

THE CONCEPT OF HYBRIDIZATION FROM THE PERSPECTIVE OF SCIENCE TEACHING UNDERGRADUATE STUDENTS: A PHENOMENOGRAPHIC STUDY

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Introduction

Science can be described as a systematic examination of nature and natural events and estimating unobserved events. Human beings should learn science in order to make a prediction about some unwatched phenomenon and events. Science provides many benefits to community relations, technology and individual life. Students learn the scientific information from the science courses. One of the basic courses of science is chemistry. Learning chemistry is not only necessary to be successful in chemistry lessons. It has become compulsory for people to learn basic chemistry information since technology improves day by day and our life environment changes every day. It is a must for people who are interested in science, and especially those who would serve as a teacher in the field of science to have high level of chemistry knowledge. Chemistry is a discipline which is regarded as difficult by most of the students (Burrows, 2015; Ellis, 2013; Cartrette & Mayo, 2011). Educators of chemistry think that the reason why students have difficulty in chemistry is that there are a lot of concepts in chemistry curriculum and that it requires specific skills (Arasasingham et al., 2004). As a remedy, students sometimes memorize the conceptions and solutions of problems rather than understanding the underlying concepts to solve the problem (Selvaratman & Canagaratna, 2008; Mutch, 2009). Many chemistry students rely solely on memorization to learn chemistry concepts which often results in the inability to recall the information in subsequent years (Haláková & Prok a, 2007; Mutch, 2009). Students enrolled in a general chemistry course come from a variety of academic backgrounds. Their life experience and previous coursework all play a role in their understanding of chemistry according to the definition of constructivist educational philosophy. Unfortunately, their experiences also create misconceptions



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Abstract. *The hybridization of carbon is an important problem of quantum chemistry. It means that atomic orbitals could mix giving hybrid orbitals. Orbitals are not physical objects; they are mathematical solutions of the Schrodinger equation. The aim of this study is to determine through phenomenographic method how Science Teaching undergraduate students comprehend "hybridization". 176 students, 78 of whom are male and 98 of whom are female, participated in the study. A semi-structured questionnaire form was used in the study as data collection tool. As a result of analysis of data, it was determined that students describe hybridization in 5 different categories and 4 different ways. According to these categories: "1) Hybridization is a kind of covalent bond, 2) an electronic transition between bonds, 3) an electronic transition between orbitals, 4) the mixing of atomic orbitals to form new orbitals suitable for bonding 5) a case observed as a result of interaction between particles. Among the categories, the one "a mixing of atomic orbitals to form new orbitals suitable for bonding" category was at the top of the list with 69 metaphors.*

Key words: *chemistry education, description category, hybridization, phenomenography, science education.*

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(Herron & Nurrenbern, 1999; Marton, 1981, Mutch, 2009). Recent research in science education has found that many students' prior experiences can lead to misconceptions about specific science concepts which hinder the learning process (National Research Council, 2000). These misconceptions encourage students to hold onto their inaccurate beliefs because it is easier to accept those beliefs than struggle to understand the true meaning of a difficult concept (Glynn, Yeany, Britton & Nakleh, 1992; Mutch, 2009). Talanquer (2014) stated that one of the reasons of misconceptions in chemistry is using of the heuristics by students. To avoid such unsolicited statuses, students' learning and thinking processes should be well understood. Understanding the various ways students approach learning chemistry concepts and use problem solving techniques, instructors can become better aware of how to help students develop a deeper approach to learning and encourage their students to move beyond surface approaches to learning, such as rote memorization (Mutch, 2009). It was remarked that over 120 manuscripts on the conceptual understanding of students in chemistry have been published in the last decade (Cooper, Corley & Underwood, 2013).

One of the concepts which commonly used in chemistry is the concept of hybridization. In order to explain formation of bonds in molecule structure, it is thought that two or more atom orbitals intervene in each other and form hybrid orbitals which are compatible with bond formation. In this way, mixing atom orbitals and forming new orbitals suitable to the aim is called hybridization and orbital formed in new type is called hybrid orbitals (Tunalı & Ozkar, 1999). The phenomenon of hybridization should be comprehended very well in order to understand many subject completely and correctly such as formation of bonds, molecule structures and bond angles.

