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Secondary Students' Reference to Properties of Matter to Chemical Bonds: Is the Onus on the Ontological Mismatch Only?

Ortaöğretim Öğrencilerinin Maddeye İlişkin Özellikleri Kimyasal Bağlara Atfetmesi: Tek Sorumlu Ontolojik Yanlış Eşleme mi?

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ABSTRACT: Grounded in the constructivist view of knowledge, the present study aimed to find out whether Turkish students have a good grasp of properties of chemical bonds after receiving the conventional teaching. A questionnaire consisted of open ended questions was used as an assessment tool. It was distributed to 11th grade chemistry students (n= 404). Questions presented mass and energy properties in relation to chemical bonding and asked students to explain what they think and why they think in that way. A small group of students were also interviewed in relation to their written responses for further probing. Findings indicated that students possess alternative ideas. Despite the conventional instruction students believe that chemical bonds have mass and volume by giving the impression that they assign the concept to the matter category. A similar ontological mismatch was also detected regarding the energy concept. Findings also showed that matter-like feature of energy conception is common among Turkish students. This misconception played an important role in the context of chemical bonding as students depend upon this faulty idea in deciding mass change during bond formation.

Keywords: Misconceptions, Constructivism, Chemical Bonding, Matter, Energy, Ontology

ÖZ: Yorumlamacı paradigma temelinde tasarlanan bu araştırma müfredatın öngördüğü öğretim sonrasında Türk öğrencilerinin kimyasal bağa ilişkin kavramalarını incelemeyi amaçlamıştır. Açık uçlu kavramsal sorulardan oluşan anket araştırmanın veri toplama aracı olarak işlev görmüştür. Anket 404 onbirinci sınıf öğrencisine uygulanmıştır. Ankette yer alan sorular ile öğrencilerin kimyasal bağın özellikleri konusundaki düşünce biçimleri ve nedenlerinin saptanması hedeflenmiştir. Öğrencilerin kimyasal bağın özellikleri konusundaki yanılgılarının altında yatan nedenleri açığa çıkarabilmek üzere, bazı öğrencilerle görüşmeler gerçekleştirilmiştir. Araştırmadan elde edilen bulgular, konu ile ilgili öğretimi almış olmalarına rağmen araştırmaya katılan öğrencilerin kimyasal bağ kavramına ilişkin yanılgıları olduğunu göstermektedir. Bulgular, kimyasal bağın kütlesi ve hacmi olduğunu düşünen öğrencilerin varlığını ortaya koyarken, ontolojik açıdan süreç kategorisinde yer alması gereken kimyasal bağ kavramını madde kategorisine yerleştirdiklerini işaret etmektedir. Ontolojik açıdan benzer yanlış eşleme enerji kavramına ilişkin de yapılmıştır. Bulgular ayrıca, öğrenciler arasında enerjinin bir madde olduğu ve kütlesinin bulunduğu yanılgısının yaygın olduğu ve bu yanılgının kimyasal bağın kütlesinin bulunacağı konusunda öğrencileri yönlendirdiğini ortaya koymaktadır.

Anahtar sözcükler: Kavram yanılgısı, Yapılandırmacılık, Kimyasal bağ, Madde, Enerji, Ontoloji

1. INTRODUCTION

Chemical bonding is the key concept in understanding the behavior of matter as well as physical and chemical changes in scientific terms. It is an explanatory tool for observable and aperceptual chemical phenomena happening around us. Thus, it is crucial that students have a good grasp of chemical bonding. However, studies indicated that they have difficulty in understanding the types and formation of chemical bonds (Goh, Khoo & Chia, 1993; Levy Nahum, Hofstein, Mamlok-Naaman & Bar-Dov, 2004; Peterson, 1993; Peterson, Treagust & Garnett, 1989), in differentiating between inter and intra molecular bonds (Barker, 1995; Birk & Kurtz, 1999; Butts & Smith, 1987; Levy Nahum, Hofstein, Mamlok-Naaman & Bar-Dov, 2004; Taber, 1993; 1995; 1998) and in explaining the change in matter via the change in its chemical bonds (Barker, 1995; Taber, 1993). These studies are few of the bulk which documented students'

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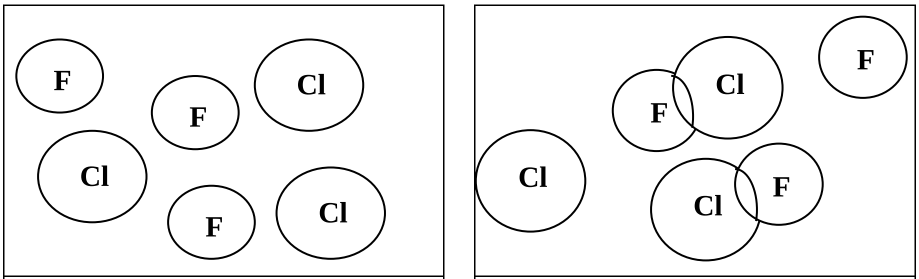
ideas regarding the concept of chemical bonding. Nearly all aspects of chemical bonding have been concern to research including those which documented students’ mental representations of atomic models (Tsaparlis & Papaphotis, 2002; Nakiboğlu & Benlikaya, 2001; Harrison & Treagust, 1996) and of chemical bonding (Nicoll, 2001; Pereira & Pestana, 1991; Taber 2001; Coll & Treagust, 2001). Some researchers studied anthropomorphic and animistic language used by students in explaining the formation of chemical bonding (Taber & Watts, 1996; Taber, 1998; Nicoll, 2001). Only a few researchers have touched upon students’ misconceptions related to properties of chemical bonds. They are mainly focused upon the thermodynamic features of chemical bonds (Ross, 1993; Barker & Millar, 2000; Boo & Watson, 2001). However, these studies do not provide information about students’ reasoning behind their ideas concerning thermodynamic features of chemical bonds. Also, they appear not to provide information about students’ reasoning on the nature of chemical bonds and whether they attribute matter-like features to them on ontological basis. Therefore, the present study aimed to find out how Turkish students who received conventional teaching on chemical bonding describe chemical bonds and to uncover the underlying reasons behind. In this way, students’ incorrect ideas concerning the nature of chemical bonds which are a result of science education can be pinpointed. This might help science teachers become aware of students’ incorrect ways of thinking resulting instruction.

