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TURKISH MIDDLE SCHOOL STUDENTS' CONCEPTIONS AND MODELLING OF CHEMICAL BONDS

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Abstract. *The purposes of this study were to identify students' conceptions of chemical bonds and to determine, after instruction, the changes these conceptions undergo. The dataset for this study arises from an administered questionnaire that includes answers to three open–ended questions from 76 6th grade students and 56 7th grade students. Analysis of the qualitative data obtained through the questionnaire indicates that the majority of students had difficulty comprehending the modelisation of chemical bonds and that levels of interpreting these concepts of chemical bonds was much lower than what is required at the end of these different grades. The study showed that students have similar conceptions of bonding affinity expressed though a language of kinship and convenience, as used in 17th century. Additionally, the students' conceptions also reflect the 18th century' macro level concept of affinity expressed through the notion that likes attract.*

Key words: *chemical bond, intermolecular bond, intramolecular bond, model, modelling, science education.*

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Introduction

Chemical transformations, represented by equations of reaction create a relationship between a symbolic verbal system (nomenclature) and an iconic symbolic system (chemical formula) by indicating atoms' organisational changes within molecules. This rearrangement demands the intervention of chemical bonding, and consequently, an understanding of the concept. A previous study (Laugier, 1998) showed that the same obstacle, which for centuries hindered scientists in linking macroscopic and microscopic representations of matter, is a major obstacle for students.

Chemical bonding is understood through diverse models, which in turn, build upon a range of physical principles. Students are expected to interpret a disparate range of symbolic representations standing for chemical bonds (Taber & Coll, 2002). Johnstone (1991) and Gabel (1996) stated that matter can be represented on three levels: macroscopic (physical phenomena), symbolic (chemical and mathematical language) and microscopic (particles). Learning about the particle nature of matter is pivotal when learning other concepts in chemistry (Adbo & Taber, 2009; Othman et al., 2008). Çökelez (2009) showed that students form their particle models on the basis of perceived motion capabilities and qualities of hardness and fluidity. Students think of the speed, energy, spaces between and contact of particles in an order ranging from the fastest moving particle form (gas) of matter to its most inert state (solids). In addition, students define the model of the particle nature of matter in terms of the variables of vibration, energy, collision and shifting, as well as the empty spaces and distance in between particles. They try to interpret, then, the basic qualities of the solid, liquid and gas states of matter on the basis of these descriptors (Adbo & Taber, 2009).

In science education, students' learning of abstract concepts, such as chemical bonding, can be facilitated through the use of models and modelling processes (Treagust et al., 2002). According to Paton (1996), a model's most general definition involves scientific and mental activities that facilitate an

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individual's comprehension of complex phenomena. Host (1989) defines the model as a representation of a real system; Drouin (1988) defines it as an object used in place of another; and Bissuel (2001) defines the model as a tool of communication. Models, then, have three main functions:

- Acting as representation of the real phenomenon or system that is to be explained (Martinand, 1990),
- Making use of an analogy – which provides an explanatory quality – with different definers in the system that need to be explained to define a characteristic or a change of a characteristic (Genzling & Pierrard, 1994), and
- Allowing predictions to be made about a developing process or the change in a system without having to observe the actual phenomenon (Drouin & Astolfi, 1992).

Robardet and Guillaud (1997) and Walliser (1977) define models using three different categories. The first is physical (scale) models that create a concrete representation of phenomena. Examples include the "planetary model" of the atom. The second category consists of analogical models that explain phenomena by making an analogy with a simple or familiar phenomenon or phenomena. An example of this category is the depiction of blood circulation with a pipeline and pump. The third category is symbolic models expressed in different types of languages, which can be written (special terminology, technical or programming language), iconic (graphic symbols, and diagrams of different structures), or logical/mathematical (languages that use abstract symbolism to explain relationships).

Rather than presenting or explaining the model itself to students as part of a science program, the process of modelling that students participate in actively gains an increased instructional value (Martinand, 1994; Van Driel & Verloop, 2002). Martinand (1994) suggested three different registers to consider when teaching with models. The first is the "empirical referent", which involves identifying the objects, tools, processes used to understand the phenomena or objects being analysed; the second is the register of "interpretive elaboration" (level of preparation for interpretation) of models based on empirical referents; and the third is the register of the "cognitive matrix" which allows an epistemological explanation for a constructed model.

Justi and Gilbert (2002) stressed the necessity of a three-stage development of theoretical knowledge when creating a model. These development stages are as follows:

- Differentiating the attributes shared and not shared by the subject and target,
- Representing the development and preservation of the components unique to a system, and
- Suggesting a predictable concept through the use of simplified representations.

Purpose of the Study

The purposes of this study are to identify students' conceptions of chemical bonds and to determine, after instruction, the changes these conceptions undergo, either individually or as a group. As previous studies on this subject have mainly concerned high school students, this study focuses on junior high school students.