The term phenomenography is originated from Greek and is the combination of words Phainomenon (appearance) and graphein (description) and means the description of what is seen (Karasakal, 2009). Phenomenography is an educational research method which analyzes how students learn (Marton & Booth, 1997). With this method, it can be analyzed what different individuals understand or perceive from the same concept. Phenomenographic method is also used in studies on chemistry education. The number of studies especially on learning chemical concepts and making chemical calculations has been increasing every day. Nakleh and Mitchell carried out a phenomenographic study in order to analyze how students learn the chemical concept of "gas laws", what they understand of this concept and how they solve chemical problems connected with this concept. As a result of their study, they stated that most of the chemical calculations of students connected with this concept are problematic. Moreover, they have detected that students do not have self-confidence about learning chemical concepts (Nakleh & Mitchell, 1993). Bhattacharyya and Bodner carried out phenomenographic study in order to analyze how students perceive "organic chemical mechanisms" which is a concept of organic chemistry and how they solve problems connected with mechanisms of organic chemistry (Bhattacharyya & Bodner, 2005). Helen E. Mutch carried out a phenomenographic study on how college students learn chemistry. In her study, she analyzed how students learn the concept of stoichiometry, what they understand from this concept and how they solve chemical problems connected with this concept (Mutch, 2009).

There are four basic chemistry courses called as General Chemistry I, General Chemistry II, Analytical Chemistry and Organic Chemistry in the Education Faculties, Science Education Programs in Turkey. The hybridization phenomena have been taught by educators in the chapter on Chemical Bonding in the General Chemistry I courses in the first half of the first year. Furthermore, the term of hybridization has been recalled in the beginning of the Organic Chemistry courses. In General Chemistry I course, hybridization has been taught as: 1) Educators firstly explain why we need the concept of hybridization. In general, electronic configuration of ground state of carbon atom is drawn, then it is emphasized that according to existing electronic configuration, the carbon atom can do only two bonds; on the other hand, in the fact, carbon can do four bonds and this fact can be explained by hybridization. 2) Educators explain the formation of different hybrid orbitals from the overlapping of atomic orbitals. 3) In an attempt to give a visual representation of the hybridization, educators generally draw the hybridized and non-hybridized orbitals of carbon atom in quantum boxes as represented in Figure 1.