Followed by Chi and her colleagues, a number of researchers have focused their effort on ontology with an attempt to understand the source of misconceptions. Ontology assumes that entities in the world essentially belong to different ontological categories (Chi & Hausmann, 2003). In her earlier paper Chi (1997) proposed three ontological categories as fundamental. These are; matter, processes and intangibles. Each category also possesses subcategories. The concepts that are named as the members of an ontological category possess features of that category (Chi, 1997, Chi & Slotta, 1993; Chi & Hausmann, 2003). If a concept is assigned to a different ontological category or subcategory rather than it scientifically belongs, a misconception is likely to emerge (Chi & Roscoe, 2002). Thus, misconceptions are considered to be closely related with ontological categories. This connection has been supported and ontological categories have been benefitted in designing and analysing students’ misconceptions by various researchers (Johnston & Southerland, 2000; Kahveci & Özalp, 2009; Özalp & Kahveci, 2011). These studies revealed that ontology could be depended upon as a theoretical framework in understanding the nature of misconceptions. Following from this, the present study, which aimed to investigate Turkish students’ ways of thinking about the chemical bonds, designed so as to benefit ontology as a framework in explaining the source of students’ misconceptions. It therefore differs from the existing misconceptions studies focusing on chemical bonding. The study might produce an explanation for the existence of students’ misconceptions concerning chemical bonding ontologically. It might also highlight the limitations of the ontology as a theoretical framework by spotting the misconceptions occurring not as a result of the ontological mismatch. The results of the study might be helpful for educators in depending on the ontological categorisations and for instructors in designing their teaching scheme.

2. METHOD

The present study is designed as a survey research. Grounded in the constructivist view of knowledge, a questionnaire consisted of three questions were designed and used as an assessment tool. Questions presented mass and energy issues in relation to the properties of chemical bonds and then asked them to explain what they think. In question 1, students were asked to predict the mass of reaction vessel after covalent bonds are formed. Question 2 required explanation whether chemical bonds have mass. In question 3, students were asked to explain the source of energy that drives a chemical reaction. All question targeted to uncover students ideas concerning the thermodynamic properties of chemical bonds. The questions were mainly in the form of multiple choices with an open-ended question. The open-ended part of the questions allows students to be free to answer the questions in their own way and in their own language. Questions used in the study can be seen below.

SORU 1. In a reaction vessel there are **Cl** and **F** atoms. After a while covalent bonds are formed between the two atoms and they form **ClF** molecules. The reaction vessel is weighed both **before** the CIF molecules are formed and **after** they are formed.



Before covalent bonds are formed	After covalent bonds are formed

What do you think about the mass of the reaction vessel before and after covalent bonds are formed? Indicate your answer by putting ✓ into the box you choose.

- ☐ The weight of the reaction vessel is more **before** covalent bonds are formed.
- ☐ The weight of the reaction vessel is more **after** covalent bonds are formed.
- ☐ The weight of the reaction vessel is the same before and after covalent bonds are formed.

Please say why you chose this answer.

SORU 2. Does chemical bond have mass? Indicate your answer by putting ✓ into the box you choose. Please tick (✓) one box.

☐ Yes ☐ No

Please say why you chose this answer.

SORU 3. Where do you think energy necessary for chemical reactions is obtained?

The questionnaire was distributed to 11th grade science students (n= 404) aged 17-18. Students were attending upper level chemistry courses in different state schools (n= 9). They completed the questionnaire right after their conventional teaching on chemical bonding. The term conventional teaching needs to be taken as constructivist in nature as there has been renovation on educational philosophy from transmission towards the constructivist one in 2004. This philosophy has been adopted gradually starting from the elementary level to secondary level. At the time of the present study, the instruction is assumed to be conducted in the line of the constructivist view. Yet, classroom observations concerning teaching of the chemical bonding and examination of students' notebooks highlight that teaching involves mainly teaching the terminology (definition) regarding types of chemical bonds and their examples. Notebooks indicated that the teacher gave definitions first and then explained the terminology by providing examples rather than encouraging students to work on examples and construct their own definitions regarding chemical bonding.

After students responded to the questions, the researcher examined their responses so as to determine students whom to be interviewed. In other words, they were selected to represent different reasoning related to properties of chemical bonds. Interviews were carried out with 30 students so as to find out the reasoning behind their responses. All interviews were audio taped and fully transcribed. Students' responses to both written and oral questions were analysed by ideographic ways (Driver ve Erickson, 1983) where responses were analysed in their own terms rather than categorising them into pre-determined sets of categories. Thus, the categories develop throughout the data analysis.

Investigator triangulation was benefited during the data analysis of open-ended questions by carrying out the reliability of coding procedures (i.e. inter-coder reliability) since students' written responses were independently coded by a second coder. An overall agreement 90% was reached with a minimum of 85% and with a maximum of 100%.