More specifically, the research questions tried to be answered are as follows:

- To what extent do students comprehend the modelisation of chemical bonding?
- How does this modelisation change from the beginning of the 6th grade to the end of the 7th grade?
- How do students define intermolecular bonds?

Literature Review

Bond in General

According to the literature, students and teachers consider chemical bonding to be a very complicated concept (Robinson, 2003; Taber, 1998, 2001). Most alternative conceptions of chemical bonding in chemistry are derived from prior science teaching (Taber, 2002). Most students' misconceptions are based on the difficulty in going from the macroscopic to microscopic world of matter (Harrison & Treagust, 2000; Robinson, 2003; Laugier & Dumon, 2004). Students often use pseudo-conceptions; they use the right terms and concepts, but do not understand their meanings or their conceptual relevance (Vinner, 1997). Students use the term "bonding" in the physical sense, such as that which maintains two pieces of material or two people together (Ben-Zvi & Eylon, 1982, 1987; Boo, 1998).

They also have difficulty differentiating between covalent and ionic bonds (Taber, 1994; Tan & Treagust, 1999; Butts & Smith, 1987; Boo, 1998). For example, in sodium chloride, a covalent bond binds the atoms Na and Cl to form a molecule of NaCl, and the crystalline structure of table salt results from an ionic bond between NaCl molecules. Students who consider ionic compounds to be molecular recognise that the intramolecular ionic bond is more solid than other bonds when the molecules are placed together (Boo, 1998). When they consider several types of bonds, the different charges are located in the atoms (De Posada, 1999), or perhaps implied in the pairs of electrons shared between two atoms (Boo, 1998).

For many students, (Taber, 1999), the interactions between atoms are considered to be neither covalent nor ionic; these interactions simply correspond to a force. The atoms are thought to bind themselves to reach a lower energy level (Taber &Watts, 1996; Taber, 2000) or because they have a field of attraction for other atoms (De Posada, 1999). Robinson (1998b) reports that for many students molecules are considered to form from isolated atoms. They also believe that there are only two types of bonds, covalent and ionic. Anything else is considered just a force and "not a proper bond". These students think that chemical bonds are thought to form to produce filled shells rather than filled shells being the consequence of the formation of many covalent bonds.

Covalent Bond

Boo (1998) shows that, for many students, a chemical bond is thought to include only one electron, in the same manner that an apple can be divided between two people. For others, the electrons are thought to be shared between atoms in covalent bonds (Peterson & Treagust, 1989; Garnett et al., 1995; Coll & Treagust, 2001). The students also think that the number of covalent bonds formed by a non-metal is equal to the number of its electrons in the valence shell (Peterson & Treagust, 1988; Garnett et al., 1995).

The interpretation of the electron sharing between two atoms rests on the octet rule and the stability of the full shells (Taber, 1994, 1995; Coll & Treagust, 2001; Robinson, 1998a, 1998b). This rule is a basic principle, a heuristic, for students (Taber, 1997; Robinson, 1998b). The chemical bond is formed so that atoms "have their last layer [s] filled" and "that [they] have the electronic configuration of a rare gas and it would be stable." It is often formulated in an animistic way (Taber & Watts, 1996):

- *"The first layer requires two electrons to become stable. A hydrogen atom joins to another atom and it collects the electron of another hydrogen, thus it knows that it has two electrons."*
- *"C and N tend to exchange their electrons of their respective orbitals to become stable also."*
- *Lastly, a molecule is nonpolar only insofar as the atoms constituting it have identical electronegativities, and the shape of a molecule is either due to the bonding electron pairs or the lone pairs of electrons (Peterson & Treagust, 1988).*

Ionic Bond

Taber (1994) states that even if the students cannot intellectually construct the concept of ionic bonds skilfully, they are able to discuss them. For example, students believe that an atom's electron configuration determines the number of ionic bonds the atom can form. Students often believe that because a sodium atom can provide only one electron, it can only form one ionic bond. Moreover, they believe that if the ions interact well with ions of opposing signs, interactions are forces of electrostatic origin and not the results of bonds (Taber, 1994, 1997; Coll & Treagust, 2001). This perception by students, confirmed by Boo (1998), shows that students believe that "bonds" is a term reserved for covalent bonds, not ionic and metallic bonds.

Robinson (1998b) reported that ionic bonds result from the transfer of electrons, rather than from the ions' attractions resulting from the transfer of electrons. Electrons are transferred to achieve a full shell, and an ionic bond only occurs between the atoms involved in an electronic transfer. Thus, sodium ion forms one ionic bond to a chloride ion in solid sodium chloride and forms in five forces with the other adjacent chloride ions. Na+ and other ions are stable because they have a filled outer shell. To form an ionic bond, an electron transfers from one atom to another, allowing both to complete their electron shells (Taber, 1999). Electron transfers occur due to atoms' needs –that is, their tendency – to acquire the configuration of a rare gas (Taber, 1994). The internal structure of an ionic crystal is shaped from an assembly of particles (small portions of the crystal) or atoms from salt or salt molecules (De Posada; 1999).