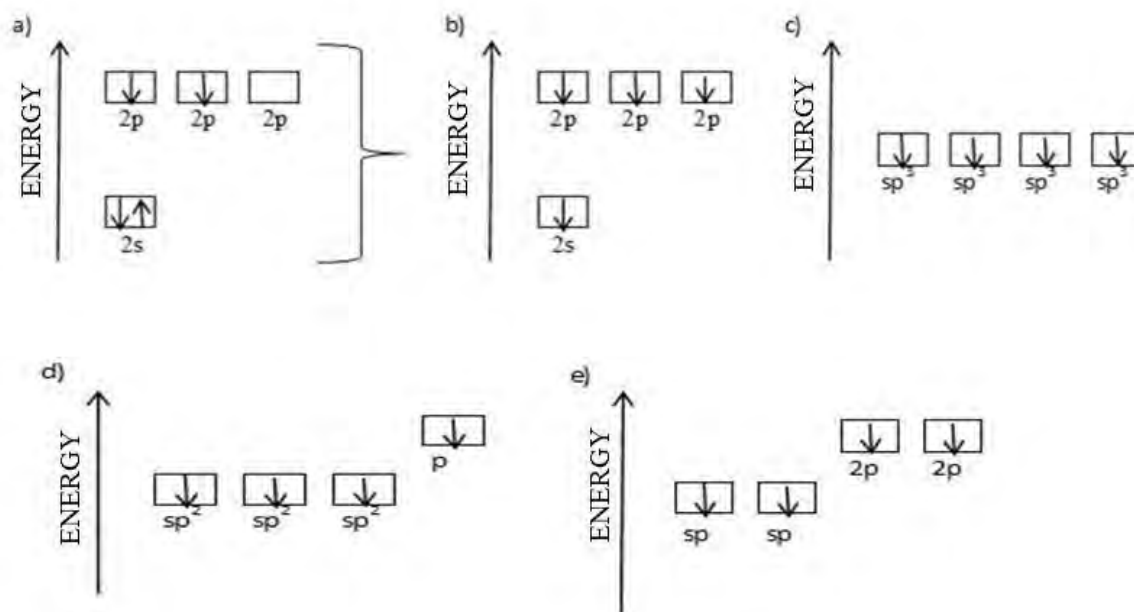


Figure 1: Schematic representation of the hybridization of the carbon atom using quantum boxes. (a) Ground state b) electronic transition c) sp^3 hybrid orbitals d) sp^2 hybrid orbitals e) sp hybrid orbitals.

The literature contains few studies about the conceptual understanding of the hybridization concept (Dumon & Sauvaitre, 1995; Taber, 2002; Nakiboglu, 2003; Stefani & Tsaparlis, 2009). In these studies, the researchers determined several misconceptions related to hybridization concept. The details of these misconceptions were discussed in the discussion section. It is important to show state-of-the-art of this problem. Thus, state-of-the-art of this problem was showed by this study. Besides, the mentioned studies in the literature were generally carried out on the students from the chemistry departments. However, there is no phenomenographic study about how pre-service science teachers describe the concept of hybridization and what they understand of this concept in the literature. So, it is quite clear that phenomenographic studies to be carried on pre-service science teachers about hybridization and other chemistry subjects would have great contributions on literature. The aim of this study is to determine through phenomenographic analysis method how Science Teaching undergraduate students understand "hybridization". For this aim answers were sought for the questions below:

1. How do the undergraduate students who receive education at Science Teaching program of Education Faculties perceive "hybridization"?
2. With which description categories and metaphors do the students explain "hybridization"?
3. By which ways do the students describe "hybridization"?

Methodology of Research

Research Model

In this study, phenomenographic research method was used in order to seek an answer to research questions. Phenomenography is an educational research method which analyzes how students learn (Marton & Booth, 1997). With this method, it can be analyzed what different individuals understand or perceive from the same concept. It is based on the fact that limited category will be attained for each concept and these categories will be formed through analyzing data obtained in the study. Categories are created by comparing differences and similarities between statements of participants. First of all, precursor concept categories are formed in the study. Description categories are formed with the second review of data obtained or current categories are changed (Didiř et al., 2008).



Research Group

Research group was determined according to a purposeful sampling method. 191 undergraduate students enrolled in Firat University Education Faculty, Department of Primary Education, Science Teaching program in 2013-2014 participated in the study. In addition to this, as a result of examination of the answers in the sense of consistency, 176 questionnaires were found to be consistent and included in the research. 176 students, 78 of whom are male (44.31%) and 98 of whom are female (55.6%) participated in the study. 51 students are from the first class, 43 of them are from the second class, 42 of them are from the third class and 40 are from the fourth class. All of the participants learned the quantum model including hybridization concept when they participated in General Chemistry I course. Details of the teaching of quantum model and hybridization in Science Teaching Program in Turkey were explained in the introduction section. Distribution of students who participated in the study according to gender and class is given in Table 1.

Table 1. Distribution of students who participated in the study, according to gender and class.