Table 1 shows students' predictions about the change in mass of reaction vessel before and after covalent bonds are formed. Majority of students (% 70) gave scientifically acceptable responses to the question. These students think that formation of covalent bonds do not affect the mass of the container. Common reasoning seems to be the conservation of mass during chemical reactions. This reasoning was aided by % 26.7 of the students. Other reasons provided were related to the abstract nature of chemical bonds. These students thought that bonds are interactions/attraction forces between particles and therefore do not possess mass.

Table 1: Students' predictions about the change in mass upon chemical bond formation

			Number of students (per cent)
	Uncodable / No response		21 (5.2)
Misconceptions	Mass decreases during bond formation	No reasoning	7 (1.7)
		Energy is released during bonds formation	14 (3.5)
		Upon chemical reaction mass decreases	6 (1.5)
	Mass increases during bond formation	No reasoning	34 (8.4)
		Chemical bonds have mass	34 (8.4)
		Energy is taken in during bonds formation	5 (1.3)
		Misconceptions total	**100 (24.8)**
Scientific ideas	Mass stays the same during bond formation	No reasoning	62 (15.3)
		Chemical bonds do not have mass	67 (16.6)
		Number of atoms do not change	40 (9.9)
		Mass is conserved during chemical reactions	108 (26.7)
		Chemical bonds are interactions/forces	6 (1.5)
		Scientific ideas total	**283 (70)**

Even though majority of students aired the scientific ideas, this finding is not as promising as it seems. These students received instruction on chemical bonding. Yet one third of them (% 30) presented misconceptions by expected either an increase (% 18.1) or decrease (% 11.9) in mass after the formation of covalent bonds. On examining students' written responses which expected an increase in mass during bond formation, two main reasoning come to the fore. The favorite one is the matter-like nature of bonds. These students (% 8.4) believed that bonds have mass. The second line of reasoning was related to thermodynamic properties of chemical bonds.

A group of students (% 1.3), albeit small proportion, based their ideas on this reasoning. They think that energy is necessary/taken for the formation of chemical bonds.

Ontologically, the concept of chemical bond belongs to the processes category. Students participated in this study thought that chemical bond has mass. These students seem to assign the concept to the Matter category as these ontological features belongs to the matter catogory. This categorical mismatch appear to be the reason for the related misconception.

Thermodynamic properties of chemical bonds were also depended upon by students who expected a decrease in mass during bond formation. These students (n= 14) thought that energy is released on formation of bonds. It seems that these students attributed properties of matter to energy. Accordingly, they expect changes in mass of the substances when energy is taken or released. When probed further during the interviews, they stated that energy has mass by giving heat as an example. In ontological terms, the concept of energy (and heat) belongs to the processes category like chemical bonding. However, students participated in this study thought that energy has mass. These students seem to assign the concept to the Matter category. This mismatch seems to grow into a "energy has mass" misconception.

Second question helped to uncover the reasons behind the misconception concerning matter-like properties of chemical bonds. Table 2 indicates students' responses to the second question.

Table 2: Students' ideas concerning the mass of chemical bonds

<table>
<tr><th></th><th></th><th></th><th>Number of students (per cent)</th></tr>
<tr><td></td><td colspan="2">Uncodable / No response</td><td>5 (1.2)</td></tr>
<tr><td rowspan="6">Misconceptions</td><td rowspan="5">Chemical bonds have mass</td><td>No reasoning</td><td>34 (8.4)</td></tr>
<tr><td>They are matter/substance</td><td>34 (8.4)</td></tr>
<tr><td>They have energy</td><td>23 (5.7)</td></tr>
<tr><td>They have volume and shape</td><td>10 (2.5)</td></tr>
<tr><td>The mass of chemical bonds is too small and can be negligible</td><td>35 (8.7)</td></tr>
<tr><td></td><td>Misconceptions total</td><td>136 (33.7)</td></tr>
<tr><td rowspan="6">Scientific ideas</td><td rowspan="5">Chemical bonds do not have mass</td><td>No reasoning</td><td>67 (16.6)</td></tr>
<tr><td>They are interactions/attraction forces not matter</td><td>146 (36.1)</td></tr>
<tr><td>They have energy, not matter, do not possess volume and mass</td><td>17 (4.2)</td></tr>
<tr><td>They are composed of atoms and atoms have mass</td><td>26 (6.4)</td></tr>
<tr><td>When the number of bonds changes mass do not change</td><td>7 (1.8)</td></tr>
<tr><td></td><td>Scientific ideas total</td><td>263 (65)</td></tr>
</table>

As it can be seen from Table 2, one third of the students (% 33.7) stated that chemical bonds have mass. They seem to come to this idea with different reasons. Majority (% 8.4) claimed that chemical bonds are matter/substance. It is apparent that these students assigned the concept of chemical bonding to the matter category rather than the process category ontologically. Thus, it is expected that these students attribute the ontological features of matter to chemical bonding. Among those features mass, volume and shape were stated mostly since some students (% 2.5) backed up their mass idea by indicating the shape and volume of the chemical bonds. Here again, an ontological mismatch is obvious between the matter and processes categories.

When probed further by asking “how they know if a chemical bond has mass” during interviews, this group of students either gave explanations like “chemical bonds are broken so they must have mass” or “so as to hold the atoms together they should exist/ be solid so they must have mass”. To some on the other hand, everything on earth has mass. It seems that these students viewed matter in their mind as “breakable” and “be able to hold or bind things”. These features do not appear on ontological categorization since matter is not necessarily breakable and does not necessarily have property of holding things. Yet, these misconceptions exist and their existence could not be explained on ontological grounds.