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Intermolecular Bond

Most students do not have a clear sense of the physical origin of the forces among particles in chemical substances (Stevens et al., 2007). Students confuse intramolecular and intermolecular bonds (Treagust et al., 2002) and few studies have been carried out on intermolecular bonds. However, Peterson and Treagust (1988, 1989) show that a quarter to a third of students do not understand the concept of intermolecular bonds. For these students, an intermolecular connection is associated with a covalent bond and such bonds exist, for example, in covalent solids such as a diamond. Coll and Taylor (2001, 2002) and De Posada (1999), who showed that, for many students, the molecules of a gas are bound by covalent bonds, made the same observation for ionic or metal solids. Misconceptions about intermolecular forces listed by Peterson et al. (1989) include:

- Intermolecular forces are the forces within a molecule,
- Strong intermolecular forces exist in a continuous covalent solid, and
- Covalent bonds are broken when a substance changes shape.

Curriculum Context

The instructional introduction of the concept of chemical bonding begins in the science and technology curriculum of 6th grade in primary school. This concept is a pivotal subject that forms the foundation for understanding the concepts of molecules and chemical reactions. From the 6th grade on, students should have the idea that "chemical bonding" means "being close to each other". For 7th grade curriculum, students are expected to grasp the concept of bonding. Summaries of the 6th and 7th grade curriculum (MEB., 2005a, 2005b) follow.

By the end of the 6th grade, students should be able to associate chemical bonds with the transfer and sharing of electrons (MEB:, 2005a: p. 229). Students should recognise the existence of a "chemical bond" between atoms that are close to one another and that the attractive force between two oppositely charged ions is an "ionic bond". Students should also learn that a "covalent bond" exists when atoms share electrons.

By the end of the 7th grade and in the context of atomic structure, students should be able to describe atoms that are in contact with each other as "bonded atoms" (MEB., 2005b: p. 233).

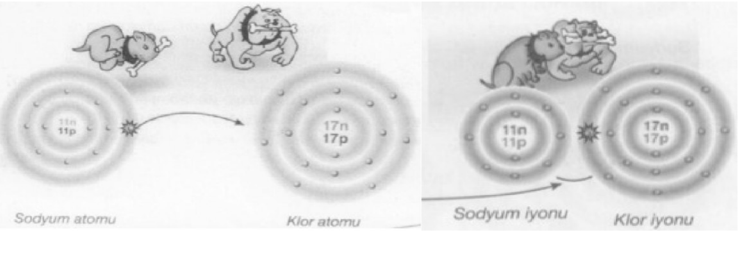
In relation to chemical bonds, students should be able to do the following:

- Associate the closeness of atoms with the concept of chemical bonding,
- Estimate the attractive/repellent force between ions, calling these attractive forces "ionic bonds," and
- Designate bonds created through the sharing of electrons as "covalent bonds".

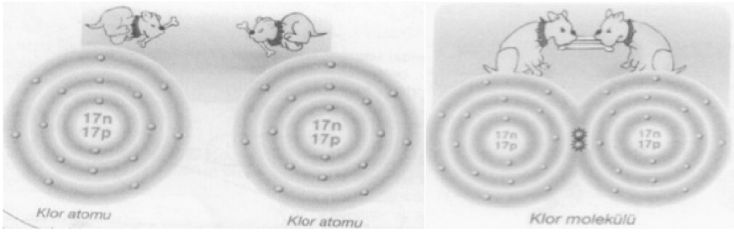
In relation to intermolecular bonds, students should be able to:

- Determine atoms, molecules, bonded atoms and bonded molecules through representations and/or models of iodine crystal, and
- Estimate, comparing intervals among bonded atoms and bonded molecules, that atomic bonds are stronger than intermolecular bonds.

A 7th grade textbook (Tunc et al., 2007) summarises a chemical bond as the attractive forces holding oppositely charged ions and atoms together, while an ionic bond is a chemical bond that is formed through the transfer of valence electrons from one atom to another. In addition, a covalent bond is a chemical bond formed through the sharing of valence electrons between atoms. These definitions are illustrated by the schematisations in Figure 1.



a) ionic bond (Tunc et al., 2007: p. 167)



b) covalent bond (Tunc et al., 2007: p. 170)

Figure 1: Schematisation of chemical bonds.

Ionic bonding is defined here as an electron transfer event. But this definition can cause some misconceptions. However, this concept should be defined as the electrostatic attraction between oppositely charged atoms.