Variable		(f)	(%)
Gender	Male	78	44.31
	Female	98	55.69
Class	1. Class	51	28.97
	2. Class	43	24.43
	3. Class	42	23.86
	4. Class	40	22.72
Total		176	100.00

Data Collection Tools

A semi-structured questionnaire form was used in the study in order to collect data. The questionnaire was formed by researchers. One of the researchers is a specialist in chemistry. In addition to this, the views of an assessment and evaluation expert were also obtained. The questionnaire took its final form after a pilot study was carried out at a different university at the beginning of the 2013-2014 academic year. 60 undergraduate students enrolled in Dicle University Education Faculty, Science Teaching program and participated in the pilot study. The first form of questionnaire was composed of three sections. The third section of the questionnaire was as following; “..... orbitals can be given as examples for hybrid orbitals”. The pilot study results show that almost all of the participants gave the same examples (sp , sp^2 and sp^3). So, the third section of the questionnaire was cancelled. The final status of the questionnaire is composed of two sections. In the first section students were asked their gender and class. In the second section of questionnaire, there are statements “Hybridization means Because hybridization is formed as a result of”. Participants were asked to fill in the blanks. Students filled in the questionnaire form in maximum 5 minutes.

In order to increase the validity of the research, the participants were explained the aim of the study given in the introduction of the questionnaire and it was stated that there should be consistency between the answers given in two blanks. For the same aim, questionnaires which include inconsistency between the answers were excluded from the evaluation. The statements in the questionnaire complete each other and these statements found their supporters among the students. By using this questionnaire, the favorable answer (39%), namely “Hybridization is the mixing of atomic orbitals to form new orbitals suitable for bonding”, is close to the correct statement. In addition, the students’ several misconceptions related to the concept of hybridization were definitively determined by using this questionnaire.



Analysis of Data

Within the scope of study, in the analysis of qualitative data which were obtained with the help of open-ended questions, "phenomenographic analysis method" and descriptive and inferential statistics methods were used. Phenomenographic analysis method in which qualitative difference categories are determined was done in four stages. These stages are respectively, (1) coding and classifying, (2) forming precursor categories, (3) forming description categories and (4) forming descriptive maps. The results which emerge in related stages were presented with the help of table and figures.

Results of Research

As a result of the analysis of data obtained, it was determined that 176 students in total who participated in the study gave 17 different answers about "hybridization", which is the subject of the research. As a result of conducting data analysis stages respectively, 5 description categories were formed about the answers. According to these categories 1) Hybridization is a kind of covalent bond, 2) an electronic transition between bonds, 3) an electronic transition between orbitals, 4) the mixing of atomic orbitals to form new orbitals suitable for bonding 5) a case observed as a result of interaction between particles. Among description categories, the category of "hybridization is the mixing of atomic orbitals to form new orbitals suitable for bonding" included the utmost number of metaphors. The related category includes 39.20% of total metaphors. This category was followed respectively by the category of "hybridization is an electronic transition between bonds" with 26.70% and "hybridization is an electronic transition between orbitals" with the rate of 14.77%. Description categories and the rate of metaphors they include are given in Table 2.

Table 2. Description categories and the rate of metaphors.

Description categories	Number of metaphors	%
Hybridization is a kind of covalent bond	19	10.79
Hybridization is an electronic transition between bonds	26	14.77
Hybridization is an electronic transition between orbitals	47	26.70
Hybridization is the mixing of atomic orbitals to form new orbitals suitable for bonding	69	39.20
Hybridization is a case observed as a result of interaction between particles	15	8.52

There are 19 metaphors in total within description category of hybridization "is a kind of covalent bond". Among these metaphors while the metaphor "it is a kind of covalent bond" is repeated 10 times, other metaphor "Hybridization is a kind of bond which is formed between atoms whose energy are close to each other" was repeated 2 times (Table 3).

Table 3. The first description category and metaphors.

Description Category	Metaphors	f	%
Hybridization is a kind of covalent bond	Hybridization is a kind of covalent bond	10	52.63
	Hybridization is a kind of bond which is formed by using of electrons jointly	7	36.84
	Hybridization is a kind of bond which is formed between atoms whose energy is close to each other	2	10.52

There are 26 metaphors in total within description category of hybridization "is an electronic transition between bonds". Among these metaphors, while the metaphor "it is an electron transition between bonds whose energy is close to each other" was repeated 15 times, the other metaphor "it is an electron transition which is only observed on single bonds" was repeated 2 times (Table 4).