In a similar manner, the ontological framework appears to be failed in explaining the source of some misconceptions aired by the students. These students referred to the mass calculations carried out in bonding to support their idea that chemical bonds are matter. It seems that they interpret energy calculations carried out in chemical bonds as mass calculations rather than possessing a mismatch in ontological categorization.

Some of the students (% 5.7) did not define chemical bonds as matter. They rather underlined the thermodynamic properties of chemical bonds and stated that bonds involve energy. Energy appears to have mass according to these students, by highlighting a mismatch in ontological categorization as previously stated. This time, not the chemical bonding but the energy is assigned to the matter category; and its ontological feature (mass) was attributed to it.

According to Table 2, some students (% 8.7) who believe that chemical bonds have mass seem to think that this mass is too small and therefore can be negligible. Interviews indicated that these students either referred to their feelings about the mass of chemical bonds or the mass of electrons. According to the latter, chemical bonds are made up of electrons and the mass of electrons are too small to be worked out in mass calculations.

As in the case of Table 1, Table 2 also indicates that majority of students (%65) think that chemical bonds do not have mass and backed up their responses with scientifically acceptable ideas such as “chemical bonds are attractive forces” (n= 146), “they are composed of atoms and atoms have mass” (n= 26) and “They have energy, not matter, do not possess volume and mass” (n= 17). The idea that “bonds involve energy” was not clear till interviews were conducted with some of these students (7 out of 17). Interview transcripts indicated that most of the students interviewed (n= 5) imagined bonds as energy stores while some meant energy taken or released during formation of chemical bonds.

So as to find out students’ ideas concerning the relationship between chemical bonds and energy the third probing question was used. The results of analysis of students’ responses to this question were presented in Table 3. On examination of the Table 3, it becomes clear that majority of students (64.3 %) have misconceptions regarding the thermodynamic properties of chemical bonds. It seems that these students divided themselves into three different misconceptions. The favorite one (58.9 %) was the idea that “energy is released when bonds are broken”. The rest was either thought that we provide the energy necessary for chemical reactions or it is released both during bond breakage and formation. These two groups of students did not provide further explanation whereas the former one backed up their idea with four different reasoning. The common reasoning used by 83 students was the idea that chemical bonds are energy stores. These students believed that bonds hold energy and upon breakage it is given off. On examination of these students it became clear that they were those who assigned the energy concept to the matter category. Thus, it is possible that these students imagine “energy” something that can be stored in chemical bonding.

Table 3: Students' ideas concerning the thermodynamic properties of chemical bonds

			Number of students (per cent)
	Uncodable / No response		9 (2.2)
Misconceptions	Energy is not released from bonds, we give the energy necessary for chemical reactions		7 (1.7)
	Energy is released both during bond breakage and bond formation		15 (3.7)
	Energy is released when bonds are broken	No further explanation	97 (24)
		Chemical bonds are energy stores	86 (21.3)
		Energy is necessary for bringing atoms together, this energy is released when bonds are broken	39 (9.7)
		Energy is released when compounds are broken into their atoms	7 (1.7)
		Energy is necessary for breaking the bonds but when bonds are broken more energy is released than we give at the beginning	9 (2.2)
		total	**238 (58.9)**
		Misconceptions total	**260 (64.3)**
Scientific ideas	Energy is released when bonds are formed	No further explanation	34 (8.4)
		Energy/heat is given off when atoms give or take electrons	23 (5.7)
		Atoms make bonds so as to be stable and to have lower energy	40 (10)
		Energy is necessary for breaking bonds	38 (9.4)
		Scientific ideas total	**135 (33.5)**

The second reasoning involves the comparison the energy provided at the beginning of a chemical reaction with that of released. According to this group (n= 9) energy is necessary for breaking the bonds but when bonds are broken more energy is released than those given at the outset. The rest two reasoning focused on the energy used during formation of compounds. Some students (n= 39) explained that energy which was used for bringing atoms together was released at the end. The rest (n= 7) could not explain the source of energy, only stated that energy released when compounds are broken.

Students were expected to explain that energy is obtained during formation of bonds and this energy was source for breakage of bonds and during the chemical reactions. According to Table 3, none of the students provided such a detailed explanation. Some (33.5 %) tended to point out "energy release during bond formation". Among this group majority (10 %) underlined the need of atoms for being stable and have less energy. A small amount of students (5.7 %) explained that energy is released when atoms give or take electrons. The rest either point out the necessity of energy for breaking bonds or could not provide further reasoning.

4. DISCUSSION and RESULTS

This study investigated Turkish secondary students' ideas related to properties of chemical bonds following from the conventional teaching and uncovered a range of misconceptions. Findings of the study indicated that students possess alternative ideas in three different areas concerning properties of chemical bonds. The first of these is the "matter-like feature of chemical bonds". Within this group several alternative ideas, which were not included in the misconception literature, were detected. “Chemical bonds have shape, volume and mass and thus they are matter” is one of those ideas. The rest was focused upon the mass concept only. The reasoning behind this misconception was differed by producing new alternative ideas. Bonds have mass because “electrons have mass”, “bonds have energy”, “bonds bind atoms”, “bonds are broken”, “everything has mass” and “we make mass calculations related to bonds” are some other examples.