Methodology of Research

Sample Selection

The research sampled 132 students, at two schools in the province of Samsun, Turkey, taught by the same teacher using the same method, from the 6th grade (n: 76) and 7th grade (n: 56). Because the same teachers at both schools used identical teaching methods, the choice of these two consecutive grades was appropriate in showing changes in the students' conceptions of chemical bonding over time.

Instrument and Procedures

A questionnaire consisting of three open-ended questions was used to examine students' comprehension of chemical bonding. The questionnaire included the following questions:

Q.1. How would you define "chemical bonding"? Please explain and show with a diagram.
Q.2. What is intermolecular bonding?
Q.3. What are the bonds inside the molecules (atomic bonding)? Please explain.

The questionnaire was developed by the researchers of the present study through consultation with two experienced science teachers, as well as through the examination of the science and technology curriculum and guidance provided by the relevant literature.

To validate the instrument used for data collection, three experts (two experienced science teachers and one experienced chemistry teacher) were consulted, and each indicated that the questionnaire was appropriate to use for data collection. To ensure reliability of the analysis of students' responses, the three experts were also asked to categorise the students' responses. The comparison of categories showed that there is consistency among their categorisations.

The first question aimed to explore students' mental models and their ideas about chemical bonding; question 2 asked students about their ideas regarding intermolecular bonding; and question 3 explored how students explain the bonds inside molecules (intramolecular bonds).

To give brief information about the general background of the present study; the first stage of the research examines schools' science curricula and textbooks to identify the intended development of the concept of chemical bonds. The next stage involves a review of existing literature related to this concept and a synthetic presentation of the students' misconceptions completed by different researchers. In order to start data collection, first of all the required permission were obtained from the provincial directorate of national education to do research with school students. Students were given half an hour to answer the questions. The questionnaire was administered to students one month before the 6th grade students began the instruction of chemical bond and approximately three weeks after the 7th grade students finished related instruction. All questions and responses are communicated in Turkish, the language of instruction was also Turkish.

Data Analysis

In the present study, authors preferred to collect qualitative data because it provides more information than a multiple-choice instrument (White and Gunstone, 1992). The analysis of the data categorised students' responses and then grouped them into sub-categories according to common characteristics of expression and main ideas. Response frequencies and rates were calculated and continuous comparisons identified common categories among student responses. Data from the main categories and sub-categories gained support from direct quotations found in students' responses. These quotations, written in italics, strikingly reflect the ideas and experiences of the participants (Yıldırım & Şimşek, 2008); the analysis drew connections and prompted interpretations. Since one student could have various expressions and ideas, the total number of characteristics in Tables 2, 3 and 4 exceed the number of students.

Results of Research

Chemical Bonding

The definitions that 6th grade students offer for chemical bonding appear in Table 1.

Table 1. Classification of responses given by 6th grade students.

Category	N	%
Attachment/bond between chemical substances	13	28
Family bond/attachment of blood vessels/personal bond/personal tie	11	24
Explication of change of matter	8	17
Bond, ropes, spindle, attachment	9	20
Others	5	11
Total	46	

When considering Table 1, 13 of the 6th grade students who responded (28%) define chemical bonding as "the attachment of chemical substances". These students seemed to have a macro level conception of affinity used in the 18th century, defining it through "like attracting like". For example, one student gave the following definition: "When we say chemical bond, I think of two substances with the same properties, of molecules and their attachment to each other". This response shows the student's confusing of macro and micro levels, as"chemical bond" creates the idea of the attachment substances may have. This idea corresponds to the definition of affinity given by Macquer in 1749 (Dumon & Cokelez, 2006): "There are, between the different bodies, both principles compounds, a convenience, report, affinity or attraction if you like, so some body is disposing/arranging to join together. " (As translated by the author of the paper).

Table 1 shows that a significant group of 6th grade students (24%) believed that a chemical bond is like a "family bond", "a personal tie" or an "attachment of blood vessels", and described a chemical bond as being "a bond with a family relative or a personal bond." This concept of affinity was also used in the 17th century and was described through notions of kinship and convenience: it is the "sympathy" established between similar things that allow their unions. This thinking might be based on a teaching analogy and could be a useful concept when beginning to think about the meaning of bonds. The definitions that these students set forth for chemical bonding include the following: "A chemical bond reminds me of a family bond" and "the attachment of elements is like how siblings are".

The definitions given by 8 students indicate that they believe that it is the chemical bond that allow and explains the changes of matter: "it is bond that changes matters"; "a bond that causes substances to change"; "it is called chemical bond because of its liquid and gas states"; and "explication of change of state, burning of paper".

This conception is similar to what chemists in the 18th century thought, as Lomonosov (1741) states: "The mixed bodies change by adding or removing one or more constituents… And this cannot occur without a change in the bonding between the particles. Therefore, there must be forces capable of destroying the cohesion of the particles" (as translated by the author of the paper).

