruction" (Gödek and Polat, 2017, 69). Therefore, all concepts and knowledge, including basic concepts, to be offered students should be gamified. The 21st century is the digital age and thus its requirements are being digitalized. Hence, digital games can be used in teaching-by-gamification activities (Uluay and Doğan, 2017). Uluay and Doğan (2017) claim that science education can be more effectively offered with digital games.

The students formed different metaphors in the "mystery" category (8.8%). This can be explained by the fact that they have the right thoughts about the subject despite its complicated and unknown aspects, as in the NATO metaphor by S. 63 and the Ottoman Empire metaphor by S. 128. S. 127 produced the metaphor "seeing the glass in a mirror" in the "mystery" category. "There are some phenomena making one's life meaningful. Mirror is among them. But this object has a bilateral value.

It is both aesthetic and mysterious. While its aesthetics mesmerizes people, its mysterious side scares them" (Sümer, 2017). What the students attempt to mean by "seeing the glass" is that one needs to know the essence of a phenomenon rather than its aesthetic and mysterious side.

7.1% of the participants created metaphors of harmony and love in the "matching" category. It is suggestive that students opted for the social formation that individuals with two different genders and raised in different families and conditions develop for the societal continuity and order since this shows that the students have developed an awareness of the importance of creating molecules from atoms for the continuity of the order in the world by thinking of the notion of marriage as the act of laying the foundation of a family.

In the "family" category, 2.9% of the students likened formation of molecules from atoms to the smallest building block of a society and its constituent elements. In view of the students' statements in this category, it can be concluded that they think that formation of molecules from atoms underlie the existing structures and they have an awareness of the subject.

1.7% of the students can be told to consider formation of molecules from atoms equal to harmonious co-existence of individuals with different social backgrounds and their sharing many professional, social, and emotional things. The reason why the students depicted the subject with "friendship" metaphors to suggest that differences can result in harmony.

1.7% of the students produced the metaphors in the "connecting" category. It can be claimed that these students who take direct ways to evaluate scientific knowledge do not use their imagination and capability of interpretation. Yet, the low percentage (1.7) concerning these students can be considered a positive finding. Students' ability to interpret scientific knowledge is indicative of the fact that they hold that specific piece of knowledge. New research areas of chemistry learning and teaching in the 21st century are guided by "changes in our understanding of how students learn and how that applies to chemistry education", "the wide-spread implementation of computer and information technologies to visualizecomplex scientific phenomena", and "global concerns about energy and water resources and the environment, and the level of chemical literacy and public understanding of science, fundamental changes in the contours of chemistry as defined by new interfaces and research areas"" (Mahaffy, 2004, 229-230). As indicated, teaching and learning chemistry are greatly important for several reasons.

Suggestions

The students' depiction of formation of molecules from atoms as a puzzle can be thought to reveal that they face difficulty learning and acquiring knowledge. Concluding from the view that puzzles boost intelligence, knowledge on this subject can be presented in the form of puzzles.

To increase the students' knowledge and awareness of the subject, students should be assigned complementing activities to be performed with cheap and easily accessible materials. The students' description of formation of molecules from atoms by associating the process with everyday life shows that subjects can be taught by means of activities and experiments closely related to everyday routines.

In consideration of the obtained data, it can be suggested that detailed teaching activities and practices should be developed as regards formation of molecules from atoms.

The derived themes revealed that the students created metaphors with positive connotations.

The students were observed to make the best effort they can even though they do not hold a good command of the subjects. More down-to-earth educational and instructional activities can be developed to support their efforts.

Moreover, these educational and instructional activities can be made more entertaining and interesting with the help of various tasks.

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