According to the findings of the study, the second area where students possess alternative ideas is “matter-like feature of energy”. In other words, students imagined energy as matter and hence it has mass. This seems to be supported by previous research findings even thought the concept seems to be “heat” rather than “energy” (Schmidt, 1997). The findings of the present study indicated that the last area where students’ alternative ideas focused was “thermodynamic properties of chemical bonds”. This misconception is also supported by the previous research findings. According to the research, students tend to think that chemical bonds are energy stores (Ross, 1993; Barker, 1995; Boo, 1998; Barker & Millar, 2000; Boo & Watson, 2001; Ebenezer & Fraser, 2001). They imagine that energy is released when bonds are broken and that this energy drives chemical reactions. In parallel with the research findings, Turkish students also appear to describe chemical bonds as energy stores and this energy is released when they are broken. However, in this study a second line of reasoning that accompanies students towards the “energy store” misconception was uncovered. According to this line of reasoning, energy is needed/taken for the formation of chemical bonds and this previously taken energy is released when they are broken.

When considering possible implications of this study, it is important to note that it highlights the importance of uncovering students’ underlying reasoning behind their ideas. In this way, it becomes possible to describe student’s conceptual network that is viewed as personal in constructivist terms. For instance, examination of students’ responses which expected either an increase or decrease in mass during bond formation indicated that both misconception groups, albeit contrary to each other, based their reasoning on the same misconception (“energy has mass”). Starting from the same misconception, however, they ended up with different mass predictions. One of the groups imagined energy is taken during bond formation. Thus, they expected an increase in mass during bond formation. In other words, this group based their prediction onto two existing as it is shown in Figure 1.

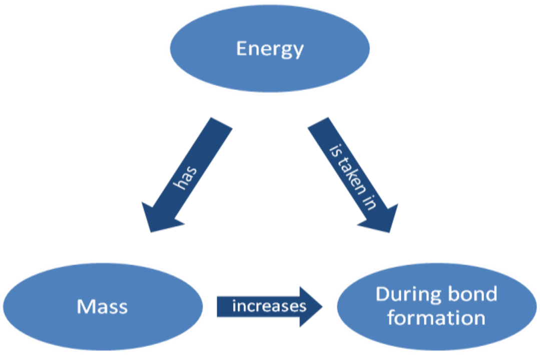


Figure 1. Some of the students’ reasoning concerning the relation of energy and mass concepts with the chemical bond formation (Model A)

On the contrary, the other group thought that “energy is released during bond formation” which is a scientifically acceptable idea. However, they predicted a decrease in mass during bond formation since they imagined “energy has mass”. Thus, this group’s predictions were leaded by a misconception and scientifically acceptable idea. Yet, this scientifically acceptable idea does not guaranteed the construction of the necessary scientific idea as it is represented in Figure 2 below.

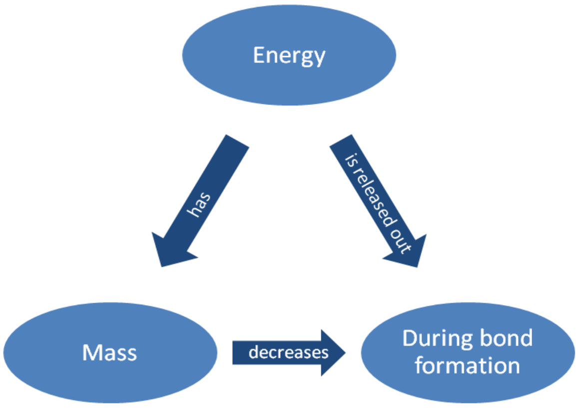


Figure 2. Some of the students' reasoning concerning the relation of energy and mass concepts with the chemical bond formation (Model B)

On the other hand, when a student think that energy does not have mass, then his conception that "energy is released or taken in during bond formation" does not affect his/her line of reasoning. S/he ends up with the idea mass does not change during bond formation (see Figure 3). It is important to note that "energy has mass" misconception is very influential in forming students reasoning. It seems that it is more influential than the misconception concerning thermodynamic properties of chemical bonds.

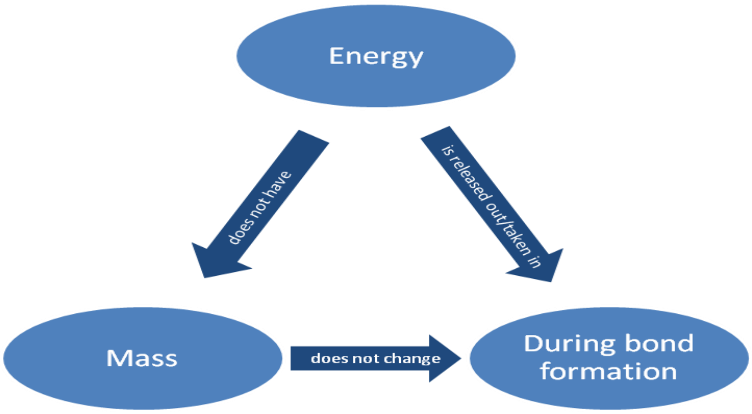


Figure 3. Expected reasoning concerning the relation of energy and mass concepts with the chemical bond formation

It is apparent that "energy has mass" misconception has a leading role in students' reasoning as compared to the one that occurs concerning the relationship between bond formation and energy. This might stem from the nature of ontological mismatch. The energy-mass misconception results from a mismatch in the main ontological categories (the processes and matter concept categories) whereas the later one (energy-bond formation) is caused by a mismatch in ontological sub categories.