Other 6th grade students (9) responses related to chemical bonding seem to assign a concrete reality to the chemical bond. This includes comments like, "the characteristic that ties chemical phenomena together"; "molecules are tied together with something that looks like a spindle"; and "attachment of ropes". Only two students seem to associate chemical bonding with the bonding between atoms in molecules. For these two students, chemical bonding is considered to be "a mixture of atoms between two substances" and an "internal bond".

The definitions that 7th grade students offer for chemical bonding appear in Table 2.

Table 2. Classification of responses given by 7th grade students.

	Chemical bond is	N	%
Attractive force between	Atoms	5	10
	Ions/atoms of opposite or different charges	12	25
	Molecules	2	4
	Atoms and ions	8	16
	Ions and molecules	9	18
	Atoms or/and molecules	3	6
	Electrons	1	2
	Only	1	2
Total		41	84
Atoms joining together to form molecules		2	4
Sharing/transfer of electrons (to remain stable; and their desire to be stable: 3)		3	6
Other	Transfer of atoms so that atoms can become steady Elements transferred or sharing atoms in order to remain stable Tying bonds	3	6
Total responses		49	

In accordance with the definition taught and given in this study, responses from 7th grade students (Table 2) demonstrate that a majority of them who responded to the question (41/49) define a chemical bond as an attractive force. Taber's study (1999) indicates a similar finding in that students reportedly defined the interactions between atoms not as bonds but as attractive forces.

In this study, 8 students had concepts similar to the following: "It's the attractive force that makes ions and atoms of different charges come together" (seen in the diagram in Figure 3a) and "it's the attractive force that makes ions and atoms stand closer to each other" (seen in the diagram in Figure 2d). In addition, one student explicitly mentioned the existence of two types of bonds: "There are two types of bonding: ionic bonding and covalent bonding". Still, no formulation satisfactorily corresponded to the definition of covalent bonding taught (the sharing of valence electrons between atoms) or ionic bonding (the transfer of valence electrons from one atom to another).

The majority of students (30/49) gave definitions accompanied by schemas. Among these schemas, there are 8 representations of electron sharing (Figure 2) and 15 representations of electron transfers (Figure 3) associated with various categories of definitions for chemical bonding. These different representations illustrate the definitions given by students.

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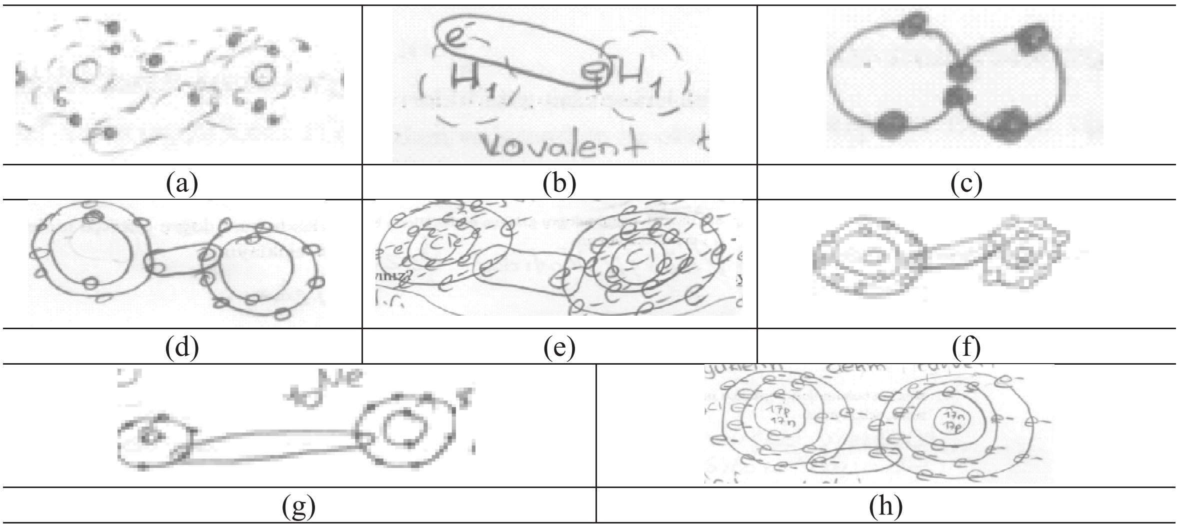

Figure 2: Representations of the bond formation by electron sharing.