Table 4. The second description category and metaphors.

Description Category	Metaphors	f	%
Hybridization is an electronic transition between bonds	Hybridization is an electronic transition from covalent bonds to ionic bonds	5	19.23
	Hybridization is an electronic transition from ionic bonds to covalent bonds	4	15.38
	Hybridization is an electron transition between bonds whose energy is close to each other	15	57.69
	Hybridization is an electron transition which is only observed on single bonds	2	7.69

There are 47 metaphors in total within description category of hybridization "is an electronic transition between orbitals". Among them, while the metaphor "it is an electron transition from s orbital to p orbital" was repeated 21 times, the other metaphor "it is an electronic transition between orbitals whose energy is low" was repeated 12 times (Table 5).

Table 5. The third description category and metaphors.

Description Category	Metaphors	f	%
Hybridization is an electronic transition between orbitals	Hybridization is an electron transition from s orbital to p orbital	21	44.68
	Hybridization is an electronic transition which is observed between all orbitals	14	29.78
	Hybridization is an electronic transition between orbitals whose energy is low	12	25.53

There are 69 metaphors in total within description category of hybridization "the mixing of atomic orbitals to form new orbitals suitable for bonding". Among them, while the metaphor "orbitals with close energy overlapping and forming new type of orbital" was repeated 30 times, the other metaphor "s and p orbitals overlapping and forming new type of orbital" was repeated 9 times (Table 6).

Table 6. The fourth description category and metaphors.

Description Category	Metaphors	f	%
Hybridization is the mixing of atomic orbitals to form new orbitals suitable for bonding	The s and p orbitals overlapping and forming new type of orbital	9	13.04
	Orbitals with close energy overlapping and forming new type of orbital	30	43.47
	Hybridization is forming of new orbitals from the league together with orbitals	17	24.63
	Hybridization is forming of orbitals such as sp, sp ² , and sp ³ from the amalgamating of atomic orbitals	13	18.84

There are 15 metaphors in total within description of category of hybridization "is a case observed as a result of interaction between particles". Among them, while the metaphor "it is a case observed on molecules making hydrogen bond" was repeated 8 times, the other metaphor "it is a result of effect of London forces" was used 9 times (Table 7).

Table 7. The fifth description category and metaphors.

Description Category	Metaphors	f	%
Hybridization is a case observed as a result of interaction between particles	Hybridization is a case observed on molecules making hydrogen bond	8	13.04
	Hybridization is a result of effect of London forces	3	43.47
	Hybridization takes place when interaction between particles is powerful	4	24.63



At the last stage, the way how students describe “hybridization” was presented with the description map. Generally, 4 different various ways of description were determined in the description map. These ways are defined as definition as electronic transition, definition as interaction between particles, definition as a type of bond and overlapping. Students’ description of hybridization was mapped as in Figure 2.