The example mentioned above supported a range of ideas that has put forward by researchers. In the first place it supports the constructivist view of learning where learner is believed to construct meanings based on his/her existing ideas (Driver, 1985; 1989; Osborne & Freyberg, 1985; Gilbert & Watts, 1983). It also supports the contention that science learning is developing personal understanding of the scientific ideas put forward by the scientific community (Driver et al. 1994). Additionally, it is possible to say that meanings are born within the interrelationship of individual ideas and that personal reasoning come to the fore as a result. Figure 1 and 2 show that misconceptions/ faulty ideas have a leading role in meaning making as compared to the scientifically acceptable ones. The strength of this leading role seems to vary depending on the nature of misconception. Finally, it shows the necessity of studying alternative ideas in a digging the root fashion by examining the interrelated ideas, even if they appear to be unrelated with the alternative idea at the first sight.

The constructivist view of learning and the contention that meanings are constructed as a result of interrelations of students existing ideas was also supported by a second example which examines relationships of chemical bonds, mass, energy and matter concepts. We expect students to relate these concepts as shown in Figure 4.

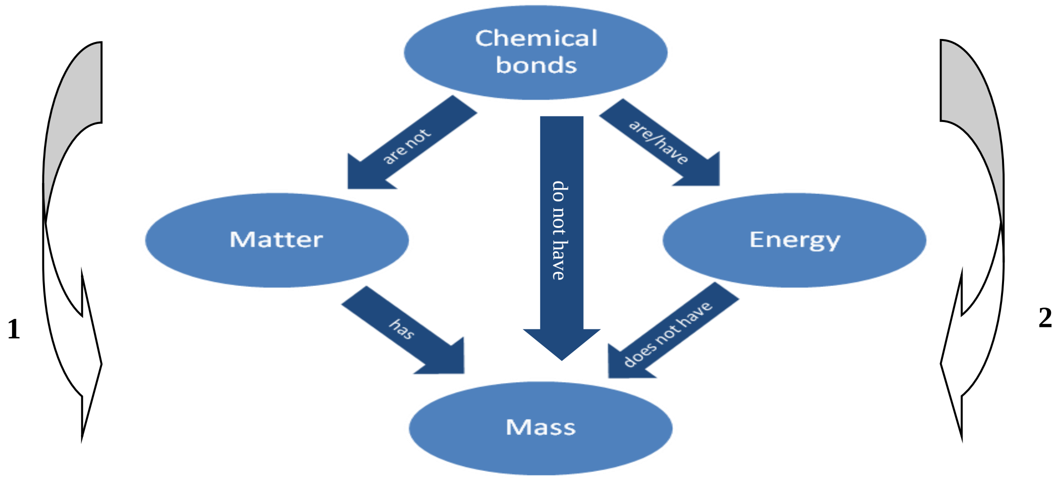


Figure 4. Expected reasoning concerning the relation of matter, mass, energy concepts with chemical bond concept

Regardless of speaking ontologically or not, students are expected to think that chemical bonds are attractive force/energy, they are not matter. They also need to think that matter has mass but attractive force/energy does not possess mass. As a result, they are expected to come to know that chemical bonds do not have mass. Interviews with students indicated that some of them came to this conclusion either through the line of reasoning that involves chemical bonds, matter and mass concepts. Or alternatively, they based their reasoning on the relationship between chemical bonds, energy and mass.

Unfortunately, the expectation aforementioned did not come true for all students interviewed. Some of the students thought that chemical bonds have mass. Upon examination of their ideas, three different reasoning was emerged as shown in Figure 5.The first of these was chemical bonds have mass because they are matter and matter has mass. The second line of reasoning seems to be chemical bonds have mass because they are energy/force and energy has mass. The third line of reasoning was not related to matter or energy ontologically. This appears to be related to other properties of chemical bonds such as formation process and their function. According to this group of students, chemical bonds have mass “because they involve electrons and electrons have mass” or “chemical bonds bind atoms and they can be broken thus they must have mass”.

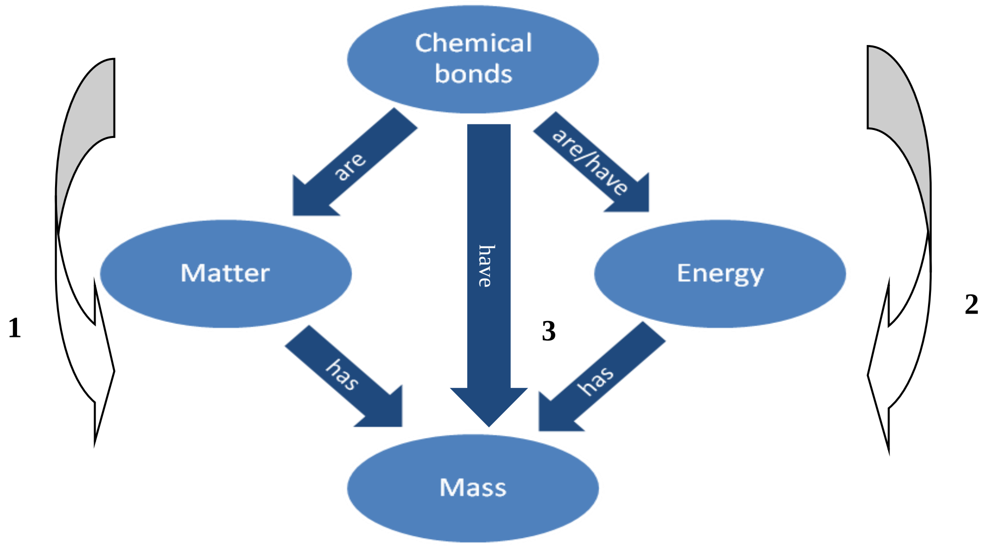


Figure 5. Students' reasoning concerning the relation of matter, mass, energy concepts with chemical bond concept

Following from the two examples examined it can be concluded that learning process need to be viewed as personally meaning making. This meaning making is a result of interactions of individual ideas, either valid or invalid. By being aware that concepts are viewed individual constructs made by the interactions of previously existing ideas, teachers need to monitor students' reasoning behind their conceptions. Teachers also need to be aware of the leading role of the misconceptions in concept formation. Thereby, they need to be alarmed of uncovering students reasoning, pinpoint misconceptions and remedy them as soon as possible. Within this model of learning, it is also important to help students to construct personal understanding of the ideas presented during teaching.