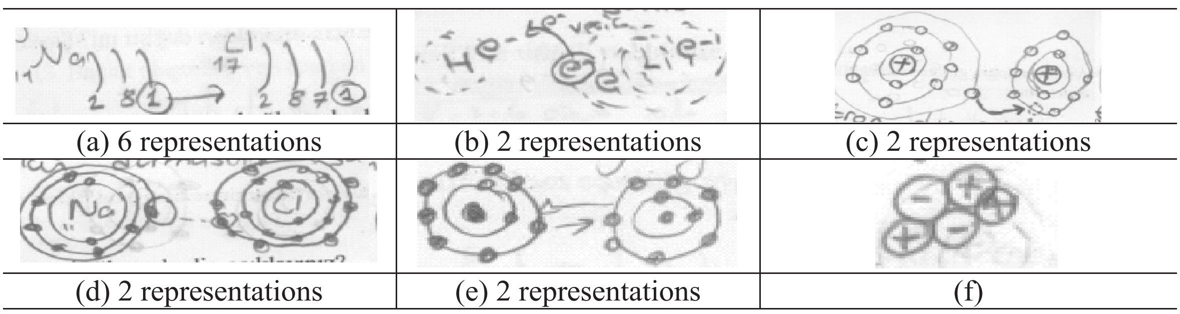

Figure 3: Types of representations of bond formation by electron transfer.

In other definitions, the attraction between ions (21 occurrences) is the primary concept: alone ("it is the attractive force between ions" (Figure 2a), an "attractive force between anion and cation" (Figure 3c), "The attractive force between oppositely charged ions" (Figure 3f), and "Chemical bonding is the force that makes two atoms of opposite charges come close to each other" (Figure 3d)) or associated with molecules ("It's the attractive force that makes oppositely charged ions and molecules come closer to each other" (Figures 2e, 3e)). These answers - despite incorrect characterising - derive from the taught definition, albeit deformed.

The attractive force between molecules appears in a total of 15 occurrences in other definitions given by the students, including "it is the attractive force between molecules" (Figure 2b) and "it's the attractive force that different types of atoms or molecules apply to each other" (Figure 3c). These students do not seem to differentiate the bonds between atoms and intermolecular bonds. Only the student drawing Figure 2b explicitly wrote that this representation of the chemical bond, which appears to confuse atoms and molecules, is a covalent bond.

Some students stated that a chemical bond between atoms appears in different forms, primarily as an attractive force between atoms (16 occurrences), and is either associated with ions, molecules or by itself: "it is the attractive force between atoms", "Two atoms joining together as a result of an attractive force that comes about when two atoms are very close to each other", and "It's two or more atoms attracting each other". For two students, the bond between atoms is associated with the formation of molecules: "It's the bond that makes atoms come together and create molecules" (Figure 2c).

The electron contribution to the formation of bonds is found only in three definitions: "It's the transfer of electrons arising from the attraction between atoms and molecules and their desire to be stable" (Figure 3c), "Chemical bonds are bonds of such a structure that they both give and take electrons" (Figure 2g) and "It's sharing and transfer of electrons in order to be stable or the attractive force of their charges." (Figure 2h). In this last definition, there is the covalent bond, ionic bonding and the mental model of the octet. This mental model associated the need and desire of atoms to be stable in formulations: "The transfer of atoms so that atoms can become steady" (Figure 2f) and "How elements transferred or shared atoms in order to remain stable" (Figure 3d). Here, students became confused about electrons and atoms. Also, students held misconception that ionic bond is formed by the transfer of valence electron from one atom to another. This inappropriate model is presented in the curriculum.

Of the 7th grade students, 19 students associate the closeness of atoms with the concept of chemical bonding when writing in their definitions, "come close to each other". On the other hand, it may be concluded from a comparative analysis of definitions and their associated representations that students are unable to clearly relate models of covalent and ionic bonds with their taught definitions and schematic representations. They only retained some "surface features" that they apply to concepts (atom, molecule, ion, electron) between which there are confusions.

Intermolecular Bonding

The definitions students offered by the 6th grade students for intermolecular bonds appear in Table 3.

Table 3. Classification of responses given by 6th grade students.

Category	N	%
Molecules are tied/bond/joined together	25	54
Similar properties/characteristics of molecules	6(+2)	17
Molecular structure/State of matter	3	7
Reference to atoms	7	15
Other	5	11
Total responses	46	

Before teaching the concept, 6th grade students stated "chemical bonding" meant "being close to each other". For 25 of these students, intermolecular bonding is logically defined as the tying/bonding/joining of molecules: "Bonds that tie molecules together"; "Bond being between two molecules"; "Something that joins molecules together". These definitions have specific formulations: first, "New types of molecules formed by joining molecules together" reveals that the student thinks that molecules somehow join to create different molecules. For this student, and certainly others, the additivity model of molecules during chemical reactions was used. It should be noted that chemists of the 18th century also believed in this idea of the union of component particles to form more complex corpuscles. In the second formulation category, a reference to the identity of characteristics or properties of molecules appears: "The joining together of similar molecules" and "Molecules locking into each other or having the same properties". This similarity of characteristics/properties between the bonded/nested molecules appears in four other definitions: "Molecules may be the same shape and the same colour", "Common properties of molecules", Molecules resembling each other", and "The similarity between two molecules". Such formulations reflect that students think it is the bond between identical molecules that leads to different states of matter at the macroscopic level. This idea is explicitly reflected in two other definitions: "Forming molecular structure combining a lot of matter" and "If bonds between molecules are weak, these substances are called gases, if molecules slide over each other, they're called liquids, and if these bonds are almost non-existent these substances are solids." In this last definition, this student's conception is identical to that of the mechanist chemists of the 17th century (in the liquid state, the particles slide over each other) and a conception, already highlighted (Mirzalar-Kabapinar, 2008), that there is no force or chemical bond between solid particles.