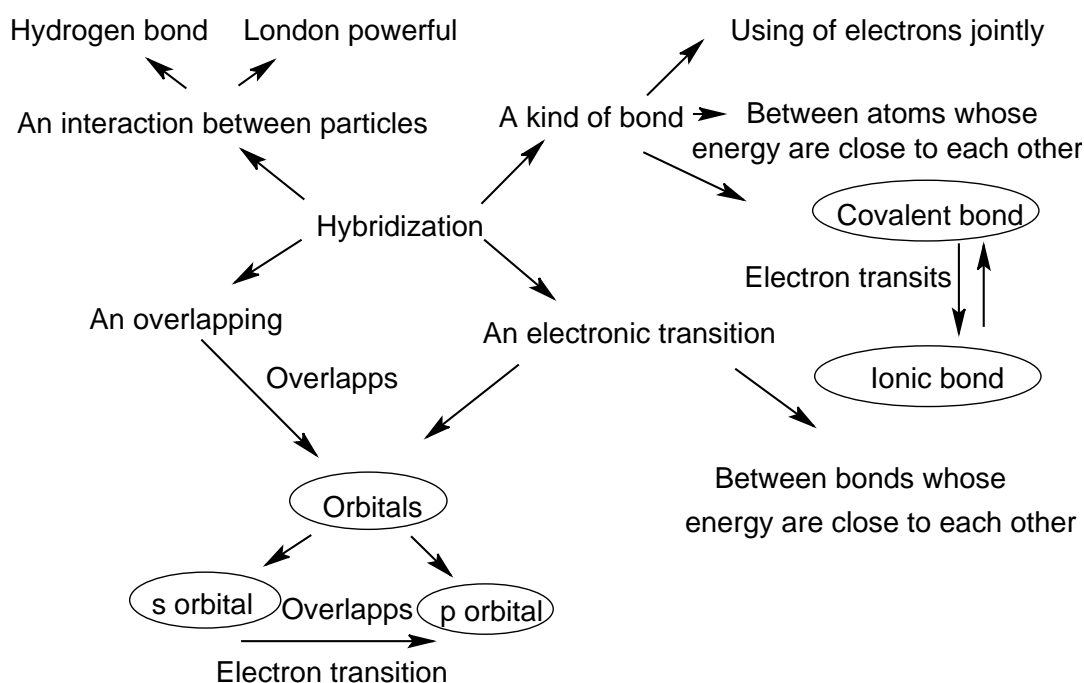


Figure 2: Students’ description map of hybridization.

Discussion

Important results were attained in this study which was carried out in order to determine how Science Teaching undergraduate students comprehend hybridization. As a result of the study it was determined that students describe hybridization in 5 different categories and 4 different ways. Among these categories, the one “is the mixing of atomic orbitals to form new orbitals suitable for bonding” category was at the top of the list with 69 metaphors (39.20%). In this category, the metaphors “orbitals with close energy overlapping and forming new type of orbital” and “ orbitals overlapping and forming new type of orbital” are repeated utmost. 39.20% of students have made correct definition. In addition to this, definitions of 59.80% of students are incorrect.

For a complete understanding of the concept of hybridization, several abstract concepts of the quantum model (electrons, electronic density, s and p atomic orbitals, linear combination of atomic orbitals, molecular orbital, orbital symmetry and orbital overlap, etc.) must also be learned correctly. When students encounter a great number of interrelated concepts, they will generally perform their “conceptual integration” by linking the various concepts involved to make sense of such complex knowledge. In this way, students build up personal “knowledge structure” (Salah & Dumon, 2011; Taber, 2005). In such cases, especially in the presence of multiple and complex information, improper action related information and eventuating of some misconceptions are possible. Misconceptions are formed by individual experiences and they are contrary to scientific facts. The misconceptions are the knowledge that inhibits teaching and learning of concepts the accuracy of which was proven by science. The literature contains several studies that aim to reveal students’ misconceptions related to hybridization concept and some of these were remarked as following: Hybridization is a process of conver-