Science educators suggested different teaching strategies that teachers can adopt (Scott, Asoko & Driver, 1992; Leach & Scott 2003, Ogborn, Kress, Martins & McGillicuddy, 1996; Osborne, Erduran & Simon, 2004). Regardless of the teaching strategy adopted, accepting that learning is personally meaning making, teachers need to design teaching intervention on the base of their students' individual ideas. Teachers need to find out their students personal thinking as a first step. Only then, teaching activities to develop students' ideas towards the scientifically acceptable one could be designed. In other words, the nature of teaching interventions designed depends on the type and nature of the reasoning uncovered. As an example, the teacher of the class in this study needs to design two specific teaching interventions. In the first of these, students are provided opportunities to discuss what matter is and what the properties are those make something as matter. They then need to debate whether chemical bonds are matter or not by providing evidence for their arguments. Similarly, students need to compare the properties of matter and energy. They need to decide whether energy is matter and justify their thinking by examining the properties of matter. In the second intervention, teacher design learning activities where students become aware of the reasons for chemical reactions and energy changes occurring during chemical reactions. Then, students are involved in teaching activities by which they relate the energy changes in chemical reaction with the energy released or taken in the process of chemical bonding.

The present study attempted to produce an explanation for the existence of students' misconceptions concerning chemical bonding ontologically. It reveals that some of the misconceptions can be considered closely related with ontological categories and their source is likely the ontological mismatch. Yet, the existence of some misconceptions determined in this study could not be explained in ontological terms. Thus, studies are needed to be conducted so as to examine the relationships between misconceptions and ontological categorisation. Such studies might both enrich the literature lacking and render to widening the scope of the ontology as a theoretical framework in understanding the nature of misconceptions.

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Uzun Özet

Maddenin gözlenebilir davranışlarını anlamada, fiziksel ve kimyasal değişimi ayırt etmede kimyasal bağ kavramı kilit rol oynamaktadır. Kimyasal bağ kavramı çevremizde gerçekleşen olayları açıklamada kullanabileceğimiz kavramsal bir modeldir. Bu çerçevede, öğrencilerden kimyasal bağları ve özelliklerini kavramış olmaları beklenir. Ancak araştırma sonuçları, öğrencilerin kimyasal bağların tür ve oluşum biçimlerini anlamakta güçlük çektiklerini (Goh, Khoo & Chia, 1993; Levy Nahum, Hofstein, Mamlok-Naaman & Bar-Dov, 2004; Peterson, 1993; Peterson, Treagust & Garnett, 1989), molekül içi ve moleküller arası bağları ayırt edemediklerini (Barker, 1995; Birk & Kurtz, 1999; Butts & Smith, 1987; Levy Nahum, Hofstein, Mamlok-Naaman & Bar-Dov, 2004; Taber, 1993; 1995; 1998) ve maddedeki değişimi kimyasal bağlardaki değişim ile açıklayamadıklarını (Barker, 1995; Taber, 1993) ortaya koymaktadır. Öğrencilerin kimyasal bağlara ilişkin zihinsel modellerini (Nicoll, 2001; Pereira & Pestana, 1991; Taber 2001; Coll & Treagust, 2001) ve kimyasal bağ oluşumunu açıklarken öğrencilerin kullandığı dili inceleyen (Taber & Watts, 1996; Taber, 1998; Nicoll, 2001) araştırmalar da mevcuttur. Buna karşın, kimyasal bağın özelliklerine ilişkin öğrenci düşünce biçimlerini araştıran çalışmaların sayısı sınırlıdır. Üstelik bu çalışmalarda kimyasal bağların sadece termodinamik özellikleri konusundaki alternatif fikirler incelenmiştir (Ross, 1993; Barker & Millar, 2000; Boo & Watson, 2001). Mevcut araştırmaların, kimyasal bağların yapısına ilişkin, öğrencilerin sahip olduğu kavram yanılgılarının altında yatan nedenleri açığa çıkarmayı hedeflemedikleri, maddeye ait özellikleri kimyasal bağlara atfetme durumlarını ontoloji temelinde analiz etmedikleri anlaşılmaktadır.

Ontoloji her şeyin temel olarak farklı kategorilere ait olduğunu farzeder (Chi ve Hausmann 2003). Buna göre, dünyadaki tüm varlıklar üç temel ontolojik kategori içinde düşünülebilir (Chi, 1997). Bu kategoriler, madde, süreçler ve zihinsel durumlar şeklindedir (Chi vd, 1994; Johnston ve Southerland, 2000). Bir ontolojik kategorinin üyesi olan bir kavram o ontolojik kategorinin özelliklerine sahiptir ve bu ontolojik özellikler ile tanımlanır (Chi, 1997; Chi & Slotta, 1993; Chi ve Hausmann, 2003). Kavram yanılgısı, bir kavram bulunması gereken ontolojik kategoriden farklı bir kategoriye ya da alt kategoriye atandığında oluşabilir (Chi & Roscoe, 2002). Bu görüşten yola çıkan bazı araştırmalar öğrencilerin sahip olduğu kavram yanılgılarını ontoloji temelinde analiz etmiştir (Johnston & Southerland, 2000; Kahveci & Özalp, 2009; Özalp & Kahveci, 2011). Bu çalışmalar kavram yanılgılarının oluşum nedeni ve yapısını anlamada ontolojinin teorik bir çatı olarak kullanılabileceğini ortaya koymuştur.