Some students (7) incorrectly associated the intermolecular bonding with atoms: "The bonds between molecules are atoms" and "It is pure and formed from two atoms". In these formulations, "Atoms are tied together" and "[a] chemical bond is a bond that joins atoms, making it a molecule" clearly display the confusion between inter- and intramolecular bonds.

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Table 4. Classification of responses given by 7th grade students.

Nature of bond	N	%
Bonds between molecules	8	14
Ionic bond	16	28
Covalent bond	20	35
Chemical bond	11	19
Other responses	2	3
Total responses	57	

The concept of intermolecular bonding is not explicitly defined in 7th grade teaching. Rather intermolecular bonding is taught to students through the representation of crystal iodine, the connection between molecules and the fact that this intermolecular bonding is weaker than the bonds between atoms. With regard to the answers given by students (Table 4), this introduction of intermolecular bonding is ineffective. Indeed, only 8 out of the 57 students who gave a response spoke about bonds between molecules: "Bonds between molecules"; "Attractive force between molecules"; and "Bonds formed between molecules. For example, water has molecular structure". Other definitions refer to different types of known bonds, including covalent bonds (20 occurrences), ionic bonds (16 occurrences) and chemical bonds (11 occurrences): "Ionic and covalent bonds", "Covalent and ionic bonds", "Covalent: chemical bond formed by sharing of electron. Ionic: attractive force between anion and cation", "Chemical bond, ionic bond, covalent bond", and "Chemical bond: attractive force between molecules. Ionic bond: bond formed by transfer of electron from one element to another in order to form compound. Covalent bond: sharing of electrons by two atoms". The results show that, contrary to what was observed in the responses to the first question, the concepts of covalent and ionic bonding are explicitly cited, accompanying each of the eight acceptable definitions (see examples above). In 11 responses, chemical bonding is mentioned with diverse definitions: as an "attractive force between molecules" (intermolecular bond), as an "attractive force applied by anion and cation between each other" (ionic bond), and as an "attractive force between two or more atoms" (covalent bond). It can be concluded that the majority of responses given by the 7th grade students reflects confusion between the meanings of intermolecular and intramolecular.

Bonds Inside Molecules

Students' responses to question 3 appear in table 5.

Table 5. Students' definitions of bonds inside molecules (intramolecular bonds).

Category	Grade 6		Grade 7	
	N	%	N	%
Bonds/joins of atoms	23	62	2	5
Intermolecular bond	2	5	1	2
Covalent and ionic bond	-	-	20	46
Chemical, covalent and ionic bond	-	-	12	27
Chemical bond	1	3	8	18
Other	11	30	1	2
Total	37		44	

As probably guided by the formulation of the question, specified through "atomic bonding", the 6th grade students mainly gave a response relating to a 'type of bond/joins of atoms' (23 responses) similar to the following: the "Joining of atoms" and "Bonds of atoms". Some specified (4 responses) that this forms molecules: "Something joining atoms of molecules" and "Atoms bonding together and forming molecules". One student described this through a concrete example: "A tie that joins atoms together, something like a cable". Additionally, some students confused the concepts of intramolecular and intermolecular bonds and stated, "Intermolecular bonds" and "The bonds between atoms are the bonds between molecules", and described these bonds as a "chemical bond".

Again, this study reveals a difference between the two categories of students used in the paper. For the 7th graders, references to known bonds, covalent and ionic, predominate (32 occurrences). This is followed by some students adding "chemical bonds" (12 occurrences), while others, in accordance with the taught definition, had the concept that "the attractive force holding oppositely charged ions and atoms together is called chemical bond", under the denomination of "chemical bond" (8 occurrences). The bond between atoms is only mentioned by two students; one student clearly explained what this bond meant by referring to the octet rule: "Atoms in a stable state that do not have a configuration of electrons interact with each other to achieve an electron configuration."

As reflected through the responses provided by most students, the three taught definitions of a chemical bond do not cohesively construct an acceptable understanding of the material. Namely, that the bonds between atoms, like those between molecules, can either be covalent or ionic. To avoid these confusions, it is preferable to reserve the term "chemical bond" to covalent bonds between atoms, while at the macroscopic level, it is preferable to use molecular or ionic interactions when describing the assembly of chemical entities.