sion of orbitals to new forms of orbitals which are energetically equivalent (Nakiboglu, 2003). Hybridization is a process wherewith the repositioning and reorganization of the valence electrons form bonds (Nakiboglu, 2003; Papaphotis & Tsaparlis 2008). Hybridization is a process in which electrons are transferred from an orbital to another in order to obtain a more stable structure. (Dumon & Sauvaitre, 1995; Taber, 2002; Nakiboglu, 2003; Stefani & Tsaparlis, 2009). Hybridization is transferring of electrons to obtain a new state (Dumon & Sauvaitre, 1995). Hybridization is a mathematical transaction, presumably related to the atom, and mainly leads to the formation of molecular orbitals (Dumon & Sauvaitre, 1995; Taber, 2002; Stefani & Tsaparlis, 2009). Hybridization is an automatic process, in short, it occurs on its own, hybridization as exact representation and hybrid orbitals exist in nature, hybridization is the promotion of electrons to higher energy orbitals in the same atom, hybridization happens when two electrons combine from two different atoms (Salah, & Dumon, 2011). Hybridization is a combination of atoms, hybrid orbitals are molecular orbitals, hybrid orbitals have real existence and they are not our own constructions (Stefani & Tsaparlis, 2009). Taber (2002) stated that according to students, the formation of hybrid orbitals progresses in three stages; 1) electronic configuration of the atom in its ground state, 2) search for a new electronic configuration that is best pertinent to hybridization 3) they consider the formation of bonds or molecular orbitals. Salah and Dumon (2011) have emphasized that these thinking ways lead to confusion. Compared with the other investigators' results in literature, both same and different misconceptions have been observed in this study. As distinct from the other results stated in the literature, we detected two new student misconceptions as "Hybridization is a kind of covalent bond" and "Hybridization is a case observed as a result of interaction between particles". Other all misconceptions detected in this study are similar to misconceptions detected by other investigators in the literature. In this study, 41.70% of students have defined hybridization as an electronic transition between bonds or orbitals. This situation shows that students comprehend that hybridization is the electronic transition which happens before hybridization. While giving lecture on hybridization, chemistry teachers generally draw electron configuration of an element and explain hybridization over these electron configurations. Therefore, it is quite possible that students may misunderstand the concept of hybridization. In order to minimize such kind of negativeness, we believe that it would be beneficial for chemistry teachers to use animation or similar visual presentations which display formation of hybrid orbitals among atom orbitals. 10.79% of students defined hybridization as a type of covalent bond. Concepts of hybridization and covalent bond are related to each other. It can be assessed as normal that students have but little confusion between these two concepts. However, it is quite difficult to estimate the reasons why 8.52% of students relate hybridization with interaction between particles which is completely irrelevant.

In the study it was determined that students define the concept of hybridization with 4 different ways of description. Students define hybridization as an electronic transition, interaction between particles, a type of bond and one of the overlapping elements. Among these descriptions, the one which is interaction between particles has no relevance with the subject of hybridization. Students who made such a description can be said that they have no interest in chemistry courses. In fact, students who made a description by using other ways have either made a successful description or at least made descriptions which are quite relevant with the subject even they are wrong.

Conclusions and Implications

In this study, it was aimed to reveal what students understand from the concept of hybridization. As a result of analysis of data, it was found out that students describe hybridization in 5 different categories and 4 different ways. The definitions of 59.80% of students and three of the ways that students used for description of hybridization are incorrect. The difficulties in the understanding of hybridization concept can result from the bad mark control of basic knowledge for its learning. (Such as atomic orbital, electron, orbital overlaps, linear combination of atomic orbitals, etc.). The difficulties also derive from the using of visual representation involving quantum boxes, including hybridized and non hybridized atomic orbitals. With better understanding of these representations, students can only reorganize the electrons in quantum boxes to represent the hybrid or atomic orbitals. This representation does not present the overlapping of atomic orbitals to form molecular orbitals. Thus, students cannot accurately understand the nature of hybridization. The difficulties can also be explained by considering the results of this study and the results of other studies together. The findings of other investigators support our results. Namely, it was detected that the 60.80% of students have made failure in



definition. Especially, 41.70% of students have defined hybridization as an electronic transition between bonds or orbitals. Particularly, these misconceptions may be due to the students' understanding stages described by Taber. The concept of hybridization should be comprehended well in order to learn various subjects of chemistry such as covalent bond, structures of molecules, bond angles and valence bond theory completely and correctly. Educators will be more beneficial to students by understanding the students' approach for learning chemistry concepts. Thinking in this way, this study has important contributions to the literature by guiding chemistry teachers. In this study, what students understand from the concept of hybridization has been revealed. However, by this study, it cannot be completely determined how and why students insufficiently learn the hybridization concept. Therefore, additional specific researches including interview and focused on consideration of conceptual understanding of all basic quantum concepts together (such as hybridization, atomic orbital, linear combination of atomic orbital, electron, molecular orbital, electronic density, etc.) are needed to explore how students understand the hybridization concepts in detail.

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