Bu çerçevede, mevcut araştırmada müfredatın öngördüğü öğretim sonrasında öğrencilerin kimyasal bağların özelliklerine ilişkin düşünce biçimlerinin incelenmesi amaçlanmıştır. Çalışmanın diğer bir amacı ise, öğrencilerin sahip olduğu kavram yanılgılarının nedenleri ve kavramlar arası ilişkilerin ontoloji temelinde analizini yapmaktır. Yorumlamacı paradigma temelinde tasarlanan çalışmada veri toplama aracı olarak, açık uçlu sorulardan oluşan bir anket kullanılmıştır.. Anket 404 lise 11. sınıf öğrencisine uygulanmıştır. Ankette yer alan sorular ile kimyasal bağın özellikleri konusunda öğrencilerin düşünce biçimleri ve nedenlerinin saptanması hedeflenmiştir. Öğrencilerin kimyasal bağın özellikleri konusundaki yanılgılarının altında yatan nedenleri açığa çıkarabilmek için, bazı öğrencilerle bireysel yüzyüze görüşmeler de gerçekleştirilmiştir. Bu görüşmelerde öğrencilerden yazılı olarak sunduğu yanıtını bir kez de sözel olarak açıklaması istenmiştir. Görüşmelerde ayrıca, açıklaması sırasında anlaşılamayan ya da kodlama sırasında ikileme neden olabilecek durumlara ilişkin örnek vermeleri de istenmiştir.

Araştırmadan elde edilen bulgular, konu ile ilgili öğretimi almış olmalarına karşın araştırmaya katılan öğrencilerin kimyasal bağ kavramına ilişkin çeşitli yanılgıları olduğunu göstermektedir. Öğrenciler arasında (%25) kimyasal bağ oluşumu sırasında kütlenin artacağını ya da azalacağını düşünenler bulunmaktadır. Yaptıkları sözlü ve yazılı açıklamalarından bu öğrencilerin kimyasal bağın kütlesi, hacmi ve şekli (n=10) olduğunu düşündükleri anlaşılmaktadır. Diğer bir deyişle, öğrenciler ontolojik açıdan süreç kategorisinde yer alması gereken kimyasal bağ kavramını madde kategorisine yerleştirmiş gibi görünmektedirler. Yazılı yanıtlarında kimyasal bağları madde olarak tanımlayan gerekçe olarak da atomları bir arada tutan şeylerin somut olması gerektiği fikrini benimseyen öğrenciler bulunmaktadır.

Ontolojik açıdan benzer yanlış eşleme enerji kavramına ilişkin de yapılmıştır. Bulgular, öğrenciler arasında enerjinin bir madde olduğu, kütlesinin bulunduğu yanılgısının yaygın olduğunu ve bu yanılgının kimyasal bağın kütlesinin bulunacağı konusunda öğrencileri yönlendirdiğini ortaya koymaktadır. Yine bulgular öğrencilerin kimyasal bağları enerji depoları (n=86) olarak hayal ettiklerini de ortaya koymuştur. Bu düşünce biçimi "kimyasal bağlar kırılırken enerji açığa çıkar" tahminini de beraberinde sürüklemiştir (%21). Bulgulara göre, kimyasal bağların termodinamik özelliklerine ilişkin bu düşünce biçimi öğrenci zihninde "enerjinin kütlesi vardır" yanılgısı ile buluşmadığı sürece öğrenciyi alternatif fikre yöneltmemiştir. Öte yandan, ister kimyasal bağları enerji deposu olarak düşünsün isterse düşünmesin öğrencinin zihninde enerji bir madde ise kimyasal bağ oluşumuna kütle değişimi eşlik etmiştir.

Bulgular ayrıca, öğrencilerde tespit edilen bazı kavram yanılgılarının nedenlerinin ontoloji temelinde açıklanamadığını da ortaya koymaktadır. Öğrencilerin bir bölümü kimyasal bağı madde olarak tanımlarken kütlesi olduğuna değinmemiştir. Bu öğrenciler kimyasal bağın "kırılabilir oluşuna" ve "atomları bir arada tutuyor olmasına" vurgu yapmıştır. Sözü edilen bu özellikler madde ontolojik kategorisine ait değildir. Nitekim, madde kırılgan özellikte olmadığı gibi ayrıca her zaman iki şeyi bir arada tutan ontolojik bir varlık da değildir. Benzer şekilde, kimyasal bağın madde olduğunu düşünen diğer bir grup öğrenci ise, düşüncelerini açıklarken kimyasal bağlarla ilgili olarak kütle hesaplamaları yaptıklarını (aslında enerji hesaplamaları) gerekçe göstermiştir. Bu çerçevede, sözü edilen düşünce biçimlerinin kaynağının öğrencilerin kimyasal bağ oluşumunun ifadesi olan enerji hesaplamalarını kütle hesaplamaları şeklindeki yorumlamaları olduğunu, ontolojik açıdan yanlış eşlemeden kaynaklanmadığını söylemek olanaklıdır.

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