Discussion

The study showed that many students tried to explain the concept of chemical bonding on a macro level, specifically in terms of family relations or friendships, a type of response previously reported by researchers (Ben-Zvi et al., 1982, 1987; Boo, 1998). Apparently students have difficulty envisioning physical and chemical phenomena at a micro level. It's also been suggested by various researchers that students have difficulty going back and forth, conceptually, between the macro and micro levels (Laugier, 1998; Laugier & Dumon, 2003; Ouertatani & Dumon, 2008). The results showed that students have similar conceptions to the first concept of affinity given in the 17th century, which is described through relations of kinship and convenience: it is the "sympathy" established between similar things that allow their union. This way of thinking may be based on a teaching analogy. Students have macro level conceptions that express the concept of affinity through attraction used in the 18th century. They also confuse macro and micro level ideas concerning the "chemical bond", a term that creates an idea of attachment that substances may have with each other.

This study uncovered the fact that students are confused in regard to the usages of intramolecular and intermolecular bonding. When trying to understand these concepts, different researchers (Cros et al., 1986; Kiokaev, 1989; Peterson & Treagust, 1989; Cokelez et al., 2008) have also established that students confuse these two types of bonding. Paradoxically, 6th grade students are able to make sense of "intermolecular bonding", while 7th grade students are not. The different definitions given to "chemical bond", as well as the fact that students feel the need to cite three different types of bonds, show a deformation of the information taught. Because there are three definitions, there are only three types of bonds: chemical bond, ionic bond and covalent bond. In order not to add another type of bond to the concept of ionic and covalent bonds, it might be more effective for teachers to speak about intermolecular interactions rather than intermolecular bonds. Studies on this subject are insufficient, and there is a need for further research (Mirzalar-Kabapınar, 2008).

Some of the 7th grade students explained intermolecular bonds as covalent and ionic bonds. Obviously, students who do not fully understand the concepts of intramolecular and intermolecular bonding cannot differentiate between the two and would have difficulty comprehending physical and chemical reactions.

The concept of chemical bonding is one of the key concepts that should be taught during upper secondary education (Nahum et al., 2010). The level of abstract thinking needed to understand chemical bonding is usually associated with Piagetian formal thinking. It may be that at this age, students have not fully developed the ability to think abstractly. Students may also lack a basic pre-requisite knowledge for understanding chemical bonding, such as the particular nature of matter. The teaching of chemical bonding, then, may lead to a cognitive overload as it might, simultaneously, introduce too many new concepts. Students might also use these terms inadequately, but still grasp a genuine meaning of chemical bonding.

The study also shows that a significant portion of students had difficulty responding to the questions asked. This calls attention to a need to review the content on chemical bonds and assess the time allotted to the study of this subject. The results also suggest the necessity of questioning the methods and techniques used for teaching this concept. The conclusion to be drawn is that students have failed to fully learn the concepts of atoms and mol-

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ecules and that they are confused (Cokelez, 2012). Clearly, before the concept of chemical bonding can be taught, the concepts of atoms and molecules, as well as the basis of the bonding concept must be meaningfully grasped by students. In addition, the use of models and modelling is important for the teaching of abstract concepts, such as atoms, molecules, and chemical bonds. Therefore, it is imperative that students first learn exactly what a model depicts, the relationship between a model and an actual concept, and the reasons for using a model. At the same time, conducting exercises to develop students' modelling skills is crucial when teaching with models to ensure that students fully understand the concepts. The scarcity of models used in teaching abstract concepts in science education makes the task of teaching much more difficult for science and technology teachers. Looking at the situation from this perspective can be useful when considering the importance of developing models in the classroom for teaching abstractions. New, in-depth research of the degree of impact that developed models have on effective teaching in the classroom will certainly contribute to understanding the difficulties encountered in this context.

Conclusion and Implications

The present study reveals that although students have been positively affected by the teaching of chemical bonding, their level of learning is far from satisfactory. In addition, upon reviewing students' responses in terms of the knowledge they have gained from their science and technology courses, they apparently have not derived from the lessons that all they were expected to learn. In students' responses, no formulation satisfactorily corresponds to the taught definition of the covalent bond (by sharing valence electrons between atoms) or ionic bond (the electrostatic attraction between oppositely charged atoms). The study showed that some students define ionic bond, as presented by the curriculum, as the transfer of valence electrons of one atom to another.

On the basis of the results of this study, one suggestion is that teachers who are taking part in the educational process need to concentrate on the basic concepts of science in the classroom and use modelling methods to teach abstract concepts that are difficult for students to learn. Key concepts and elemental principles that are common for all chemical bonds between two atoms should be used first, followed by the teaching of molecules and lattices (Nahum et al., 2007).

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